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Comparative Analysis of Methods for Identifying Opportunities for Reusing Solid Waste

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Abstract. Waste produces a significant impact on the environment. According to the hierarchy of waste management, reuse should be preferred to material recovery and recycling, since less energy tends to be used. In order to prioritize waste reuse, the question of how to do it becomes important. There is no standard method aimed at finding reuse opportunities, and most of the published examples of reuse were identified through intuitive techniques, such as brainstorming, or even by chance. We have found two main systematic techniques: Product DNA and SMIROSG (Systematic Method for Identifying Reuse Opportunities of Supporting Goods). In this paper, we report a test involving both methods, focusing on an ordinary solid waste – the styrofoam tray. The results were analyzed, and improvements to the techniques were suggested. The main research methodology used to structure this study was the DRM (Design Research Methodology). The specific methods, Product DNA and SMIROSG were also used. We have found out that the SMIROSG method offers a greater scope of possibilities for reuse, although it is necessary to screen these possibilities, while Product DNA provides a more succinct range of opportunities for reuse, sometimes lacking more possibilities, however, all the alternatives offered are readily applicable, thus not requiring a new screening. Therefore, these are the aspects of each method in which improvements have been suggested. Given this, the requirements for a new method containing the best aspects of both SMIROSG and Product DNA were defined, aiming to eliminate the deficiencies presented in each method, improve the performance of the future method and enable an exponential increase of the effectiveness in identifying reuse opportunities.

Keywords: Systematic Method for Identifying Reuse Opportunities of Supporting Goods (SMIROSG), Product DNA, Waste Reuse, Waste Recycling, Design Research Methodology (DRM)

1 Introduction

Every day, tons of garbage are produced, resulting in a growing environmental impact that harms the planet and that is a threat to life [6]. In this context, several policies and strategies were created for waste management, aiming to reduce the environmental impact caused by garbage and even reverse the damage already done. Among these strategies, we have the concept of the three R's [6], which consists of reducing, recycling, and reusing. Reuse is preferable to the other alternatives, due to its lower energy expenditure [5].

Although the issue of reuse is very relevant, when researching methods to identify opportunities for waste reuse, the literature presents only one specific systematic alternative, the Systematic Method for Identifying Reuse Opportunities of Supporting Goods (SMIROSG) [1]. Another systematic method that can be easily applied for this purpose is Product DNA [2]. However, its steps are highly dependent on the researcher's experience, which makes Product DNA slightly less systematic than

the SMIROSG method. There are also articles reporting the use of non-specific intuitive processes, such as brainstorming [1] and serendipity [1]. Other approaches that can support the identification of reuse opportunities are the Life Cycle Assessment [8, 9, 10, 11], Industrial Symbiosis [1, 12, 13, 14], Reverse Logistics [15, 16], and programming methods and decision models [17, 18, 19].

Considering that SMIROSG and Product DNA are the only methods that have a systematic approach and include a practical tool easy to be applied by product development teams, we decided to investigate these methods in greater depth. Two papers present practical applications of SMIROSG: that of Verhaegen et al. [3] and that of Frazão et al. [1]. The practical application of Product DNA is demonstrated in the article by Dewulf [2]. From the applications, it appears that both methods have great potential for reuse. The next questions are: how effective is each one? Are there possibilities for complementarity between the methods? Are there possibilities for improving these methods? Considering these research questions, a comparative analysis is necessary. To this end, it was decided to focus on a very common type of solid waste: the Styrofoam tray (Figure 1). This type of tray has many uses, but it is most often employed to store cold cuts and meats. The final destination of this waste is problematic since Styrofoam is known to be difficult to recycle [7].



Fig.1. Typical Styrofoam tray.

2 Methodology

In this work, we use the Design Research Methodology (DRM) as the basic research structure. In addition to DRM, the methods to be compared (SMIROSG and Product DNA) are also applied.

2.1 Design Research Methodology (DRM)

DRM is defined as an approach and a set of methods and support guidelines that are used as a framework for doing research in the area of design [4]. DRM consists of four stages: Research Clarification (RC), Descriptive Study I (DS I), Prescriptive Study (PS), and Descriptive Study II (DS II). Figure 2 synthesizes the structure of DRM, with the methods and results obtained for each stage.

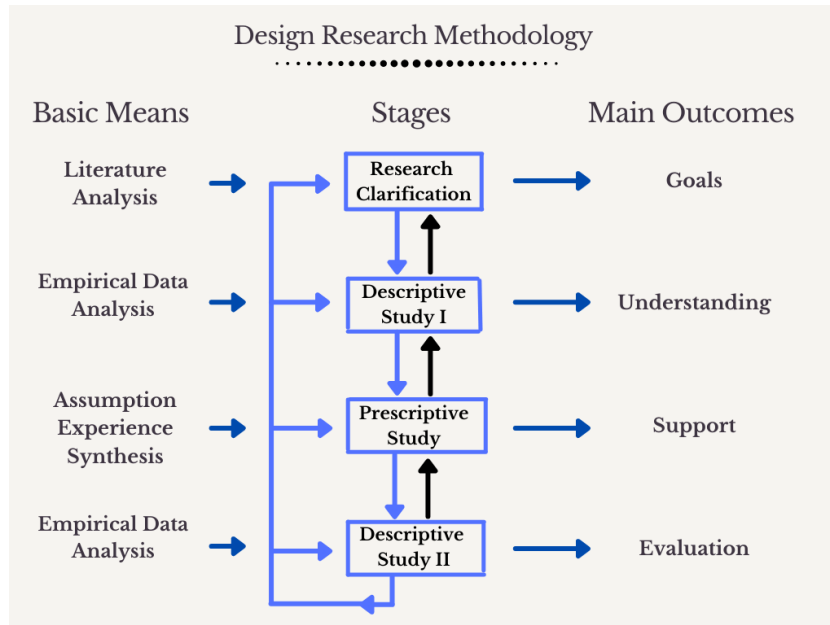


Fig.2.DRM structure, with the representation of the stages, basic means, and results.

It is not mandatory for a specific research project to include each stage, or to undertake all stages in equal depth. In some cases, literature alone will provide enough material for a particular stage. In other situations, a research project may focus only on one stage for an in-depth study, due to time constraints or because the project is part of a larger program. Figure 3 illustrates the seven existing study alternatives for applying DRM.

Types of Design Research	Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1	Review-based	→ Comprehensive		
2	Review-based	→ Comprehensive	→ Initial	
3	Review-based	→ Review-based	→ Comprehensive	→ Initial
4	Review-based	→ Review-based	Review-based/ Initial/ Comprehensive	→ Comprehensive
5	Review-based	→ Comprehensive	→ Comprehensive	→ Initial
6	Review-based	→ Review-based	→ Comprehensive	→ Comprehensive
7	Review-based	→ Comprehensive	→ Comprehensive	→ Comprehensive

Fig.3.Types of projects using DRM and their respective main focci.

Research and hypothesis questions, as well as the time and resources available, will determine the type of research to be undertaken. This paper describes a type 2 study since the methods analyzed are applied practically and their results are used for

comparison and analysis between the results generated by each method. Thus, proposal number 2 was used, as shown in Figure 3. Hence, it is proposed to use the first three stages of DRM, with the conclusion of the study in the Prescriptive Study stage.

Therefore, in the Research Clarification stage, an extensive literature review was carried out, aiming at finding methods previously used to identify opportunities for reusing solid waste, with the purpose of delineating the research objectives and the desired results to be obtained. Besides, criteria are obtained that will be used as measures to evaluate the result of the study. The RC also has the function of providing a focus for the DS-I and drawing up a study plan to be carried out in the second phase of the research.

In the DS-I stage, the practical application of the Product DNA and SMIROSG methods was carried out in the case of the Styrofoam tray to obtain the necessary information for a better understanding of the existing situation and also to allow the performance of the comparison between the methods. With this, a basis is provided for the next stage, making it possible to start developing a support that addresses the factors that have the greatest influence on the success of the situation studied.

On the PS stage, once we obtained a greater understanding of the original situation, the description of the desired situation was corrected and elaborated, thus initiating the systematic development of the proposal to solve the problem. Therefore, the main contributions to be obtained in the PS stage are: a description of the points at which each method can be improved, aiming to enhance the identification of opportunities for reuse when using Product DNA or SMIROSG; and a description of the requirements for a new method for identifying reuse opportunities, which is derived from both Product DNA and SMIROSG but does not include the flaws presented in each of these methods and, consequently, has the best characteristics of each one, which will result in the most ideal method for identifying reuse opportunities. Figure 4 illustrates the DRM methodology used in the context of this paper.

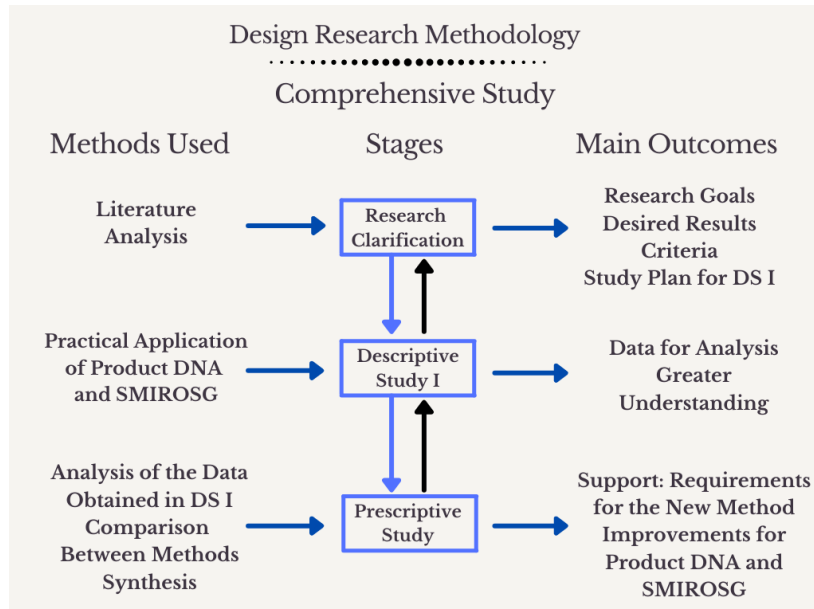


Fig.4. Use of DRM in the context of the current study.

2.2 Product DNA

Product DNA consists of a systematic innovation method that promotes a simple way of describing a product, and its main focus is to connect previously unrelated domains, with the aim of transferring existing knowledge to a new area or domain, thus aiming to provide innovative solutions. These connections that are created are based on properties and functions, and by listing such characteristics of a system, it is possible to distinguish one object from another. Through Product DNA, it is possible to categorize the products by their properties and functions [2]. A property is an attribute, a dimension, a trait by which objects or individuals can be distinguished. And the analysis of properties is the first part of the Product DNA work chain. In the second step, there is an analysis of the function, purpose, intention, or use of the material.

In its initial conception, Product DNA is a method in which each property of the material is analyzed and this property is modified, thus gaining a new or improved function for the material. Or, knowing the desired function, one must analyze which properties must be modified. This process allows identifying products that are related and technological domains that act as inspiration for the innovation of a product or system. Therefore, through the properties and functions of an existing system, new markets can be identified that require those properties and functions.

However, it was identified that the process present in the Product DNA for analyzing the properties and functions of a given material, with subsequent alteration of the properties in order to exercise new functions, would be of great use in identifying opportunities for reuse of the same material. This occurs because, once finding new functions for a product, it is possible to reuse it in innovative and creative ways.

Therefore, despite not having been created for this purpose, Product DNA can help a lot in the process of identifying opportunities for reusing products.

The first step of the Product DNA method is to characterize the product along the lines of Dewulf's article. This characterization consists of the description of a material or object in relation to spectra of properties. The standard spectra considered are porosity, surface, flexibility, color, components, state, unity, transparency, information, automation, and senses. Once all the characterization of a given product is obtained, it is also possible to fit it into domains or compare it with other products.

Once such characterization is carried out according to the material's properties, its functions are then analyzed, taking into account the regular use of the material. Considering the current product functions and how they relate to each property, in the stage of identifying opportunities for reuse the procedure used is to analyze each property of the material and how that property can be modified or adapted to gain a new or improved function. Or it is also possible to proceed as follows: knowing the desired function, analyze which properties must be changed so that the product fits the specific function. In this way, new possible functions are found for the product, consisting of possibilities in which the material can be reused.

2.3 SMIROSG (Systematic Method for Identifying Reuse Opportunities of Supporting Goods)

The SMIROSG method aims at finding opportunities for reusing products [1]. It was designed to focus on supporting goods, which are products created to contribute to the manufacture of other products [3], such as packaging. However, with the necessary adaptations, it can be used for any product.

When applying the SMIROSG method, the first step is to describe the product to be analyzed through a set of properties or qualitative attributes, obtaining a list of about 10 to 12 attributes in total. The next step to the definition of attributes is the formation of pairs of attributes to be searched in an online image search tool since the search for only one of the terms does not provide appropriate results. As the results found in the surveys subsequently pass through an analysis and screening process, in this step all the results obtained are considered.

The third step of the method is to register each product category that appears as result, keeping it related to the pair of attributes whose search resulted in the specific product. It is important, due to the large number of research pairs and product categories obtained for each pair, to keep the recorded information organized in an easily quantifiable way, as in an Excel spreadsheet.

Then, there is the analysis of the data obtained, in which the products are classified according to the number of times that each one appeared as a result of the researches, and then this information is recorded in a new table and a graph, for easier observation of the results. Products that appear more frequently can be expected to be the best paths for innovation in the area of reuse of the waste in question, but it is also possible that the most frequent products are those that have already been developed through the reuse of that specific waste [1].

2.4 Comparison of Methods

After applying both methods and obtaining the respective results, an analysis of both results is made and a comparison between them is performed, thus following the study plan based on DRM, described in summary form in Figure 4. It is observed whether there were results that were obtained through one method, but they were not through the other, and vice versa. If this occurs, these results are then analyzed to find an explanation for the discrepancy noted. Besides, it is also analyzed whether there was any possibility of reuse that, although possible and applicable, was not found as a result of any of the methods used. With this, it is possible to draw a draft of the possible improvements to be applied in each method, in addition to the requirements for a future new method focused on identifying opportunities for reusing solid waste.

It is noteworthy that the research implemented in this article, having presented as its main objective the comparison between the Product DNA and the SMIROSG methods, as well as identifying which method is reported to be more effective, did not delimit a specific number of reuse opportunities intended to be found as one of its objectives. On the contrary, we tried to find the highest number of reuse opportunities in each method, thus exploring their maximum potential.

Since this article is focused on establishing a comparison between two possible methods to identify solid waste reuse opportunities, the main criterion used to identify which method would be the most appropriate for this application was precisely to establish a qualitative comparison between both methods, evaluating parameters such as the practicality of application and the number of results obtained. However, when applying one of those methods to identify opportunities for reuse of a given solid waste, it will be necessary to deal with the range of results obtained, and choose the most viable among them. Therefore, it is necessary to have a set of criteria that will help determine the most viable reuse opportunities. Concerning possible criteria to establish the most viable opportunities for reuse among those obtained as a result of the application of a certain method, it is possible to make use of some key criteria widely used on creative design projects, such as creativity, innovation, and quality of the obtained results.

3 Results

3.1 Applying the Product DNA Method to Identify Opportunities for Reusing Styrofoam Trays

For the first step of the Product DNA method, the EPS tray was described according to the following categories: porosity, surface, flexibility, color, components, state, unity, transparency, information, automation, and senses. The characteristics obtained are shown in the table below.

Table 1. Characterization of the Styrofoam tray according to the property categories presented by Dewulf.

Category	Material Property
Porosity	Porous
Surface	Flat, with curved edges
Flexibility	Rigid

Color	White
Components	Single
State	Solid
Unity	Plates
Transparency	Opaque
Information	<i>Does not apply</i>
Automation	<i>Does not apply</i>
Senses	<i>Does not apply</i>

It is important to note that it was considered that the categories of "Information", "Automation" and "Senses" did not apply to the context of the Styrofoam tray, therefore they were disregarded for the application of the method. Besides, it seemed pertinent to highlight some other properties of the material that relate to its functions, so the following characteristics were also taken into account during the application of Product DNA:

- Light;
- Low density;
- Low thermal conductivity;
- Inert;
- Resistant to aging;
- Non-hygroscopic, insensitive to humidity;
- High mechanical resistance;
- Good shock absorber.

Then, considering the regular use of Styrofoam trays, which is storing sliced cold cuts in markets, the functions of this material were then analyzed. The result of this step is shown in the table below.

Table 2.Styrofoam tray functions definition.

EPS tray functions
Promote protection against impacts, shocks, and mechanical wear
Thermal insulation
Protection against moisture
Storage
Facilitate transportation
Facilitate grouping

Describing the relationship between the functions and properties of the Styrofoam tray, we have that, since the tray has high mechanical resistance and is an effective shock absorber, it has the function of protecting against impacts, preventing any damage of the food contained in it. Regarding the property of low thermal conductivity presented in the EPS tray, this fact explains its function of acting as a thermal insulator, thus preventing the food contained within it from losing its ideal temperature too quickly. As a non-hygroscopic material, the Styrofoam packaging also has the function of protecting food from moisture. The typical lightness of the Styrofoam contributes to

facilitating the transport of the products and their grouping and stacking. Also, the anatomy of the tray itself, flat with curved edges, has the function of storing food inside.

For the stage of identifying reuse opportunities, the surface property of the Styrofoam trays was first analyzed. The trays are flat with curved edges, however, changing this characteristic so that the material acquires a spherically shaped surface, it can be applied to the production of helmets. The material would then assume the main function of protecting against mechanical shocks, in addition to preventing mold and the proliferation of microorganisms, promoting thermal insulation, and increasing comfort due to the lightness of the material.

Still thinking about its surface, if it is altered so that the material presents a flat surface, thus removing the curved edges, it can then assume the function of decoration, the function of preventing mold and moisture in buildings, or even the function of enhancing thermal and acoustic insulation of buildings.

In the decorative function, it is possible to texturize walls with brick-shaped rectangles cut out of the trays, which can be fixed with an adhering material to the wall. In addition, this type of decoration with Styrofoam materials can also be painted, since EPS is compatible with several types of paint.

For the function of protecting buildings from mold and moisture, the material can be applied, in the form of flat plates, directly on the wall with contact glue, forming a protective layer. This layer is then coated with spackle or paint, making the styrofoam invisible. In this way, it is possible to prevent the proliferation of fungi and bacteria, eliminate mold and moisture and also promote greater thermal insulation.

Thinking of the function of enhancing the thermal and acoustic insulation of environments, it is possible to use layers of compacted EPS plates inside the walls of buildings, which also reduces the weight of the structure and the use of cement and wood, without impairing the resistance of the edification. Besides, there is also the application of compacted styrofoam sheets in the composition of thermoacoustic tiles, or "sandwich tiles", in which a metal tile is filled with Styrofoam inside, which reduces the structural weight and promotes thermal and acoustic insulation.

Now analyzing the unit item, the Styrofoam trays have the plate itself as a unit. However, if this property is changed and the unit cell becomes small Styrofoam flakes, after processing the tray, such flakes can be applied with the function of constituting the concrete, thus replacing the crushed stone. The function of EPS in the so-called light concrete is precisely to reduce the apparent density of the concrete, promoting lightness, thermal insulation, and increasing the strength of the material. Besides, styrofoam also has the function of facilitating the handling of the concrete itself.

Still, in the context of Styrofoam flakes as a unit cell, the product can also be adapted to the role of plant substrate component. When used in this way, Styrofoam flakes mixed with soil have the function of contributing to the aeration of roots, making the soils less compacted, in addition to controlling erosion, increasing water retention by plants, and reducing the spread of microorganisms and insects.

3.2 Applying the SMIROSG method to identify reuse opportunities for Styrofoam trays

In the first step of the method, when describing the product to be analyzed through a set of properties or qualitative attributes, a total of 12 attributes were assigned to the Styrofoam tray. These attributes are shown in the table below.

Table3.Styrofoam tray attribute set.

EPS tray attributes
Porous
Lightweight
Rigid
Opaque
Impact Resistant
Wear-resistant
Massive
Thermal Insulation
Aging Resistant
Moisture Resistant
Acoustic Insulation
Chemical Resistant

The next step to define the attributes is the formation of pairs of attributes to be searched in an online image search tool. The image search tool used was Google Image Search [20], and a total of 51 combinations of attributes were made to be searched in pairs. For each search, the images provided in the results were annotated in an Excel spreadsheet, and after searching all 51 attribute pairs, an analysis was made of the frequency that each type of result appeared.

The following image illustrates the search process for an attribute pair. In this example, the attributes “Porous” and “Thermal insulation” were searched together. It is possible to observe that some of the results provided were: light concrete, styrofoam sheets, bricks, plumbing pipes, among others.



Fig.5.Search results for a pair of attributes.

Thus, from the 51 pairs of attributes surveyed, a total of 158 results was obtained. These results were transferred to a table and used to create a graph, as shown below. The table below presents a list of the most frequent image results throughout the surveys, separated into categories, and the number of times each item was noticed.

Table 4. Image search results were separated into categories and frequencies in which they appeared.

Result	Frequency
Thermal/Acoustic insulation panels	18
Shoes, sneakers, boots, and sandals	12
Helmets	12
Bricks	11
Walls	9
Results related to concrete and paving	8
Roof tiles	7
Gloves	6
Cellphone case	5
Container	5
Bags and backpacks	4
Suitcase	3
Blocks	3
Tables	3
Protective Clothing	3
Acoustic insulation for vehicles	2
Visors	2
Beads and Jewelry	1
Chairs	1
Others	43
Total Results	158
Total of Pairs of Attributes Searched	51

According to the results obtained through the application of the SMIROSG method, it was observed that the greatest possibility of reuse for Styrofoam trays is probably within the area of panels and plates for thermal and/ or acoustic insulation; in the construction sector with bricks, tiles and materials such as lightweight concrete; in the area of shoes; and the helmets sector. However, there is also the possibility of reuse within the other areas.

4 Discussion

When comparing the results obtained using the SMIROSG method with the results obtained using the Product DNA method, it is possible to observe some similarities. Items such as insulation panels, bricks, tiles, helmets, walls, building blocks, concrete, and paving were obtained in both research methods. However, there are also some discrepancies between them, and the following table compares the performance of each method concerning some questions.

Table 5. Comparison between Product DNA and SMIROSG methods.

Method	The total amount of different results obtained	Number of most relevant results obtained	Number of results obtained exclusively in the respective method
Product DNA	7	7	1
SMIROSG	19	10	10

As we can see, the SMIROSG method had a greater variety of results, presenting more opportunities for reuse at the end of its application. However, among the 19 results obtained, after analyzing these, only 10 were considered to have a realizable and therefore more credible application. On the other hand, the Product DNA method offered 7 opportunities for reuse as a result, but all of these are relevant and possible to be applied. Therefore, it is possible to conclude that, despite the wide range of results obtained through SMIROSG, they are very varied results that require further analysis and filtering, while Product DNA, despite having a reduced scope of results, does not require further filtration, delivering the results ready for use.

Likewise, a reasonable amount of results obtained through SMIROSG was not obtained through Product DNA, however, most of these were not among the most relevant reuse opportunities. The result obtained by the Product DNA that SMIROSG failed to identify is the use of Styrofoam flakes as a component of plant substrate, which is a very relevant and important possibility to be included among the possibilities of reuse obtained in research.

Therefore, it is possible to infer that the use of Product DNA results in a more filtered range of possibilities, with all its results worthy of attention and consideration, while SMIROSG delivers a wide range of results, which still need to be filtered and passed through a selection of the best among them. However, SMIROSG also presents a method that has well-defined stages and allows easy application, which makes obtaining the results a more accessible process.

Regarding the analysis of the results as a whole, it is noteworthy that both methods have failed to provide handicrafts as a result, which is an area in which the possibilities for reusing Styrofoam trays are quite wide. In fact, an area in which the reuse of Styrofoam is widely applied is the samba school sector, since the cars used in parades in Brazil are mostly built from Styrofoam, and often trays and other Styrofoam packaging are reused on these parade cars.

Some items that appeared among the results and deserve attention were the bricks and tiles "stuffed" with styrofoam, the light concrete, and the use for agriculture. These items in particular are worthy of attention because they are useful and easy to apply reuse possibilities, in addition to using Styrofoam in creative and innovative situations.

5 Requirements for the New Method

When analyzing the results from the application of the Product DNA method and those from the SMIROSG method, it is possible to outline a set of requirements for a new method whose focus would be the identification of opportunities for reusing solid waste. Therefore, the future method must incorporate the most effective and efficient aspects of both Product DNA and SMIROSG. It is also necessary that this method is constituted by a systematic approach, of easy application, reproduction, and documentation, whose implementation will help to organize creativity in order to identify innovative opportunities for reuse. Furthermore, the method should provide a large scope of results, while not requiring an extensive accumulation of data in the steps preceding its application. Besides, the future method must present a step-by-step process, thus being less dependent on the user's experience, that is simple to understand and teach, and that can be applied to identify opportunities for reusing any solid waste, without being focused only on "supporting goods" or in another specific solid waste category.

6 Conclusion

Product DNA, although wasn't developed with the intention of identifying reuse opportunities, presented an excellent performance in this function, with significantly positive results. However, due to the fact that the SMIROSG method has a more objective methodology and consists of better-specified steps, which do not depend on the researcher's experience, obtaining and analyzing the results is facilitated. In addition, the inclusion of the image search tool is a great way to use technology to our advantage, in an innovative and creative way. And the great asset of the SMIROSG method is precisely the search for images, which results in a greater variety of results and, consequently, delivers greater possibilities of reuse for the analyzed waste.

Therefore, the method that provided the greatest number of opportunities for reuse was SMIROSG. However, it is worth mentioning that the results obtained through the Product DNA corresponded to the results of the SMIROSG with the greatest potential for application in the reuse area, and that, despite having delivered fewer alternatives, the Product DNA was able to identify an opportunity for reuse in the agriculture area, an opportunity that SMIROSG failed to identify. Therefore, aiming at enhancing the identification of reuse opportunities, it may be more advantageous to make use of both methods concomitantly, which will make it possible to use what each has of best and help to cover all existing possibilities.

Regarding the possibilities of reuse that both methods failed to identify, there is the possibility that a method that relies on the interconnection of Product DNA with SMIROSG will resolve this issue. Also, it would be interesting to review the

methodology of the methods to identify the reason for this failure, which would allow to implement some improvements to the methods and make them even more efficient.

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