PRODUCT
Management & Development
An International Journal for Transdisciplinary Research in Innovation

ISSN 2237-5228

Journal homepage
www.pmd.igdp.org.br

Review Article

Design for Excellence (DfX) in vehicle armoring operations: improvements and speed up a systematic literature review

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Abstract

Several references in the literature help manufacturing companies improve quality, production performance, and waste reductions in shop floor processes. Different Systematic Literature Reviews (SLR) help researchers refine their reference results to apply them to manufacturing activities. Thus, to improve and speed up the research of the state-of-the-art references from the engineering and scientific platforms on a given topic, this article presented an improvement of the systematic review named iSLR. It consists of a detailed analysis of bibliographic results first searched in predefined publishers and next in databases using the Automatic Bibliography Researcher (ABRe) program to generate valuable references in an organized list. This procedure ensures the addition of relevant references not in the database results. A case study using iSLR was applied to search and select the DfX (Design for Excellence) references related to Civilian Armored Vehicle (CAV) operations in Brazil to help these automotive aftermarket firms to guidelines and enhance their armoring operations. Additionally, to validate the consistency of iSLR and the case outcomes analysis, the authors performed VOSviewer®, a bibliography network map software. The iSLR can be replicated for research on other topics where the Scopus platform databases and other scientific bases are used, adjusting the ABRe program.

Keywords: systematic literature review, bibliography network, design for excellence, automotive manufacturing process, civilian armored vehicles.

1. Introduction

The increasing rates of violence and insufficient public security policies, especially in large urban areas of developing countries, have significantly affected the civilian armored vehicle (CAV) market segment. Since the 2000s, Brazil has been the world's largest manufacturer of new CAVs, producing more than 210.000 brand-new vehicles until 2021 (Silva, 2021).

After automakers or OEMs (Original Equipment Manufacturers) entirely manufacture the vehicles, the shop floor employees manually perform the ballistic protection process requested by customers in independent workshops named Armoring Firms (AF). Unfortunately, to speed up the ballistic protection processes, CAV production is usually carried out in AFs without following automotive criteria. As a result, they are not certified or qualified as OEM formal suppliers. These factors may compromise the OEM component warranties regarding product quality and performance.

Therefore, the armoring process performed in AFs in Brazil neither involves the OEMs manufacturing nor complies with automotive requirements, such as IATF. The IATF 16949:2016 (International Standard for Automotive Quality Management Systems) was submitted by The International Organization for Standardization (ISO). It is a common automotive quality system requirement, based on ISO 9001, related to quality standards and customer-specific requirements from the automotive sector (International Automotive Task Force, 2016).

Design engineers constantly incorporate new components and new product technologies into vehicle product designs. In addition, product changes are triggered based on innovative features or technology modifications added to existing vehicle models (Shivankar & Deivanathan, 2021). Therefore, these frequent design changes increase the difficulty of protecting brand-new vehicles at AFs, which are not regular OEM suppliers.

Based on this context, the authors propose an improved Systematic Literature Review (iSLR) methodology to automatically create an organized list of reference results from a bibliographic search in a spreadsheet. Thus, the outcomes are expected to enhance the AF operations in civil armor vehicles. Furthermore, most of the state-of-the-art references of the DfX tools related to vehicle armoring are available in scientific and engineering databases. Therefore, the DfX tools help AFs to maintain the original functionality of the automotive

Received: July 14,2022. **Accepted:** September 5, 2022.
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components, so the passenger compartment structures of the vehicle remain the same. Thus, the AFs tend to keep the electric/electronic and safety features working correctly, as previously designed by OEMs.

Scientific and engineering databases have different reference search tools and techniques to find related documents. This article presented a systematic review named iSLR to improve and speed up the research of state-of-the-art references from the leading engineering and scientific platforms on a given topic using automatic literature researcher software. Furthermore, a research case study was carried out on the DfX theme for application in CAV operations to exemplify how the methodology can be used. Finally, for applying the iSLR to the case study, the authors propose a framework to perform a deep research analysis on engineering and scientific platforms.

1.1. Process of armoring civilian vehicles

Typically, the armoring process surrounds the passenger compartment with ballistic components impervious to handguns and submachine gun munitions. Usually, AFs use two types of armor materials in the process: transparent and opaque. Transparent armors, such as resistant glasses, are used for the windows and consist of layered resistant glass laminated to a rigid inner spall shield of resilient polycarbonate. Depending on the ballistic protection level, the resistant glass ranges from 18 mm to more than 50 mm in thickness of polyurethane, polycarbonate, and glass layers. Opaque armor consists of lightweight composite armor, such as aramid plates – a class of heat-resistant and high-resistant synthetic fibers – high-hardened stainless steel and other ballistic resistant materials. Once the vehicle has been armored, AFs reassemble the interior components to mirror the OEM finish (Candido & Kaminski, 2021).

Figure 1 shows the location of ballistic protection components in passenger vehicles. Usually, AF's employees install stainless steel components on A, B, C (and D for SUVs) pillars, door locks, roof rails, and other small areas of the passenger compartment. Additionally, they assemble the aramid plates in the passenger compartment in uniform and flat areas such as the roof, tailgate inner panel (SUVs), under the hood (near the windshield), and inside the door panels. Finally, resistant glasses replace the original automaker windows.

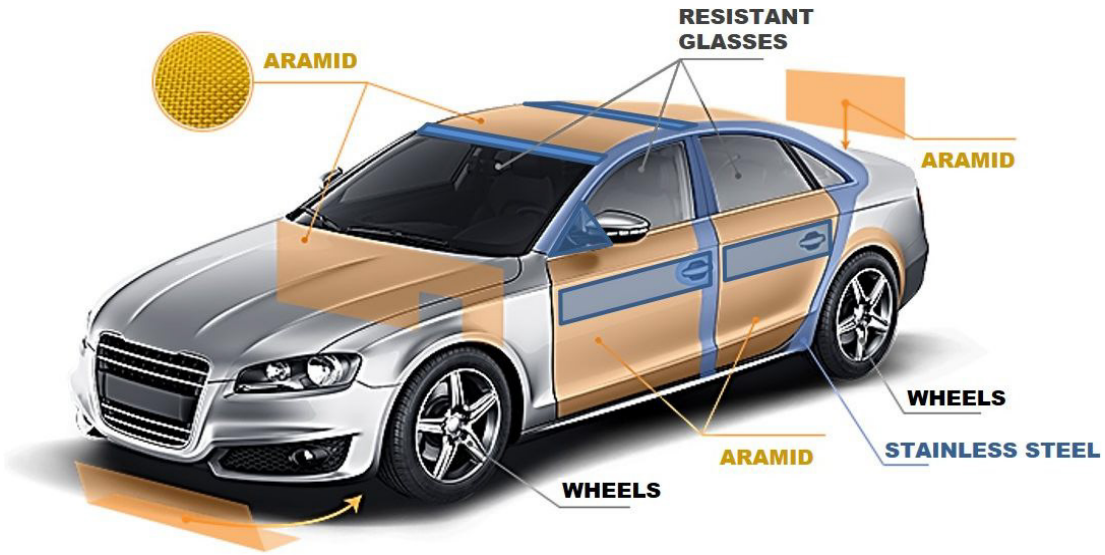

Figure 1. Civil armored vehicle with ballistic protection parts (adapted from Karvi, 2020).

Figure 2 presents an example of a typical CAV operation flowchart performed in Brazil. In the first step, AF receives the customer's vehicle armoring order. Next, it opens the customer armoring service order and asks for the Brazilian Army's approval. Once approved, the AF requests from its suppliers the corresponding opaque and transparent armor set parts of the respective vehicle. In the sequence, the vehicle arrives at the AF shop floor and proceeds with the income quality inspection through a vehicle's functioning and appearance checklist (step 3). In case of non-conformity, the AF owner informs the customer that the shop floor employees report that they solve the problem before starting the armoring procedures at the AFs. Next, it starts to disassemble and store the passenger compartment components as if they were in the middle of current vehicle production at the OEM factory to add the ballistic protection parts (steps 4 and 5). Then, in the sequence, a wrap protection adhesive film is applied to interior and exterior vehicle areas (step 6) before starting the armoring operations. After that, the shop floor team attaches the opaque armor parts into those empty spaces in the passenger compartment area, depending on the vehicle model and armor level required. Once the vehicle cockpit is wholly assembled with

opaque materials, the shop floor team replaces the automotive glass set with bullet-resistant glass with layered and polymer laminates (steps 7, 8, and 9). Finally, after the civilian vehicle has been armored, the AFs reassemble it to mirror the original OEM finish (step 10). Then, the technical team performs the audit tests (static and dynamic evaluations), checks out the list inspection, and delivers it to the customer (steps 11, 12, and 13). Armoring also aims to make the automobile appear unmodified inside and outside (Candido & Kaminski, 2020).

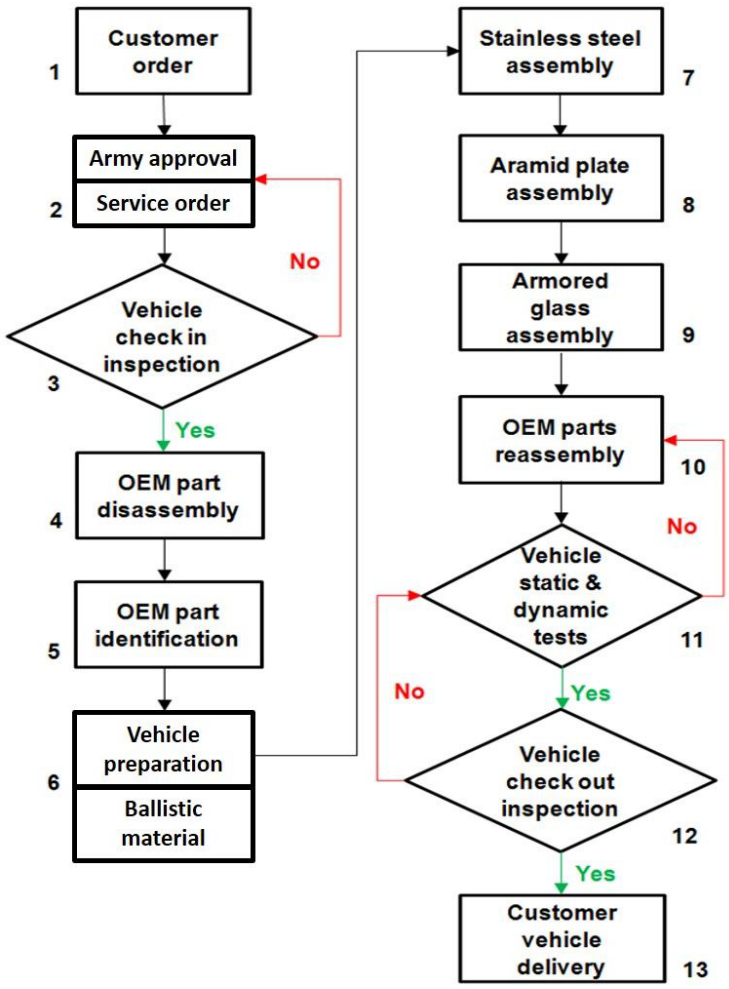

Figure 2. Typical civil vehicle armoring flowchart (adapted from Candido & Kaminski, 2020).

2. Theoretical background

Initially, the systematic literature reviews are briefly introduced. Next, related to the case study, the concepts of DfX tools focused on armoring operation gaps in AFs are presented.

2.1. Systematic literature review (SLR)

Several SLRs were published with different procedures to find the most trustworthy and reliable references for a particular topic. SLR seeks to systematically search for, appraise, and synthesize research evidence, often adhering to guidelines for conducting a review. Thus, SLR is "[...] a means of evaluating and interpreting all available research relevant to a particular research question, topic area or phenomenon of interest. So, systematic reviews aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology" (Kitchenham & Charters, 2007, p. 6). The SLRs are primarily concerned with the problem of aggregating empirical evidence, which can be obtained using various techniques, and in (potentially) widely differing contexts (Brereton et al., 2007). Thus, Jones et al. (2020) proposed an SLR method started on Google Scholar to refine and filter duplicate results. Usually, SLR initially performs the search for references on databases or a single platform. For instance, Sassaneli et al. (2020) conducted their search using the ScienceDirect and Scopus platforms, while Dixit et al. (2021) searched only in Scopus. In Buzzetto et al. (2020), the search for articles included Scopus and Web of Science platforms.

2.2. Design for Excellence (DfX) concepts: DFMA, DFD, and DFS

When a product design is feasible to manufacture, the result usually is a lower production assembly time and process cost. In addition, experienced designers understand and use knowledge of manufacturing processes to improve the design of parts, assemblies, and exclusive products. Thus, the DfX techniques encompass the knowledge of experts, giving designers guidelines for analysis and redesign (Jack, 2013). Therefore, the DfX tools - DFMA, DFD, and DFS -, considered relevant to AFs, were selected for literature reviews to guide CAV operations in procedures for handling, insertion, and fastening of ballistic and automotive components.

DFMA (Design for Manufacturing and Assembly) is an integrated methodology that provides a systematic procedure to reduce product costs, shorten development time, and simplify the design. It considers the manufacturing and assembly processes as early as the design phase, reducing the need for rework. As a result, the product is simplified by reducing the number of components and eliminating unnecessary parts. In addition to reducing the costs and the production time, the DFMA methodology also proposes tools to estimate both parameters (Boothroyd, 1994).

DFD (Design for Disassembly) is a methodology that aims to help designers develop products considering their components' disassembly process, making the process simpler, easier, and less costly. This methodology is closely related to environmental concerns since it increases useful product lifetime and decreases the environmental impact of product disposal (Boothroyd & Alting, 1992). Furthermore, DFD can also reduce costs related to maintenance, reuse, remanufacturing, and recycling product components. Therefore, DFD makes it possible to increase useful product lifetime and decrease product disposal's cost and environmental impact.

DFS (Design for Service) is a methodology that aims to develop disassembly sequences for a product and make this process more efficient, improving repairs and maintenance services. Thus, DFS increases reliability and lowers the costs of these services, increasing the competitiveness of the respective product. Furthermore, DFS also promotes an increase in lifetime, which generates positive environmental impacts. Note that DFS uses information from DFA and previous maintenance and services (Emerald Insight, 1994).

3. Research methodology

This chapter presents the improved Systematic Literature Review (iSLR) methodology, describing its phases, characteristics, and distinctions of current research. The iSLR consists of a detailed analysis of bibliographic reference list results from predefined databases employing the application named ABRe (Automatic Bibliography Researcher). Starting from themes or keywords defined by the researcher, ABRe provides an organized list of relevant references collected from engineering publishers and databases, regardless of how each research source presents the search results. Therefore, ABRe is part of the iSLR methodology.

3.1. ABRe program

Vizioli et al. (2020) designed the ABRe program in Python software with the support of a function library named Selenium, a suite of tools for automating web browsers. Python is a computer programming language often used to build websites and software, automate tasks, and conduct data analysis (Coursera, 2022). Selenium Library is a web-testing library for robot frameworks that uses the Selenium tool internally (Robot Framework, 2022).

The ABRe program covers four relevant publishers of scientific and engineering journals: Emerald Publishing, Science Direct, Taylor & Francis, and Wiley. The Python computer language and the Selenium Library allow the ABRe program to communicate with the Google Chrome® browser and enable it to enter each corresponding publisher's website (Vizioli et al., 2020). Then, ABRe performs an automatic search in the chosen publishers' databases, locates the most relevant articles found, and generates an organized list in a spreadsheet file with the most acceptable reference results. Using this software, the data collection process for the iSLR is automated, reducing research time and effort. For the practical application of the CAV case, it was considered that the four publishers would be sufficient. Thus, the authors did not include Springer Publishing in the ABRe program because preliminary research being carried out without automation served as a parameter for the choice of publishers for this particular case study. The steps to use the ABRe program to reference research are described below:

- Define the keywords for the search;
- Select one of the publishers' surveys websites via a browser;
- Search keywords in the defined websites, using filters if necessary;
- Copy the survey result link available at the URL (Uniform Resource Locator) of the publishers' survey website;
- Insert the URL link copied into the ABRe program when required;
- Define how many references the software acquires from the ABRe display;

- Save the spreadsheet file generated by ABRe with the reference results.

ABRe requires two pieces of information: the URL of the publisher survey website and the number of articles of interest. After inputting this into the software, it drives a browser locally using the Selenium server. Next, the program accesses the Hyper Text Markup Language (HTML) information from the publisher's website and collects data about each article in search results.

As a result, ABRe automatically creates an organized spreadsheet list containing the same sequence: title, published year, authors, abstract, keywords, reference link, journal name, publisher name, search terms, and initial year of the most relevant articles. Therefore, ABRe can automatically collect data from uncountable references and organize them into a list. After that, the authors apply refinement criteria based on the relevance of the articles, frequent authors, and terms in the keywords, with a critical assessment of the list generated (Vizioli et al., 2020).

3.2. The iSLR flowchart

This chapter presents the iSLR flowchart to obtain highly relevant references regarding a given topic. Figure 3 shows a detailed iSLR, including the usage of ABRe software to improve the form and the systematics of the SLR. After defining the theme and respective keywords, the first step of the iSLR is to install the ABRe program (1) and then outline the publishers (2) to conduct the research. Next, define and apply the keywords in each publisher's search tool (3). Determining keywords is an iterative process, which is required to choose keywords related to the theme. Then, the following phases are: correlate them with Boolean operators "AND" "OR" and "NOT"; test the sets created on these websites; obtain the results with ABRe, and check if such results (4) are satisfactory or if further iterations need to restart. Finally, ABRe automatically extracts the primary information from each reference and creates a spreadsheet list.

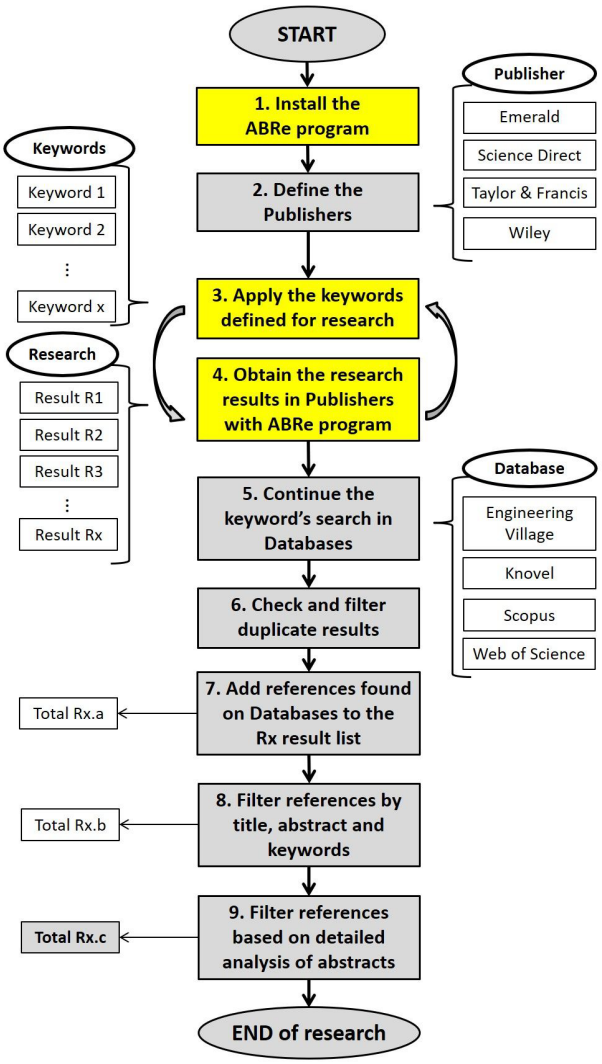

Figure 3. The iSLR flowchart (authors, 2022).

To conclude the search in publishers not defined, it is necessary to repeat the research of the selected keywords in other databases, such as Engineering Village, Knovel, Scopus, and Web of Science. These databases cover journals on engineering and scientific publishers, such as Emerald Publishing, Science Direct, Taylor & Francis, and Wiley (5). Typically, most SLRs only start the search analysis at databases. Next, it checks if any results from the databases were already among the results from the other publishers, excludes the duplicate documents found (6), and adds the remaining references from databases to references of previous publishers (7).

In the sequence, the authors submitted the references acquired to a filtering process, which consists of evaluating the references in two stages: the analysis of the title, abstract, and keywords and the individual analysis of each abstract. The objective of the first stage is to exclude references in which none of the searched keywords appeared in the title, abstract, or keywords (8). Therefore, the themes of these references are not related to the desired theme, and such searched keywords appeared in the text briefly. Second, the authors read the abstracts of each remaining reference individually to identify the relevance of the theme of each one. Finally, in the sequence, the authors exclude those papers whose themes differ highly from the selected theme (9).

4. iSLR applied to search DfX references for armoring operations

This chapter presents a case study using the iSLR framework to obtain fine-tuned state-of-the-art DfX references, which are helpful for the manufacturing process of CAVs.

Therefore, the authors selected the related keywords to search DfX references at the engineering databases and publishers: Design for Manufacturing and Assembly (DFMA), Design for Disassembly (DFD), and Design for Serviceability (DFS). These keywords were chosen since they are essential themes in the manufacturing process that improve the quality and the accuracy of the vehicle armoring development process, reducing assembly time production, production costs, and rework at AF workshops. The application of the iSLR with these keywords covered bibliographic references available in the publishers and databases cited until November 2021.

Figure 4 represents the application of the iSLR framework with the case study related to armor civilian vehicles at AFs. Considering the adoption of DFMA, DFD, DFS, and automotive as the keywords relevant to the theme of armor civilian vehicles in the aftermarket segment, the reference results available in Database and Publishers arrive at 25 relevant documents. Note that the iSLR procedure aims to guarantee the addition of results from relevant references in publishers that were not necessarily found in the searches in databases on the same topic.

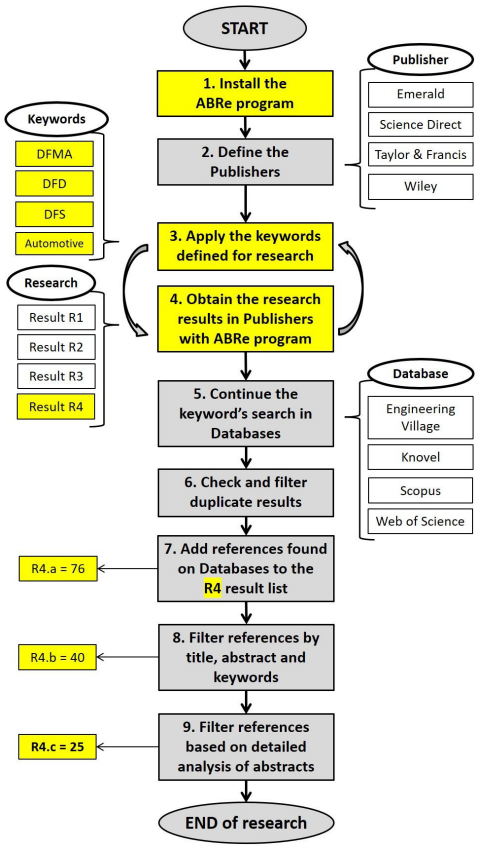

Figure 4. Applying the iSLR flowchart to the case study (authors, 2022).

4.1. Results

As the theme deals with the manufacturing process of CAVs, the keywords initially selected for the Boolean search were "DFM AND Automotive" (research named "R1 result"). However, despite obtaining a relatively high number of results (720), the references that contain the term "Design for Manufacturing" instead of the acronym "DFM" would not be obtained. The same occurred with "cars" as "vehicles". Thus, to avoid excluding documents that could be relevant to the theme, the authors decided to use a complete set of keywords instead of "R1 result", which was named "R2 result". The "R2 result" consists of the following Boolean keyword search: "DFM" OR "Design for Manufacturing" AND "automotive" OR "vehicle".

As the number of references from the "R2 result" was very high (17,774 documents were found), more terms had to be added as keywords to precise the relevant references. Thus, by using the "R3 result", which consists of the following keywords: ("DFMA" OR "Design for Manufacturing and Assembly") AND ("automotive" OR "vehicle"), 656 documents were found.

Continuing with the refinement, in the "R4 result" research, the term '("Design for Disassembly")' was added to the previous keyword research, filtering and processing the results even more and then reducing them to 53 articles (closer to the reasonable value of 20 documents).

Continuing to perform the "R5 result" research, adding the terms "DFS" OR "Design for Service" to the survey, the authors obtained ten results, nine of which were from ScienceDirect. Considering that ten references have an insufficient number of research results and that the "R5" results were also in the "R4", the authors evaluated the "R4 results" in the 53 documents from the four databases and 27 references from Scopus to be deeply analyzed.

Therefore, as summarized in Table 1, from R1 to R5, the reference results are presented in each publisher. Note that in none of the previous surveys, the Boolean operator "NOT" is used since it could limit the size of the study and exclude documents that could be relevant.

Table 1. Summary of literature references research results.

Platform	Portal type	Type of documents covered	Research criteria ("all fields" range)	Nb of reference results to each keyword search (Rx)						
				R1	R2	R3	R4			R5
							R4.a	R4.b	R4.c	
Emerald Publishing	Publisher	Journal articles, books, expert briefings, and case studies	Title, keywords, abstract, text, references	91	476	121	7	6	4	1
Science Direct	Publisher	Articles, encyclopedias, book chapters, conference summaries, books, editorials, errata, news	Title, keywords, abstract, text, references	364	16.544	394	38	19	9	9
Taylor & Francis	Publisher	Journal articles and books	Title, keywords, abstract, text, references	128	306	71	7	2	2	0
Wiley	Publisher	Journal articles, book chapters, reference works	Title, keywords, abstract, text, references	137	448	70	1	1	1	0
Total results of the publishers				720	17.774	656	53	28	16	10
Scopus	Database	Journal articles, book series, conference materials	Title, keywords, abstract, references, conference	383	1.665	461	27	15	9	4
Total of duplicate references				NP	NP	NP	4	3	0	0
Total documents except for duplicate references				NP	NP	NP	76	40	**25**	14

NP = Not performed. R1 = result of DFM AND automotive. R2 = result of: ("DFM" OR "Design for Manufacturing") AND ("automotive" OR "vehicle"). R3 = result of: ("DFMA" OR "Design for Manufacturing and Assembly") AND ("automotive" OR "vehicle"). R4 = result of: ("DFMA" OR "Design for Manufacturing and Assembly") AND ("automotive" OR "vehicle") AND ("Design for Disassembly"). R5 = result of: ("DFMA" OR "Design for Manufacturing and Assembly") AND ("automotive" OR "vehicle") AND ("Design for Disassembly") AND ("DFS" OR "Design for Service"). The authors conducted the keyword searches in publishers and databases until November 2021.

4.2. Title, abstracts, and keywords analysis

The small intersection between the research in the publishers and the one in the Scopus database demonstrated that in most of the documents presented, some searched keywords were only in the text. When authors read these

references, the keywords frequently appeared only once and in a brief context in the text. Usually, the paragraphs in which such keywords appeared were not the document's focus, and they only mattered as specific examples of another subject. The reference results confirm the need to filter the number of results even more. Therefore, a new filter was applied to avoid references with keywords that briefly appeared, of low relevance, and whose scope differed from the defined theme. In this procedure, it considered that if the theme of a document is minimally similar to the desired theme, at least one of the searched keywords would appear in titles, abstracts, or keywords. Thus, the authors excluded all references in which no keywords appeared in one of these three sections from the spreadsheet list.

Through this filtering process in the spreadsheet list mentioned earlier, the authors dismissed 19 results from ScienceDirect, one from Emerald Publishing, five from Taylor & Francis, and 12 from Scopus. Thus, the number of references decreases from 76 to 40 (research named "R4.b result"), already excluding the duplicate references. The exclusion of the 12 Scopus results seems unconventional at first. However, it is justified since the range of this database does not cover the entire text or the references.

The authors read each abstract carefully to determine if the acquired references contributed and were relevant to the subject and were not only similar to the chosen theme. Thus, the authors excluded 15 more references whose themes were irrelevant, resulting in 25 remaining references (research named "R4.c result"). Table 2 presents these 25 references. Note that, in the "R4.c result" shown in Table 1, there are no duplicate references because the authors excluded the three duplicates from the "R4.b result". Therefore, the nine remaining Scopus references (highlighted in bold, as shown in Table 2) are not from journals covered by these four publishers but from others that are not in the scope of this work. As previously stated, the fact that only nine Scopus references remained does not mean that the other references are not indexed in its platform. However, it means that the documents were unavailable when using the "R4 result" keywords on its website (because the searches in it do not cover the text of the references). Therefore, two references found were not available in Scopus.

Table 2. Selection of relevant literature references for armoring vehicle operations (R4.c).

	Year	Title of the reference	Reference keywords	Platform	Is it in Scopus?	Bibliographic reference
1	**2021**	**The addition of Design for Armoring as an engineering methodology in the development of premium civilian vehicles**	**Armor; Automobile manufacture; Automobile materials; Ballistics; Design for manufacturability; Fleet operations; Military vehicles; Automotive component; Ballistic Protection; Design for Manufacturing; Engineering methodology; National Institute of Justice; Protective materials; Quality requirements; Vehicle development;**	**Scopus**	**-**	**Candido & Kaminski**
2	**2020**	**A Framework to Facilitate Automated Assembly Sequence Planning in Design Strategies**	**ASP; DFA; DFE; DFMA; DFR; Part concatenation method; Commerce; Environmental protection; Machinery; Manufacture; Automated assembly; Design and assemblies; Design strategies; Environmental policy; Follow up; Manufacturing industries; Product development stages; Machine design;**	**Scopus**	**-**	**Kolur et al.**
3	2020	Addressing circular economy through design for X approaches: A systematic literature review	Circular design; Design for X; Circular economy; End-of-Life; Sustainability; Product-Service System; Design guidelines; Knowledge management; Product design approach; Environmental product design; Design for sustainability; Design for environment; Remanufacturing; Recycling; Recover; Reuse; Reliability; Circular design decision-support; Circular design metrics and evaluation; Systematic literature review;	Science Direct	Yes	Sassaneli et al.
4	**2020**	**Construction-Oriented Design for Manufacture and Assembly Guidelines**	**Architecture; Assembly; Construction; Design for manufacture and assembly; Design guidelines; Manufacturing;**	**Scopus**	**-**	**Tan et al.**

Table 2. Continued…

	Year	Title of the reference	Reference keywords	Platform	Is it in Scopus?	Bibliographic reference
5	**2019**	**Design for disassembly in extension cable manufacturing**	**DFMA; Disassembly; Green design; Sustainability;**	**Scopus**	**-**	**Mamat et al.**
6	2017	Approaches and Challenges in Product Disassembly Planning for Sustainability	Product design; Product life cycle; Disassembly Planning; Sustainability; Emerging Technology;	Science Direct	Yes	Chang et al.
7	2016	An Integrated Approach for Product Remanufacturing Assessment and Planning	Remanufacturing; Disassembly; Remanufacturing Process planning;	Science Direct	Yes	Fang et al.
8	2016	Design for assembly and disassembly for remanufacturing	Remanufacturing; Product design; Disassembly; Assembly;	Emerald Publishing	Yes	Soh et al.
9	2015	Integration of DFE and DFMA for the sustainable development of an automotive component	Integrated approach; Environmental product design; Product design and manufacture; Design for Environment; Design for Manufacture and Assembly;	Taylor & Francis	Yes	Suresh et al.
10	2015	A new design tool for DFA/DFD based on rating factors	Lean manufacturing; Design for assembly;	Emerald Publishing	Yes	Shetty & Ali
11	2013	Universal design topics	Not available;	Science Direct	No	Jack
12	**2012**	**Representations: Reconciling design for disassembly rules with design for manufacturing rules**	**Design for assembly; Design for disassembly; Design for manufacturing; End-of-life; Recovery conditions; Recovery options;**	**Scopus**	**-**	**Rayate & Summers**
13	**2012**	**Toward a method for improving product architecture solutions by integrating designs for assembly, disassembly, and maintenance**	**Axiomatic design; DFA; DFD; DFMa and DFS; Product architecture;**	**Scopus**	**-**	**Dagman & Söderberg**
14	**2010**	**The Design Guidelines Collaborative Framework: A Design for Multi-X Method for Product Development**	**Unmanned Ground Vehicles; Energy Efficiency; Design (Project);**	**Scopus**	**-**	**Filippi & Cristofolini**
15	**2010**	**Integrated sustainable life cycle design: a review**	**Eco-design; Manufacturing; Product design; Supply chain; Sustainable design;**	**Scopus**	**-**	**Ramani et al.**
16	2008	Product innovation for sustainability: on product properties for efficient disassembly	Product development; Product properties; Disassembly;	Taylor & Francis	Yes	Johansson
17	2005	From Life Cycle Assessment to Sustainable Production: Status and Perspectives	Lifecycle; Sustainable production; Eco-design; Integrated Product Policy;	Science Direct	Yes	Hauschild et al.
18	2001	Design for manufacture and design for 'X': concepts, applications, and perspectives	Design for manufacture; Design for lifecycle; Design for disassembly; Design for X;	Science Direct	Yes	Kuo et al.
19	1999	Systems design engineering	Not available	Wiley	Yes	White
20	1998	A geometric algorithm for single selective disassembly using the wave propagation abstraction	Selective disassembly; Disassembly wave propagation; Design for disassembly and product design;	Science Direct	Yes	Srinivasan & Gadh
21	**1997**	**The effectiveness of design for manufacturing and assembly as applied to the design of the AH64D helicopter**	**Systems Health Monitoring; Rotary Wing Aircraft; Helicopters;**	**Scopus**	**-**	**Herrera**

Table 2. Continued…

	Year	Title of the reference	Reference keywords	Platform	Is it in Scopus?	Bibliographic reference
22	1994	Product design for manufacture and assembly	Assembly; Manufacture;	Science Direct	Yes	Boothroyd
23	1994	Editorial: Designing for the Future	Customer service; Engineering; Environment; Motor industry; Product design; Product lifecycle; Recycling; Teamwork;	Emerald Publishing	No	Emerald Insight
24	1992	Design for Assembly and Disassembly	Design; Assembly; Disassembly;	Science Direct	Yes	Boothroyd & Alting
25	1992	Life after death for consumer products: designing for disassembling	Not available	Emerald Publishing	Yes	Wittenberg

References in bold are available only in the Scopus database; the references in regular text are in one of the publishers: Emerald Publishing, Science Direct, Taylor & Francis, or Wiley.

5. Results analysis

After defining the most relevant references, the data extracted by the ABRe program to validate and support the case study theme were also used to carry out numerical and analytical studies. The objective of the iSLR was not limited to understanding solely the importance of the references found and related to the study case but also confirming that reference results obtained by the iSLR were much more relevant than the current document search tools available in databases. Therefore, the relevance of the documents found and selected confirms the effectiveness of the iSLR. Figure 5 displayed a Word Cloud image of the case study, showing which words most frequently appeared in titles and keywords of these 25 references. The bigger and bolder the word appears, the more often it is mentioned and the more important it is. Thus, the most frequent words in the Word Cloud are: "design", "product", "disassembly", "manufacture", "assembly", and "sustainability". Most of the themes of these 25 references were related to such words, and most referred to keywords used for the search (see Table 1).

Figure 5. Relevant words in titles and keywords in 25 references were selected (authors, 2022).

5.1. Bibliographic network map

A bibliographic network map better demonstrates the connection between the references found according to citations, co-citations, and countries of origin. Thus, the authors used the VOSviewer® software, a computer program that creates and graphically displays bibliographic maps based on co-occurrence and citation data (Van Eck & Waltman, 2010). To make those maps, VOSviewer® supports data from Web of Science, Scopus,

Dimensions, and PubMed databases (Van Eck & Waltman, 2010). Since it was possible to find the vast majority of the results in the Scopus database, the "R4.c result" reference results were selected to generate the data required for VOSviewer®. Thus, Figure 6 represents the citation by document map for the "R4. c result". If two items are linked, it means that one document was cited by the other. In this map, 16 articles were distributed into six clusters and interconnected by 16 links. Through the map shown in Figure 6, the authors most cited in other works were Boothroyd, Kuo, and Hauschild. Figure 6 confirms that the articles written by them were widely cited as a reference by the other authors found in the iSLR method, which indicates, therefore, the high importance of the three most cited authors for the development of the researched subject, the DfX.

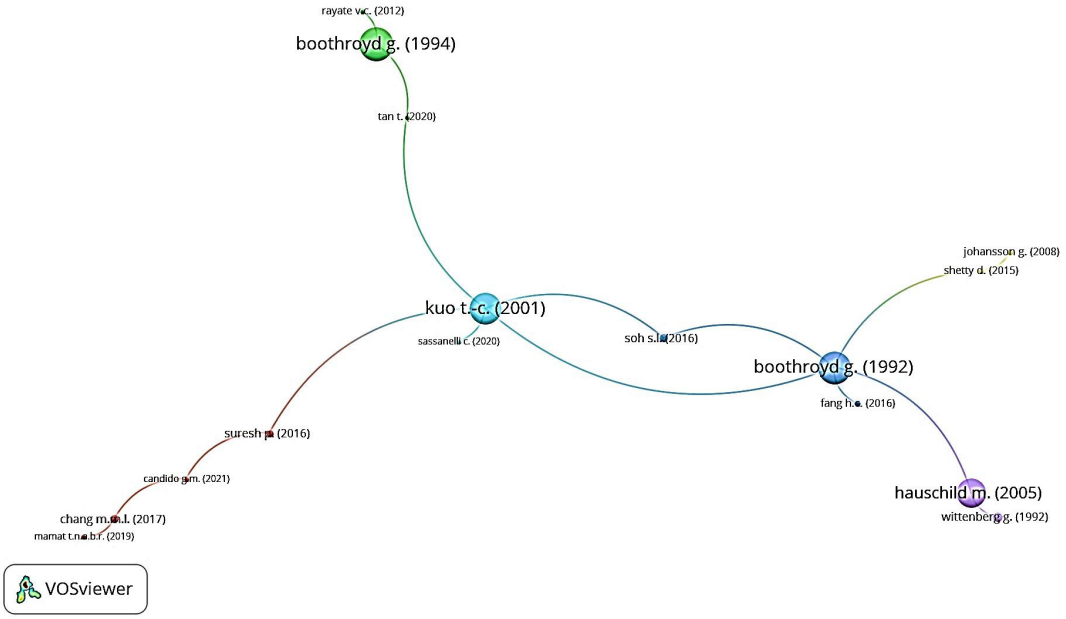

Figure 6. Citation by document map of the "R4.c" reference results using VOSviewer® (authors, 2022).

6. Conclusions and future work

This article review aimed to improve and speed up the research of the state-of-the-art references from the leading engineering and scientific platforms on a given topic. Thus, this work presented an iSLR methodology aided by an automated program named ABRe. The advantage of the program was to create automatically, by using predefined keywords, an organized list with the same sequence of information of relevant references in a spreadsheet file came from four high-quality scientific and engineering publishers: Emerald Publishing, Science Direct, Taylor & Francis, and Wiley. Therefore, the iSLR was not limited to the Scopus platform website but has also covered those four scientific publishers and quickly provided organized reference results.

To validate the effectiveness of iSLR, the authors presented a case study of civil vehicle armoring operations in which the use of the more relevant DfX principles in this segment, such as DFMA, DFD, and DFS, are recommended. These principles are considered helpful to AF's shop floors because the guidelines related to handling, insertion, and fastening of the ballistic and automotive components during the armoring process are critical to keeping the OEM functionalities after concluding the protection. The set of DfX and automotive keywords was applied to the ABRe program to find relevant references, from a defined period, from 1994 until the end of 2021. The ABRe program, regarding the iSLR, was demonstrated to be very useful and efficient when applied to the case study. The methodology generates 25 robust references of high relevance themes of DfX: DFMA, automotive, manufacturing, serviceability, assembly, and disassembly documents. Results in Table 1 of R1, R2, R3, R4, and R5 show that the quantity of references depends on the number of terms searched and the Boolean criteria adopted. The more words and Booleans in the search increase the refinement and reduce the number of documents found.

The authors searched the references in Scopus and four publishers since most of the results found in such publishers did not appear among those in Scopus. This situation occurred because the search tool parameters on the Scopus website were limited to each document's title, abstract, keywords, and references, not covering the entire text. In contrast, on the four publishers' websites, the search tool covered it. Therefore, after obtaining the 25 references, it was feasible to carry out numerical and analytical studies. The authors with the most documents related to the theme were: L. Alting, G. Boothroyd, A. Y. C. Nee, and S. K. Ong; and the most frequent words

in the titles and the keywords were: "design", "product", "disassembly", "manufacture", "assembly" and "sustainability".

In addition, the VOSViewer® map presented the citations related to the references found, showing that authors G. Boothroyd, M. Hauschild, and T.-C. Kuo stood out on the map. It confirms the importance and relevance of such authors to developing the DfX principles.

The academic contributions of the iSLR are: organizing the state-of-the-art reference results automatically in a spreadsheet list, reducing research time and effort, and comparing keyword search results between publishers and databases. The contributions of this review to AF operations using the iSLR method are: enabling the AFs to redesign the processes and shop floor arrangements with DfX references, guiding the AFs to comply with automotive and quality requirements, reducing production costs and time production, reducing the need of reworks and shop floor inspections and standardizing procedures.

For future works using the iSLR, it is possible to extend the research period and add scientific publishers to the ABRe program, such as Springer, to spread the literature research using the iSLR to other academic and industrial domains and themes. Also, as books and book chapters do not have abstracts or keywords, it is essential to add book searches in the ABRe program.

7. Acknowledgements

Authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazilian National Council for Scientific and Technological Development) – CNPq for research funding. PIBIC fellowships 138980/2021-7 and 135926/2020-3. PhD fellowship 141558/2019-9.

8. References

Boothroyd, G. (1994). Product design for manufacture and assembly. *Computer Aided Design*, *26*(7), 505-520. http://dx.doi.org/10.1016/0010-4485(94)90082-5.

Boothroyd, G., & Alting, L. (1992). Design for assembly and disassembly. *CIRP Annals*, *41*(2), 625-636. http://dx.doi.org/10.1016/S0007-8506(07)63249-1.

Brereton, P., Kitchenham, B. A., Budgen, D., Turner, M., & Khalil, M. (2007). Lessons from applying the systematic literature review process within the software engineering domain. *Journal of Systems and Software*, *80*(4), 571-583. http://dx.doi.org/10.1016/j.jss.2006.07.009.

Buzzetto, R. R., Bauli, M. R., & Carvalho, M. M. (2020). The critical aspects of procurement in project management: investigating the effects of selection criteria, supplier integration, and dynamics of acquisitions. *Production*, *30*, e20190112. http://dx.doi.org/10.1590/0103-6513.20190112.

Candido, G. M. & Kaminski, P. C. (2020). *Basic technical requirements for ballistic safety to guarantee the quality of civilian automotive armoring services in Brazil* (SAE Technical Paper 2019-36-0329). USA: Society of Automotive Engineers (SAE). https://doi.org/10.4271/2019-36-0329.

Candido, G. M. & Kaminski, P. C. (2021). The addition of Design for Armoring as an engineering methodology in developing premium civilian vehicles (SAE Technical Paper 2020-36-0086). USA: Society of Automotive Engineers (SAE). https://doi.org/10.4271/2020-36-0086.

Chang, M. M. L., Ong, S. K., & Nee, A. Y. C. (2017). Approaches and challenges in product disassembly planning for sustainability. *Procedia CIRP*, *60*, 506-511. http://dx.doi.org/10.1016/j.procir.2017.01.013.

Coursera. (2022, August 10). *What is Python used for? A beginner's guide*. Retrieved in 2022 July 12, from https://www.coursera.org/articles/what-is-python-used-for-a-beginners-guide-to-using-python

Dagman, A. & Söderberg, R. (2012). Toward a method for improving product architecture solutions by integrating designs for assembly, disassembly, and maintenance. In *International Mechanical Engineering Congress and Exposition* (Technical paper IMECE2012-87466, pp. 377-387). USA: The American Society of Mechanical Engineers (ASME). https://doi.org/10.1115/IMECE2012-87466.

Dixit, N., Sharma, V., & Kumar, P. (2021). Research trends in abrasive flow machining: a systematic review. *Journal of Manufacturing Processes*, *64*, 1434-1461. http://dx.doi.org/10.1016/j.jmapro.2021.03.009.

Emerald Insight. (1994). Editorial: designing for the future. *World Class Design to Manufacture*, *1*(4), 46-48. http://dx.doi.org/10.1108/EUM0000000003942.

Fang, H. C., Ong, S. K., & Nee, A. Y. C. (2016). An integrated approach for product remanufacturing assessment and planning. *Procedia CIRP*, *40*, 262-267. http://dx.doi.org/10.1016/j.procir.2016.01.118.

Filippi, S., & Cristofolini, I. (2010). *The design guidelines collaborative framework: a design for multi-X method for product development*. London: SpringerVerlag.

Hauschild, M., Jeswiet, J., & Alting, L. (2005). From life cycle assessment to sustainable production: status and perspectives. *CIRP Annals*, *54*(2), 1-21. http://dx.doi.org/10.1016/S0007-8506(07)60017-1.

Herrera, A. (1997). *The effectiveness of design for manufacturing and assembly as applied to the design of the AH64D helicopter*. USA: Society of Automotive Engineers (SAE). https://doi.org/10.4271/972242.

International Automotive Task Force. (2016). *Quality management system for organizations in the automotive industry* (IATF 16949). Genève: IATF.

Jack, H. (2013). Universal design topics. In: Jack H. *Engineering design, planning, and management* (Chap. 9, pp. 323-380). Cambridge: Academic Press. https://doi.org/10.1016/B978-0-12-397158-6.00009-7.

Johansson, G. (2008). Product innovation for sustainability: on product properties for efficient disassembly. *International Journal of Sustainable Engineering*, *1*(1), 32-41. http://dx.doi.org/10.1080/19397030802113835.

Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterizing the Digital Twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology*, *29*(Pt A), 36-52. http://dx.doi.org/10.1016/j.cirpj.2020.02.002.

Karvi. (2020, December 20). *O que você deve saber antes de blindar seu carro*. Retrieved in 2022 July 11, from https://www.karvi.com.br/blog/o-que-voce-deve-saber-antes-de-blindar-seu-carro/

Kitchenham, B., & Charters, S. (2007). *Guidelines for performing systematic literature reviews in software engineering* (Technical report, Version 2.3, EBSE-2007-01). United Kingdom: Keele University.

Kolur, D. K., Yadav, S., Gulvindala, A. K., & Bahubalendruni, M. R. (2020). A framework to facilitate automated assembly sequence planning in design strategies. *International Journal of Performability Engineering*, *16*(10), 1517-1524. http://dx.doi.org/10.23940/ijpe.20.10.p3.15171524.

Kuo, T. C., Huang, S. H., & Zhang, H. C. (2001). Design for manufacture and design for 'X': concepts, applications, and perspectives. *Computers & Industrial Engineering*, *41*(3), 241-260. http://dx.doi.org/10.1016/S0360-8352(01)00045-6.

Mamat, T. N. A. B. R., B. Jaafar, A. A. & Taib, M. K. A. B. M. (2019). Design for disassembly in extension cable manufacturing. *International Journal of Innovative Technology Exploring Engineering*, *8*(8S), 321-326.

Ramani, K., Ramanujan, D., Bernstein, W. Z., Zhao, F., Sutherland, J., Handwerker, C., Choi, J., Kim, H., & Thurston, D. (2010). Integrated sustainable life cycle design: a review. *Journal of Mechanical Design*, *132*(9), 0910041-09100415. http://dx.doi.org/10.1115/1.4002308.

Rayate, V. C., & Summers, J. D. (2012). Representations: reconciling design for disassembly rules with design for manufacturing rules. In *Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2012* (Vol. 5, pp. 369-379). Canada: ASME. https://doi.org/10.1115/DETC2012-70987.

Robot Framework. (2022). *Selenium library*. Retrieved in 2022 July 11, from https://robotframework.org/SeleniumLibrary/

Sassaneli, C., Urbinati, A., Rosa, P., Chiaroni, D., & Terzi, S. (2020). Addressing circular economy through design for X approaches: a systematic literature review. *Computers in Industry*, *120*, 103245. http://dx.doi.org/10.1016/j.compind.2020.103245.

Shetty, D., & Ali, A. (2015). A new design tool for DFA/DFD based on rating factors. *Assembly Automation*, *35*(4), 348-357. http://dx.doi.org/10.1108/AA-11-2014-088.

Shivankar, S. D., & Deivanathan, R. (2021). Product design change propagation in automotive supply chain considering product life cycle. *CIRP Journal of Manufacturing Science and Technology*, *35*, 390-399. http://dx.doi.org/10.1016/j.cirpj.2021.07.001.

Silva, G. (2021, April 27). *Modelos VW dominam ranking de blindagem de carros*. Web Motors. Retrieved in 2022 July 11, from https://www.webmotors.com.br/wm1/dinheiro-e-economia/modelos-vw-dominam-ranking-de-blindagem-de-carros.

Soh, S. L., Ong, S. K., & Nee, A. Y. C. (2016). Design for assembly and disassembly for remanufacturing. *Assembly Automation*, *36*(1), 12-24. http://dx.doi.org/10.1108/AA-05-2015-040.

Srinivasan, H., & Gadh, R. A. (1998). Geometric algorithm for single selective disassembly using the wave propagation abstraction. *Computer Aided Design*, *30*(8), 603-613. http://dx.doi.org/10.1016/S0010-4485(98)00009-8.

Suresh, P., Ramabalan, S., & Natarajan, U. (2015). Integration of DFE and DFMA for the sustainable development of an automotive component. *International Journal of Sustainable Engineering*, *9*(2), 107-118. http://dx.doi.org/10.1080/19397038.2015.1096313.

Tan, T., Lu, W., Tan, G., Xue, F., Chen, K., Xu, J., Wang, J., & Gao, S. (2020). Construction-oriented design for manufacture and assembly guidelines. *Journal of Construction Engineering and Management*, *146*(8), 04020085. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001877.

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*, 523-538. http://dx.doi.org/10.1007/s11192-009-0146-3.

Vizioli, R., Kaminski, P. C., & Athanasio, V. A. C. (2020). Investigation of tools related to design thinking for developing IOT solutions using systematic literature review. In *Proceedings of the 3th annual International Conference of Education, Research and Innovation* (pp. 5098-5106). Online Conference. https://doi.org/10.21125/iceri.2020.

White, K. P. (1999). Systems design engineering. *Systems Engineering*, *1*(4), 285-302. http://dx.doi.org/10.1002/(SICI)1520-6858(1998)1:4<285:AID-SYS4>3.0.CO;2-E.

Wittenberg, G. (1992). Life after death for consumer products: designing for disassembling. *Assembly Automation*, *12*(2), 21-25. http://dx.doi.org/10.1108/eb004361.