RBPD
Revista Brasileira de Planejamento e Desenvolvimento

Revista Brasileira de Planejamento e Desenvolvimento
ISSN: 2317-2363

https://periodicos.utfpr.edu.br/rbpd

Determination of key references on product development using discarded materials

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ABSTRACT

The acceleration of the goods consumption and the instantaneous food and products massive waste will exhaust the capacity of landfill of the planet in a few years. In order to avoid this catastrophe, actions in terms of materials reuse, reverse logistics, reverse engineering and development of remanufactured products become imperative. In this context, the focus of this research is the identification of the leading researches and authors, their contribution and limitations regarding the development of sustainable products built/manufactured from the reuse of discarded materials (waste) using a systematic literature review allied with critical content analysis. The systematic review started with the determination of the research questions and the keywords and criteria used in the scientific databases searching for articles. The first result of the scientific databases surveys resulted in 11.762 articles. They were submitted to careful analyses and inclusion/exclusion criteria, and at the end of the systematic literature review 13 articles were considered the most relevant to the proposed research theme. A regression analysis of the systematic literature result corroborated the findings. The 13 articles were analysed in their entirety and investigated concerning the proposed approaches, their scientific contributions and limitations as well as the analysis for identifying the authors most frequently cited in these articles. The research resulted in a comprehensive panorama of the scientific works published in the last decade regarding the research theme. The identification of the most recent and relevant researches and milestones authors contributed to widening the understanding of the concepts, approaches, technologies and methodologies as well as their applications and limitations in solving the issues of product development process using discarded materials.

KEYWORDS: Product Design; Sustainable; Waste Disposal, Reuse;

1 INTRODUCTION

In the global context, Brazil had one of the biggest intensifications in waste production in the recent years and only in the year of 2017 around 215 thousand tons per day were generated (ABELPRE, 2018). According to Carlos Filho (CEO ABELPRE), in 2017 each Brazilian inhabitant generated on average 370 kg of garbage/year, which means a football field the size of the Maracanã Stadium (RJ) for a single person if their annual waste was evenly spread over a thin layer.

One of the main causes that contributed to this significant growth was the "programmed obsolescence", a term that has emerged in recent years to explain the unbridled consumer-style existent mainly in countries that are in economic growth, such as Brazil. Planned obsolescence was created to recover the damage caused by the 1929 Great Depression, which destroyed the economy of many countries, preventing further overproduction that can occur in crises caused by lack of review and overstock. In short, programmed obsolescence would be a way for automakers, consumer goods and especially technology companies to force their consumers to change their goods even if they have no malfunctions, just to "spin the economy" by encouraging the consumption of new products (SAMARA et al., 2005).

With this incentive to consume, there has been a growing production of waste, and its destination becomes more complex every year, since the legislation in many countries, including Brazil, determines that the use of open dumps is prohibited and only the use of licensed sanitary landfills by responsible companies should be used. According to the website of the Brazilian Government (Portal Brasil), there is a law in force since 2010 (Law No 12.305, August 2010), which establishes that all municipalities must have the correct destination of their household solid waste. Thus, each city should hire environmental engineering companies that are responsible for the waste collection and final destination. It is a high-cost service, and if the Brazilian population continues to consume and produce waste at the pace of the last 5 years within 30 to 40 years, there will no longer have land to construct licensed sanitary landfill (ABELPRE, 2018).

The creation of remanufactured products becomes indispensable for any nation to avoid such a phenomenon and to minimising the consumption of primary natural resources. Several products are currently discarded without reaching their final life cycle due to programmed obsolescence. According to Dubey (2015), companies are increasingly connected with the need to incorporate sustainability and the triple bottom line in their production line, evaluating the economic, environmental and social impacts of their activities, highlighting the relationship between sustainability and performance throughout their production chain, not only in production itself but in all stages, such as distribution, sales and return (Kleindorfer et al., 2005).

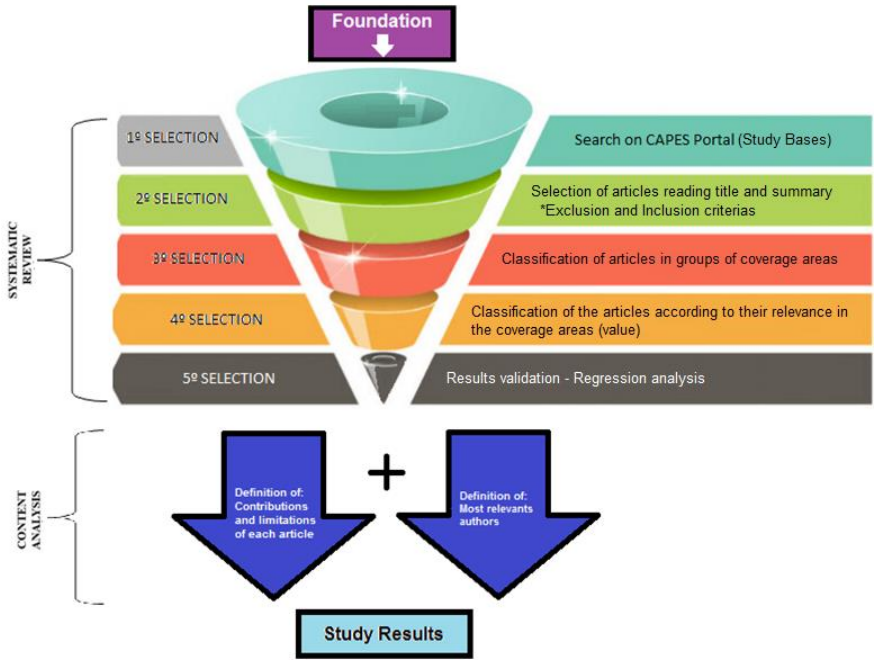
In this context, this research proposes a systematic review and content analysis to determine the researches and authors in the recent scientific literature that are relevant for the development of products built/manufactured from the use of discarded materials (waste). The technical procedures applied in this research were systematic review and content analysis. The systematic review methodology is reliable and rigorous to synthesise and evaluate research relevant to the study theme (BUEHLER et al., 2012; MATTIODA et al., 2015; MULLER et al., 2019; TEIXEIRA and CANCIGLIERI JUNIOR, 2019). The content analysis is a

methodology that analyses the content of the works filtered by the systematic review, revealing the degree of relevance of the articles content to the research theme, as well as their contributions and limitations (MORAES, 1999). In this way, the study contributes to the understanding of the proposed field of research, assisting in the development of new approaches to product design from discarded materials in a sustainable way.

2 RESEARCH METHODOLOGY

The research methodology was developed following two conceptual steps, which are (Figure 1): i) systematic review and ii) content analysis.

Figure 1 – Research Methodology



2.1 Systematic Review

The elaboration of a systematic review, as well as other types of study, is a research that uses as data source the available literature on a given subject in different bases. This type of research provides a summary of the evidence related to a specific intervention strategy, by applying explicit and systematised methods of search, critical appreciation and synthesis of the selected information. Systematic reviews integrate information from different studies performed separately on a given line of thinking that may present conflicting and/or coincidental results as well as identify themes that need further deepening, that is, which themes need further investigation (SAMPAIO, 2006). Buehler et. al. (2012) considers the systematic review as “a method of synthesizing evidence that critically evaluates and interprets all relevant research available for a specific issue, area of knowledge or phenomenon of interest, because it is an explicit and systematic method for identifying, selecting and evaluating the quality of evidence”.

The methodological principles developed by the works of Mattioda et al. (2015) and Szejka et al. (2017) were used to guide the development of this study, supporting the structuring process that was adapted to this theme. A preliminary research (Foundation) on articles connected to the use of discarded materials applied in the development of new products identified the opportunities for further studies and was used in the formulation of search questions and keyword identification. The systematic literature review was structured in 8 stages: i) determination of research questions; ii) determination of keywords (pillars of research); iii) definition of the type of relationship between keywords; iv) search for articles in the scientific databases; v) analysis of titles and abstracts for selection of articles based on inclusion/exclusion criteria; vi) classification of selected articles in groups according to the scope -Simultaneity; vii) analysis for selection refinement of the most relevant articles for the research themes; and viii) validation of the result of the articles' selection.

2.1.1 Determination of the Research Questions

The determination of the research questions aims to identify the main scientific references published on the proposed theme. The previous research (Foundation) was used as a basis for the formulation of 2 research questions:

i) "What are the recent and relevant research that addresses the development of products using discarded materials as raw materials applying sustainable productive processes?" ;

ii) "Which are the most relevant authors and who has recently contributed the most to this research theme?"

2.1.2 Determination of the keywords

The definition of keywords are the pillars of research and was based on the proposed research questions and was carried out rigorously so that they would clearly and objectively represent the entire universe of research. The words "Waste Disposal", "Product Development" and "Sustainability" were defined as keywords, and correlated words were incorporated for greater coverage of the proposed themes.

For "Product Development" and "Sustainability" the related words were based on research by Mattioda et al., (2015). For "Waste Disposal", the online dictionary called Thesaurus was used (THESAURUS, 2015), which listed all possible correlated terms. In this stage, it was possible to determine 28 terms (20 words related to "Product Development"; 7 words related to "Waste Disposal"; and only 1 word related to "Sustainability").

During the search in the Brazilian scientific database - Portal Periódicos of the Coordination for the Improvement of Higher Education Personnel (CAPES/MEC), it was found that the whole universe of research of the word "Sustainability" was contained in the term "Sustainable". Thus, for optimisation purposes, the word Sustainability has been disregarded in this research, considerably reducing duplicate articles for the correlated terms of the

Sustainability pillar. Table 1 shows the defined keywords and their correlated terms.

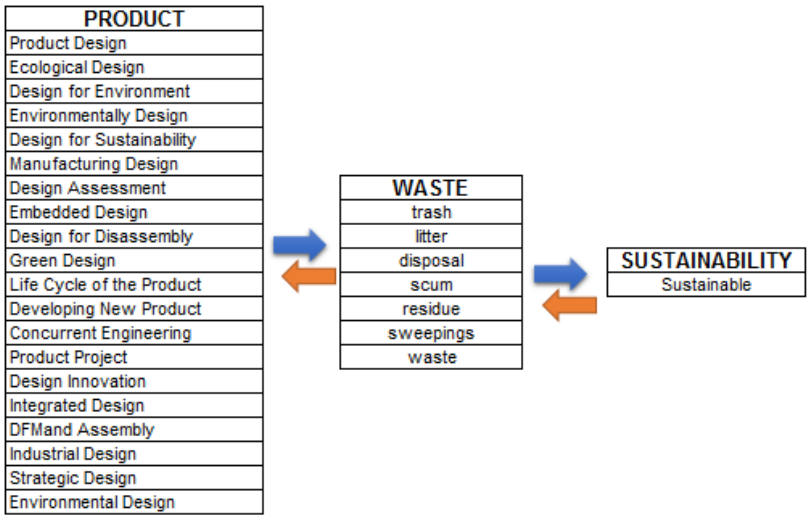
Table 1 – Keywords and their correlated words.

PRODUCT DEVELOPMENT	WASTE DISPOSAL	SUSTAINABILITY
Product Design	trash	Sustainable
Ecological Design	litter	
Design for Environment	disposal	
Environmentally Sustainability Design	scum	
Design for Sustainability	residue	
Manufacturing Design	sweepings	
Design Assessment	waste	
Embedded Design		
Design for Disassembly		
Green Design		
Life Cycle of the Product		
Developing New Product		
Concurrent Engineering		
Product Project		
Design Innovation		
Integrated Design		
Design for Manufacturing and Assembly		
Industrial Design		
Strategic Design		
Environmental Design		

2.1.3 Definition of the definition of the type of relationship between keywords

After defining the keywords, the second stage is to understand how they should relate to each other. It was tested 1x1 crossings of words format that did not effectively cover the research universe. In this way, the 1x1x1 crossing format was used to meet the requirements of the research. The result of this stage was 28 keywords combined 1x1x1, totalling 140 word combinations, as shown in Figure 2.

Figure 2 – keywords crossing.

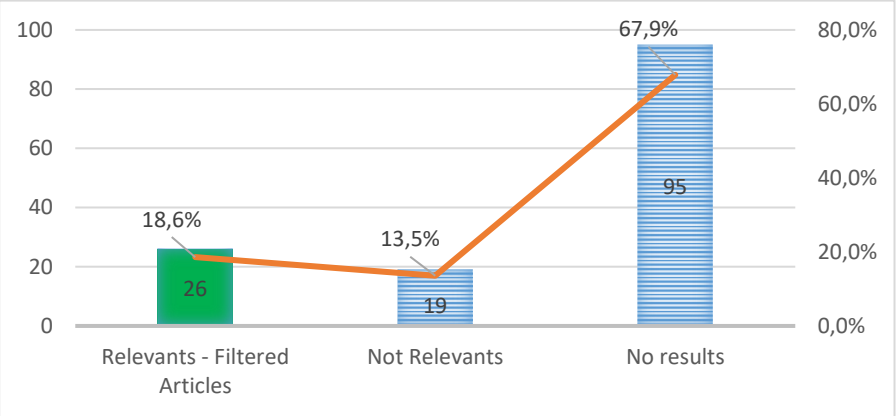


2.1.4 Searching for articles in the scientific databases

This stage was carried out within the research platform Portal CAPES/MEC (Coordination of Improvement of Higher Level Personnel), which has a virtual library of scientific titles and complete texts in more than 530 reference base (PORTAL DE JORNAIS CAPES / MEC, 2019). The Portal has filters, called "search parameters" that allow the effective findings of articles related to the desired topics. In this stage, the following filters were used as input: i) trios of keywords and their correlates linked by the connector “AND”; ii) date of publication – period from 2008 to 2019; iii) type of material - articles; iv) articles in English Language; and v) articles reviewed by peers. The definition of the time interval was based on the Foundation phase where it was observed that in the last 11 years (2008-2019) the concentration and growth of publication of scientific articles on the proposed theme occurred.

The 140 combinations of words defined in the previous step were inserted in the database and the result of the search, presented in Figure 3, showed that only 18.6% (only 26 of the 140 word combinations) resulted in articles related to the proposed research theme (highlighted in a different colour from the others). On the other hand, 13.5% (19 word combinations) did not obtain significant results, i.e., articles were found in the scientific base but did not meet the defined exclusion criteria. The remainder, that is, 67.9% (95 combinations) did not show any results. The 26 combinations relevant to the topics of study resulted in the selection of 11,762 articles related to the subject of this research. The selected articles formed the basis of the study and were submitted to the next steps in order to answer the proposed research questions.

Figure 3 - Search results with keyword combinations.



2.1.5 Analysis of titles and abstracts for articles' selection – Inclusion/Exclusion criteria

This phase consisted of the refinement of the articles selected in the previous step through the application of inclusion and exclusion criteria. The criteria for this selection were defined based on the Foundation stage and covered only themes on product development using discarded materials. Table 2 shows the defined criteria for this phase.

Table 2 - Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
The title and abstract contains the theme of the rubbish/waste description related to product development, focusing on the reuse of materials/optimisation processes.	Chemical, physical and biological articles on waste, its effects, applications.
	Detailing of materials focused on the discovery of new products, such as polymer plastics, fibres.
Forms of correct management of waste generation, focusing on the decrease/extinction of waste production in industries and cities.	Political laws and resolutions on waste and its destination
	Articles that are not written in the English language - review
Articles published only between 2008 to 2019 – review of the year of publishing	Articles that are not peer-reviewed
	Articles that explore mathematical approaches or modelling

The criteria were applied in the 11,762 elected articles through the reading of the titles and abstracts, resulting in 136 selected articles related to the research theme. Subsequently, it was carried out the refinement for duplicity, being removed 9 articles, reducing the total of articles selected in this step to 127, as described in Table 3.

Table 3 - Selected articles through keyword combination.

Keyword 1 Product Development	Keyword 2 Waste Disposal	Keyword 3 Sustainability	Total Articles	Selected Articles	% Relevance
Design for Sustainability	waste	Sustainable	21	1	4,8%
Design Innovation	disposal	Sustainable	164	1	0,6%
Ecological Design	trash	Sustainable	11	1	9,1%
Ecological Design	disposal	Sustainable	126	2	1,6%
Ecological Design	waste	Sustainable	306	2	0,7%
Environmental Design	trash	Sustainable	81	1	1,2%
Environmental Design	litter	Sustainable	73	2	2,7%
Environmental Design	disposal	Sustainable	678	3	0,4%
Environmental Design	residue	Sustainable	67	2	3,0%
Environmental Design	waste	Sustainable	1628	4	0,2%
Green Design	trash	Sustainable	38	3	7,9%
Green Design	litter	Sustainable	19	1	5,3%
Green Design	disposal	Sustainable	531	5	0,9%
Green Design	residue	Sustainable	60	2	3,3%
Green Design	waste	Sustainable	1045	5	0,5%
Industrial Design	trash	Sustainable	19	1	5,3%
Industrial Design	disposal	Sustainable	160	3	1,9%
Manufacturing Design	trash	Sustainable	6	1	16,7%
Manufacturing Design	disposal	Sustainable	89	2	2,2%
Manufacturing Design	waste	Sustainable	182	2	1,1%
Product Design	trash	Sustainable	107	6	5,6%
Product Design	litter	Sustainable	69	3	4,3%
Product Design	disposal	Sustainable	2099	3	0,1%
Product Design	residue	Sustainable	240	10	4,2%
Product Design	sweepings	Sustainable	4	3	75,0%
Product Design	waste	Sustainable	3680	58	1,6%
Total				**127**	

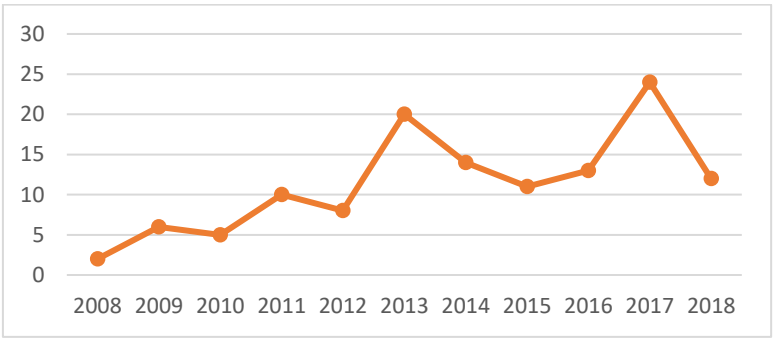
The 127 selected articles were analysed concerning the reference bases, research areas, year of publication and geographical distribution. The objective of this analysis was to know in more detail how the use of discarded materials applied to product development is being explored by the scientific community over the years, in which countries, on what reference basis and in which areas of research. The results showed that the selected articles were distributed in reference bases such as Elsevier, Sage Journals, Science Direct and Springer-Verlag. The highest concentration is in the Engineering area with 77% of the selected articles (94 articles). Thus, it can be said that the application of discarded materials in the product development process is almost exclusively aligned with the Engineering area, where research is being developed to help in the search for sustainable solutions for remanufactured products design (BUEHLER et al., 2012). The configuration of the analysed time interval, 2008 to 2019, defined according to the Foundation phase ensured that only recent publications together with the ones that were in accordance with the new environmental laws were filtered.

Figure 4 illustrates the number of articles published in each year and shows that from 2008 to 2012, the publications remained practically stable, with a small increase in publications each year. From 2013, there has been a significant

increase in publications on the research theme. However, between 2014 and 2016 there was a small drop, but still above the values of 2012. In 2017 there was a significant increase in publications again, showing that the subject is relevant and is in the process of expansion. In 2018 there was a small drop, but still a more significant number than in the years before 2017.

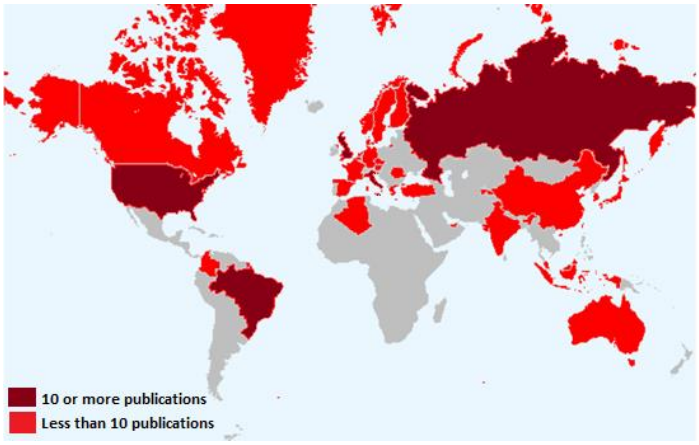
The publications increasing in recent years is due to the actions for people environment awareness, in addition to the interest of large companies in the theme, since it is possible to reduce raw material costs by using products remanufacturing. In this context, when analysing the timeline of publications, the subject needs a greater maturity in the scientific environment, confirming the opportunity for innovation within the theme of this study.

Figure 4 – Articles by year of publication.



In the geographical distribution analysis, it was observed that the concentration of research occurs in 34 countries, representing more than 17% of coverage in the world (UN, 2018). Most of the scientific production is concentrated in the USA, the UK, Brazil, China and Italy. The analysis showed that although the USA concentrates a greater absolute quantity, the European Continent presents a higher concentration when all the researches of its countries are added. This significant incidence of articles in Europe is partly because the European Union has concrete and short-term objectives to reduce pollutant emissions, such as encouraging the use of resources efficiently. Besides, industrial policy is being supported for the practice of sustainability, with the development of research in the areas of technological innovation, ensuring less use of finite natural resources and reduction in the amount of materials discarded daily (COMISSÃO EUROPEIA, 2017).

Figure 5 – Geographical concentration of the analyzed publications.



2.1.6 Classification of selected articles in groups according to the area – Simultaneity

A classification system of the selected articles according to the scope area was defined to optimise the analysis and determine the articles with greater adherence to the research theme. The main pillars of the research allowed the definition of 4 groups, which are presented in Table 4. In Group 1, FRW, the articles relating to sustainable product design are classified, focusing on optimization of the processes and reuse of waste since the product conception; in Group 2, EXR, is classified the articles related to the products remanufactured from the waste; Group 3, ECW, classified the articles related to reverse logistics and "zero waste"; in group 4, SCM, the articles referring to the ways of final disposal and waste management are classified.

Table 4 –Criteria of Groups classification.

TOPIC	GROUP DESCRIPTION	INITIALS
1	The article presented a framework for the production of sustainable products since the phase of the design	*FRW*
2	The article shows ideas/examples of products which have been remanufactured or reproved - creation of new products with "garbage"-	*EXR*
3	The article shows ideas/concepts on the circular economy or reverse logistics or "zero waste"-	*ECW*
4	Article presenting data on waste management through any productive chain	*SCM*

All selected articles were classified according to the group inclusiveness through full reading, and the same article can be classified in more than one group simultaneously. Table 5 presents a sample of the classification of the most relevant articles in order of importance according to the topic inclusiveness groups in the last 11 years.

Table 5 – Sample of the Articles Classification by topic inclusiveness Groups.

ARTICLE TITLE	YEAR	FRW	EXR	ECW	SCM
Resource recovery from post-consumer waste: important lessons for the upcoming circular economy	2016	✓	✓	✓	✓
An assessment of the recycling potential of materials based on environmental and economic factors; case study in South Korea	2009	✓		✓	✓
Ecodesign methods focused on remanufacturing	2009	✓		✓	✓

ARTICLE TITLE	YEAR	FRW	EXR	ECW	SCM
Incorporating waste into an experimental school prototype: lessons regarding materials reclamation opportunities	2012		✓	✓	✓
Collaboration between design and waste management: Can it help close the material loop?	2013		✓	✓	✓
Design for remanufacturing in China: a case study of electrical and electronic equipment	2013		✓	✓	✓
Introducing the All Seeing Eye of Business: a model for understanding the nature, impact and potential uses of waste	2013	✓		✓	✓
Minimizing the increasing solid waste through zero waste strategy	2014	✓		✓	✓
A comprehensive review of the development of zero waste management: lessons learned and guidelines	2015	✓		✓	✓
Reducing and reusing industrial scraps: a proposed method for industrial designers	2015		✓	✓	✓
Analysis of electronic waste reverse logistics decisions using Strategic Options Development Analysis methodology: A Brazilian case	2016	✓		✓	✓
Application of exergy-based approach for implementing design for reuse: The case of microwave oven	2017	✓		✓	✓
Remanufacturing strategies: A solution for WEEE problem	2017	✓		✓	✓
Integrating sustainable waste management into product design: sustainability as a functional requirement	2010			✓	✓
A novel approach to product modularity and product disassembly with the consideration of 3R-abilities	2011		✓		✓
Challenges and Opportunities in Transforming a City into a "Zero Waste City"	2011		✓	✓	
Sustainable supply chain for collaborative manufacturing	2011	✓			✓
Reuse-oriented redesign method of used products based on axiomatic design theory and QFD	2012		✓	✓	

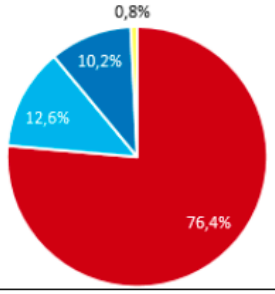
ARTICLE TITLE	YEAR	FRW	EXR	ECW	SCM
Design for sustainability (DFS): the intersection of supply chain and environment	2014		✓		✓
Progress and challenges to the global waste management system	2014		✓		✓
Identifying best design strategies for construction waste minimization	2015		✓	✓	
A design tool to diagnose product recyclability during product design phase	2016		✓	✓	
Lean/Green integration focused on waste reduction techniques	2016	✓			✓
Benefits, challenges and critical factors of success for Zero Waste: A systematic literature review	2017			✓	✓
End-of-life decision tool with emphasis on remanufacturing	2017		✓	✓	
In search of standards to support circularity in product policies: A systematic approach	2017		✓		✓
Influence of recycling programmes on waste separation behaviour	2017	✓			✓
Waste prevention for sustainable resource and waste management	2017		✓	✓	
Remanufacturing challenges and possible lean improvements	2018		✓		✓
Comparative evaluation of life cycle assessment models for solid waste management	2008			✓	
Exploring e-waste management systems in the United States	2008			✓	
A purview of waste management evolution: Special emphasis on USA	2009				✓
E-waste and the sustainable organisation: Griffith University's approach to e-waste	2009			✓	
Experimental study of recycling lightweight concrete with aggregates containing expanded glass	2009			✓	
Perspectives in reverse logistics: A review	2009		✓		
A study of reverse logistics flow management in vehicle battery industries in the midwest of the state of São Paulo (Brazil)	2010			✓	

ARTICLE TITLE	YEAR	FRW	EXR	ECW	SCM
Can companies profit from greener manufacturing?	2010			✓	
Life cycle of products and cycles	2010		✓		

The articles, showing simultaneity, presented more complete content, that is, a higher level of knowledge, complexity and domain of the subject related to the research theme. Consequently, simultaneity was used as a criterion for an improvement in the selection of articles and based on it, articles included simultaneously in 2 of the coverage groups would be selected for the next step. The others that did not meet this requirement were discarded.

The application of this criterion in the 127 articles resulted in the selection of 31 articles: i) 1 article (0.8%) with approaches comprised the 4 groups simultaneously; ii) 13 articles (10.2%) that addressed themes belonging to 3 of the groups, and iii) 16 articles (12.6%) that approached the themes of 2 groups. The remaining articles, 97 (76.4%) were discarded for exploring only 1 of the 4 groups. Figure 6 shows the result of this selection.

Figure 6 - Percentage of articles classified by the simultaneity of themes.

TOPIC	INITIALS	LEGEND	TOPICS COVERED
1	*FRW*		
2	*EXR*		
3	*ECW*		
4	*SCM*		

2.1.7 Analysis for the refinement of the selection of the most relevant articles for the proposed research themes

The articles selected in the previous phase were related to the subjects studied, but there was a need to identify which of these researches were the most adherent to the scope of the research. In consequence, the selected articles were submitted to a new analysis where weighted variables (value) were assigned from 0.00 to 10.00 for each group, according to their degree of importance for the research. The allocation was therefore as follows: the FRW group received the assigned value of 3.75 or 38% of relevance, as it represents all articles that in their content presented frameworks for production of sustainable products through the materials reuse. The EXR group was considered the second most important, receiving the value of 2.95, or 30% of relevance. The ECW and SCM groups were assigned values of 2.30 or 23% and 1.00 or 10% of relevance, respectively. Table 6 shows the groups with the assigned grades and percentages of relevance.

Table 6 – Groups weighted variables – Regression equation

TOPIC	INITIAL	VARIABLE	VALUE	% RELEVANCE
1	FRW	xi	3,75	38%
2	EXR	xii	2,95	30%
3	ECW	xiii	2,30	23%
4	SCM	xiv	1,00	10%
	Total		10,00	100%

This weighting system was applied to the 31 selected articles and the total sum of the weights of the groups in which the article is inserted determined the degree of their relevance to the research. Articles that reached a sum greater than or equal to 6 (>= 6) were considered relevant; the others with a score less than or equal to 5 (<= 5) were discarded. Thus, this analysis resulted in 13 articles considered as the most relevant, with approaches more adherent to the proposed research theme. Table 7 presents the classification of the 13 selected articles concerning their relevance to the research (relevant and very relevant).

Table 7 – Articles classification by relevance area.

ARTICLE TITLE	YEAR	CLASSIFICATION	GROUPS			
			FRW	EXR	ECW	SCM
An assessment of the recycling potential of materials based on environmental and economic factors; case study in South Korea	2009	Relevant	✓		✓	✓
Ecodesign methods focused on remanufacturing	2009	Relevant	✓		✓	✓
Sustainable supply chain for collaborative manufacturing	2011	Relevant	✓			✓
Collaboration between design and waste management: Can it help close the material loop?	2013	Relevant		✓	✓	✓
Introducing the All Seeing Eye of Business: a model for understanding the nature, impact and potential uses of waste	2013	Relevant	✓		✓	✓
Minimizing the increasing solid waste through zero waste strategy	2014	Relevant	✓		✓	✓
A comprehensive review of the development of zero waste	2015	Relevant	✓		✓	✓

ARTICLE TITLE	YEAR	CLASSIFICATION	GROUPS			
			FRW	EXR	ECW	SCM
management: lessons learned and guidelines						
Reducing and reusing industrial scraps: a proposed method for industrial designers	2015	Relevant		✓	✓	✓
Analysis of electronic waste reverse logistics decisions using Strategic Options Development Analysis methodology: A Brazilian case	2016	Relevant	✓		✓	✓
Resource recovery from post-consumer waste: important lessons for the upcoming circular economy	2016	Very Relevant	✓	✓	✓	✓
Application of exergy-based approach for implementing design for reuse: The case of microwave oven	2017	Relevant	✓		✓	✓
Remanufacturing strategies: A solution for WEEE problem	2017	Relevant	✓		✓	✓
Use to use – A user perspective on product circularity	2019	Relevant	✓	✓	✓	

The articles were also submitted to analysis concerning the indicators JCR and SJR. The Journal Citations Report (JCR) was created to identify which impact factor each Journal has in the academic community. SCImago Journal Rank (SJR) is an indicator of the influence of a given journal through the average number of quotes received in the last 3 years preceding the year analysed. The classification criterion of greater than or equal to 1 for both indicators was adopted by the academic community as a reference for these indicators and used in this research. The analysis showed that all articles selected in this phase were within the criterion and published on Journals that impact and influence the academic community.

2.1.8 Validation of the articles selection results

The selection standards adopted in the systematic literature review were consistent and reliable, it was applied the mathematical methodology of regression analysis, which among other functionalities confirms the established grade patterns and ensures that no article is erroneously discarded (Charnet et al., 2008). According to the author, the regression analysis consists of conducting statistical analysis in order to verify the existence of a functional relationship

between a dependent variable and one or more independent (free) variables. Applying this mathematical tool allows the development of an equation that tries to explain the behaviour of the dependent variable with the behaviour of the various levels that can be reached by the independent variable (s). As there is only one variable for analysis, which is the grade of each article according to its classification in the groups, this research used the simple linear regression, or 1st degree, that follows the statistical model of:

Figure 7 – Simple regression equation model.

$$\gamma i + \beta 0 + \beta i X i + e i \qquad (1)$$

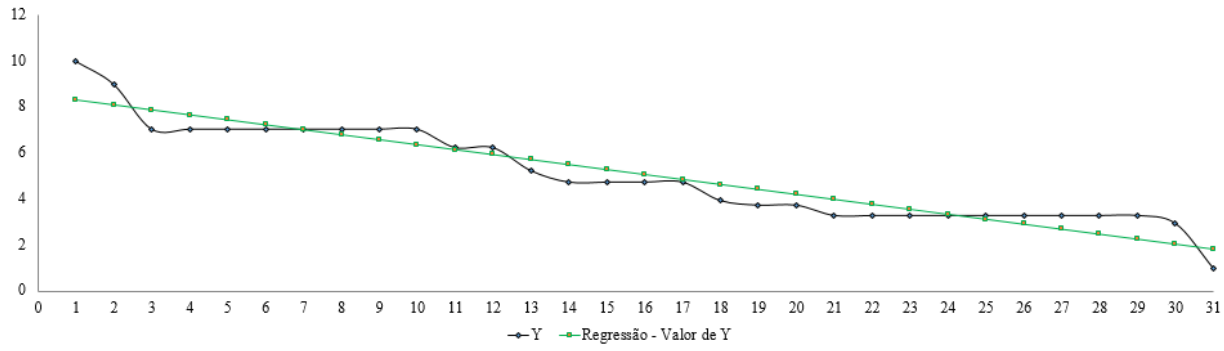
Thus, according to Charnet et. al. (2008) and considering that the research was based on the simple regression equation, the equation for the articles' analysis of this research were:

Figure 8 – Simple regression equation

5,34 + 3,75xi + 2,95xii + 2,30xiii + 1,0xiv + z(i = 1 – 31) = yi

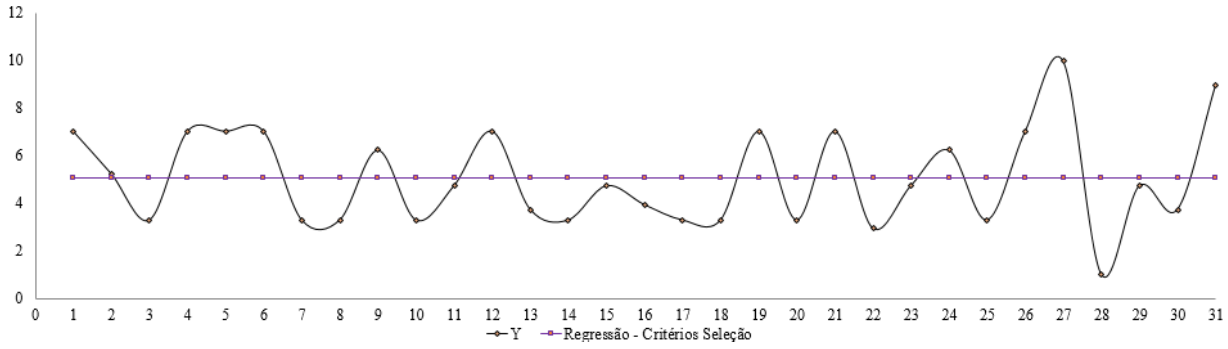
The application of the linear regression tool corroborates that all articles followed a uniform selection pattern. The regression analysis confirms the results of the systematic literature review, which 13 articles were selected and considered the most relevant for the scope of the research and 18 were discarded. The graphics of Figures 9 and 10 show the application of the linear regression tool in the validation of a uniform and consistent article selection pattern.

Figure 9 – Regression Analysis (Y Value).



In Figure 9 the regression line representing the free variable and shows that it is close and constant to the variations found in the analysed articles, confirming the existence of a pattern. In this way, it is possible to conclude that with the creation of the groups and the assigned value weightings, the refinement of articles followed a pattern and allowed to select articles that are relevant to the research without ruling inappropriately out any study.

Figure 10 – Regression Analysis (Multiple Variables).



The same occurs in the chart of Figure 10; the straight line shows the pattern that multiple variables represent when analysed in each of the examined articles, also confirming the selection pattern of the articles. Again, it is possible to conclude by the behaviour of the curve of the multiple variables that with the creation of the groups and weightings of assigned values, the refinement of the articles' selection followed a pattern and allowed the selection of articles that are relevant to research.

2.2 Content Analysis

At this stage, the author proposes a critical analysis of the 13 articles selected in the systematic literature review, complementing and corroborating the information in order to accurately answer the questions proposed in the research.

The content analysis was carried out on each of the 13 final articles, investigating their proposed approaches, their limitations and contributions. Such analysis is a methodological form of research with the main objective of describing and interpreting the profound content of all types of documents and texts (MORAES, 1999). This process permits the identification of gaps not yet explored and can serve as a guide for the development of new research, promoting the scientific advance of the studied area.

The answer to the second problem question was reached through an analysis to identify the leading authors who are working with the development of products using discarded materials. This analysis was performed in two stages: a) verification of all authors cited in the 13 relevant articles; and b) verification of the frequency of citation of each author in the selected articles. This analysis allowed the identification of the important authors in participation and which positively impact the field studied.

2.2.1 Critical Analysis

In this stage, the 13 articles were analysed in their entirety (full reading of the article) exploring the proposed approaches, their contributions and limitations in relation to the theme of product development using waste materials as raw material. Table 8 presents the articles in chronological order of publication and the critical analysis of their scientific contributions and limitations in the area.

Table 8 - Content Analysis Summary.

ARTICLE	TITLE	YEAR	CONTRIBUTION	LIMITATION
1	An assessment of the recycling potential of materials based on environmental and economic factors; case study in South Korea	2009	The paper shows the costs of re-routing of each type of raw material (metal, paper, plastic)	The article only presents the cost of recycling some types of materials, but did not show how to put these products in line production again.
2	Ecodesign methods focused on remanufacturing	2009	There are definitions about eco-design or design for remanufacturing, explaining what means eco-design and how to apply it. Besides that, the author correlates 5 methods to implement Eco-Design in industries, and each one applied depending on the needs of each company characteristics.	The article presents the 5 Eco Design templates but does not apply them to products (examples). The article also does not define what the strengths and limitations of each Eco-Design template are.
3	Sustainable supply chain for collaborative manufacturing	2011	The article explains the sustainable supply chain and the 6Rs of sustainability, what each 'R' means and how to apply them in the supply chain.	The article did not present the interactions of collaborative manufacturing and sustainability in a supply chain, not showing the relationship between all supply chain members.
4	Collaboration between design and waste management: Can it help close the material loop?	2013	It shows product design that is manufactured from the idea of reuse, creating closed economic cycles, which the end of the life cycle becomes the beginning of a new cycle for another product.	Although the authors have identified a lack of collaboration between Designers and Waste Management professionals to improve sustainable manufacturing, they have not presented ideas of how to enhance the relationship between these professionals.
5	Introducing the All Seeing Eye of Business: a model for understanding the nature, impact and potential uses of waste	2013	This paper presents methodologies for waste reuse and reduction. It provides an idea of how to minimise the increase in waste disposal. Moreover, presents ideas for the reduction of waste at the time of production, in line production.	The article did not present applied examples of each methodology and not present the levels of profit or loss, neither comparations between the methods.
6	Minimizing the increasing solid waste through zero waste strategy	2014	The article defines Zero Waste concepts and has 2 detailed flowcharts of how to apply them. Besides, there are detailed images of circular economy, helping to a better understanding of this subject.	The article shows ideas of implementation of zero waste methodology in some scenarios, but the focus of study was only in the municipal solid waste (MSW)

ARTICLE	TITLE	YEAR	CONTRIBUTION	LIMITATION
				This represents only 20% of all solid waste.
7	A comprehensive review of the development of zero waste management: lessons learned and guidelines	2015	The article explains zero waste, which means and how cities can try to use this methodology in their waste management.	The article focus only on the correct management of solid waste at the city level (zero waste cities management).
8	Reducing and reusing industrial scraps: a proposed method for industrial designers	2015	Focus on the attempt to interweave the areas of design and engineering in the construction of new products. It also proposes the reuse of materials at the end of the life cycle, transforming them again into raw material for the production process (there are some product examples).	The author did not apply the methodology created in different production contexts. There are some product examples, but all of them are made in the same production context.
9	Analysis of electronic waste reverse logistics decisions using Strategic Options Development Analysis methodology: A Brazilian case	2016	It shows how important it is that all involved in the production of a particular product be engaged to make it sustainable, ensuring that logistics and engineering reserve are satisfactory. It includes all stakeholders, from suppliers to final consumers.	The article focuses exclusively on electronic waste production, not showing how to apply the integrated supply chain in different types of waste. Besides, the article research was made only with Brazilian interviewees, being necessary some adjusts to apply in other countries.
10	Resource recovery from post-consumer waste: important lessons for the upcoming circular economy	2016	There is a detailed explanation of the circular economy and the recovery routes products. Besides, the article presents examples of remanufactured products (circular economy), which were built from products which would be discarded in landfills.	Although the definition of recovery routes of products was based on the analysis of 58 distinct product examples, the research showed that this number is not enough too guaranty the robustness of the study.
11	Application of exergy-based approach for implementing design for reuse: The case of microwave oven	2017	The article presents a method for design aimed at reuse. Besides, there is a flowchart for product dismounting at the end of its life cycle, helping to reuse products as raw material.	It focuses on mathematical formulas based on the 2º law of the thermodynamics and does not explain how it is possible to create a product from the design phase reusing products already discarded.
12	Remanufacturing strategies: A solution for WEEE problem	2017	The article shows concepts of waste sorting and how to apply them in remanufacturing processes. Besides, there is an applied case of XEROX	It focuses on electronic waste remanufacturing. The method is not generic and can be only used on electronic waste.

ARTICLE	TITLE	YEAR	CONTRIBUTION	LIMITATION
			Company in UK, reusing products to building new ones.	
13	Use to use – A user perspective on product circularity	2019	The article presents concepts showing the user's perspective regarding the acquisition of products and their next steps at the end of their life cycle.	The article did not evaluate the design strategies ideas created through application in a real design process. It also did not show the different paths that each type of product go during the consumption process.

Source: The Author.

2.2.2 Analysis of the references cited in the selected relevant articles

This last step focused on the analysis of the references to identify the main authors who research and have an important impact in this area of study. The analysis consisted of identifying the authors most frequently cited in the relevant articles to the research. At the end of this stage of the authors' survey resulted in 1610 authors that were evaluated in different ways by assigning three types of values: i) values of 1.00 to ∞ that represent the number of times the authors were referenced in the References Section of each article; ii) values from 0.00 to 0.20 for each citation that the author had throughout the texts of the analysed articles; and iii) values of 1.00 to ∞ that represent the incidence of articles in which the author appears among the 13 filtered in the systematic review. If throughout the text of the article, the same author is cited twice, the value assigned is 0.1, and so on up to the value of 0.20 as described in Table 9. From 5 times that an author is cited throughout the development of an article, the value of 0.2 is fixed.

Table 9 – Citation values.

Citation Number	Value	Citation Number	Value	Citation Number	Value
1	0	7	0,2	13	0,2
2	0,1	8	0,2	14	0,2
3	0,15	9	0,2	15	0,2
4	0,18	10	0,2	16	0,2
5	0,2	11	0,2	17	0,2
6	0,2	12	0,2	...	0,2

The classification of the most relevant authors for this research theme and their respective grades can be observed in Table 10. This classification was based on the number of times that the author was cited in the "References Section" of the scientific articles and the number of times the author is cited in the body of the text (Table 9) represented by the column "Score" of table 10. The column "Incidences" shows the number of different articles in which each author was referenced. The total value of different articles in which each author was

referenced was established as a fundamental classification criterion (Column "Incidences" of Table 10) and its respective levels of influence on the research topics (Column "Influence Level" of Table 10).

It is important to note that authors who obtained higher marks in the sum of reference values and citations may not be classified as the most relevant researchers for the subject under study. The researcher Zeng X. is an example because although he obtained the value of 8.10 in the "Column Score", he is referenced only in 3 different articles, being classified inferior to the researcher Williams, I. D. who obtained value 4.10 in the "Column Score" but is referenced in 4 different articles. Authors who did not reach the sum > 4.00 in the "Column Score", or who were not referenced in at least 3 different articles were not considered and did not appear in Table 10.

The authors Li J. and Williams I. D. can be considered the most significant authors for the subject under study since both were referenced in 4 of the 12 selected articles. Li J. was considered the author with the greatest impact on the studied area since he obtained a value of 10,20 in the "Column Score and was referenced in 4 different articles.

Table 10 – Most relevant authors.

Authors	Score	Incidences	Influence Level
Li, J.	10,20	4,00	1º
Williams, I.D.	4,10	4,00	2º
Van Hemel, C.	4,00	4,00	3º
Zeng, X.	8,10	3,00	4º
Braungart, M.	5,28	3,00	5º
Stevels, A.	5,10	3,00	6º
Zhang, H.C./ H-C	4,10	3,00	7º
McDonough W.	4,00	3,00	8º
Sutherland, J.W	4,00	3,00	
Sarkis, J.	4,00	3,00	
Other Authors	Less than 4,00	Less than 3,00	Others

3 FINAL CONSIDERATION

Waste production has been growing over the years due to various factors such as stimulation of consumption, which makes it increasingly difficult the disposal of the amount of waste produced. Starting from this, the understanding and systematisation of the development of products that use discarded materials as raw material become fundamental for any company and public administration. In this context, this article aimed to determine the leading research and authors that are impacting this area of research through a systematic literature review and content analysis

The first part of the study focused on the systematic review of literature and started with the formulation of the research questions and the definition of the

interval of time (from 2008 to 2019) as well as the keywords and their correlated words based on a previous study (Foundation). The 3 main keywords and 28 correlated words were defined as Product development and 20 correlated words, Waste Disposal and 7 correlated words and Sustainability and 1 correlated word. With the intent of covering all research universe, these words were combined in a 1x1x1 format linked with the word “and” resulting in 140 combinations that were used to search the scientific databases. From the 140 combinations only 26 (18,6 %) presented results related to the research scope, selecting 11,762 articles.

The 11,762 selected articles addressed topics such concepts, frameworks, ideas and examples of product development of a product using waste as raw materials, waste management, reverse logistics and were submitted to inclusion and exclusion criteria resulting in selection of 127 articles that were within the research. The analysis overview in this phase showed that 77% of the selected articles were concentrated in the Engineering area as well as the journals main reference bases and research areas. It also showed that USA, United Kingdom, Brazil, China, Italy concentrate the geographical distribution of the scientific research in the analysed period. Moreover, it was observed a significant increase in the publications from 2017, revealing that the theme addressed is relevant and is in process of expansion.

A classification system of the selected articles according to the scope area was defined to optimise the analysis and determine the articles with greater adherence to the research theme. The simultaneity was used as an exclusion criterion since it means a higher level of knowledge, complexity and domain of the article and resulted in the selection of 30 articles. These articles were submitted to a new analysis, and weighted variables were assigned to the groups defined in the previous step according to their relevance to the study and resulted in the selection of 13 articles considered as the most relevant, with approaches more adherent to the proposed research theme. It represents only 0,11% of the 11.762 articles found in the scientific databases survey.

The mathematical methodology of regression analysis was applied in the selection standards adopted in the systematic literature review to ensure that they were consistent and reliable. This analysis corroborated the systematic literature review results, showing that the used methodology followed a uniform selection pattern and allowed the selection of articles that are relevant to the research without incorrectly ruling out any study. Therefore, it can be stated that the 13 selected articles are the answer for the first research question, that they are the recent and relevant scientific research in the development of products using discarded materials as raw materials over the period from 2008 to 2019.

In the second part of the research, the focus was on the content analysis. The 13 articles resulted from the systematic literature review were analysed in their entirety and investigated concerning the proposed approaches, their scientific contributions and limitations as well as the analysis for identifying the authors most frequently cited in these articles.

The Content analysis showed that in the approaches explored in the 13 selected articles there is a shortage of effective scientific methods and models that can support the process of integrated development of sustainable products using discarded materials as raw material. The articles did not fully and effectively present all the necessary steps for the development of remanufactured products,

focusing only on a specific stage of the development process or on in specific type of waste material. It became evident that the issues in product development using discarded materials have not all perspectives addressed, given opportunities for new studies. The analysis of the References cited on the 13 found 1610 quoted authors. A classification system for the author's citation frequency was defined and applied to the 1610 authors. The results answered the second research question showing that 2 authors, Li J. and Williams I. D., can be considered the most significant authors for the subject under study. Li J. is considered the author with the most significant impact on the studied area as he obtained the highest combined score in the classification system.

To conclude, the research provided a comprehensive panorama of the scientific works published in the last decade. The identification of the most recent and relevant researches and milestones authors contributed to widening the understanding of the concepts, approaches, technologies and methodologies as well as their applications and limitations in solving the issues of product development process using discarded materials. At the same time, it provided a clear understanding that is essential that new perspectives must be explored in order to find new solutions for the use of the waste materials in the product development and the incorporation of sustainability and triple bottom line into the production line, minimising the consumption of primary natural resources. The authors believe that a new research perspective would open with the proposal and development of a conceptual framework that takes into consideration aspects of manufacturing processes, reuse of waste as raw material and sustainability throughout all the product development phases. The concept of this framework should contribute in a friendly and effective way to the decision-making process during the integrated development of sustainable products based on the economic and environmental dimensions of the triple bottom line concept.

4 ACKNOWLEDGEMENT

The authors especially thank the financial support of Pontifical Catholic University of Paraná (PUCPR) - Polytechnic School – Industrial and Systems Engineering Graduate Program (PPGEPS), by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001 and by the Brazilian National Council for Scientific and Technological Development (CNPq).

Determinação de principais referências no desenvolvimento de produtos utilizando materiais descartados

RESUMO

Com o desenfreado consumo de bens materiais e o grande desperdício de alimentos e produtos de consumo ditos instantâneos, em poucos anos a capacidade de aterros sanitários estará acabada. Para evitar essa catástrofe, ações em termos de reutilização de materiais, logística reversa, engenharia reversa e desenvolvimento de produtos remanufaturados tornam-se mandatórias. Nesse contexto, o foco desta pesquisa é a identificação das principais pesquisas e autores, suas contribuições e limitações, em relação ao desenvolvimento de produtos sustentáveis construídos / fabricados a partir da reutilização de materiais descartados (resíduos). Utilizando para tanto uma revisão sistemática da literatura aliada a uma análise crítica de conteúdo. A revisão sistemática começou com a determinação das questões de pesquisa, palavras-chave e critérios utilizados nas bases de dados científicas na busca dos artigos. O primeiro resultado das pesquisas em bancos de dados científicos resultou em 11.762 artigos. Eles foram submetidos a análises com base nos critérios de inclusão / exclusão e, ao final da revisão sistemática da literatura, 13 artigos foram considerados os mais relevantes para o tema de pesquisa proposto. Uma análise de regressão sobre o resultado da revisão da literatura corroborou os artigos encontrados. Os 13 artigos foram analisados na íntegra e investigados quanto às abordagens propostas, suas contribuições e limitações científicas, bem como a análise para identificação dos autores mais citados nesses artigos. A pesquisa resultou em um panorama abrangente dos trabalhos científicos publicados na última década sobre o tema da pesquisa. A identificação dos autores de pesquisas e marcos mais recentes e relevantes contribuiu para ampliar a compreensão dos conceitos, abordagens, tecnologias e metodologias, bem como suas aplicações e limitações na resolução de problemas do processo de desenvolvimento de produtos utilizando materiais descartados.

PALAVRAS-CHAVE: Design de Produto; Sustentabilidade; Destinação de resíduos, Reutilização;

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Recebido: 20 abr. 2020.
Aprovado: 01 out. 2020.
DOI: 10.3895/rbpd.v10n1.12037
Como citar: CONTADOR, F. A. Z.; JUNIOR, O. C. Determination of key references on product development using discarded materials. **R. bras. Planej. Desenv.** Curitiba, v. 10, n. 01, p. 154-195, jan./abr. 2021. Disponível em: <https://periodicos.utfpr.edu.br/rbpd>. Acesso em: XXX.
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