Innovative Disassembly Sequence Applied to a Virtual Mechanical Reducer

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Abstract

The life of industrial products is getting shorter due to the rapid evolution of technologies. Because of that, the creation of models that are interested in last part of the product's life are becoming extremely relevant. In recent years, many investments have been made in the recycling of raw materials and the reuse of End-Of-Life (EOL) products in order to reduce the waste of resources. Strategies of Design for Environment (DfE) have been searched and, for this reason, the Design for Disassembly (DfD) has become a fundamental phase in the product life cycle with the subsequent creation of design techniques aimed precisely at disassembly. Using this methodology, the designer can study and plan the optimal sequence which should be based on countless factors and criteria because there is not a straightforward path or a single combination of operations to follow. This paper describes and compares multiple disassembly methods based on minimum disassembly time with reference to a worm gear reducer. In particular, the component was made entirely on CAD (SolidWorks) and the sequences were applied in a virtual environment. In this way, it was possible to evaluate different algorithms and obtain the optimal disassembly sequence that minimize the overall disassembly time.

Keywords
Disassembly; Virtual Reality; CAD; Sequence; TMU

1. Introduction
The life of industrial products has shortened rapidly, the dynamic evolution of modern technologies is one of the main problems that lead to this end. Because of that, a greater focus on the recycling and revitalization of End-Of-Life (EOL) products evolved in the recent years, with the aim of reducing waste and in particular waste of material optimizing all the resources from the beginning of the design phase. Disassembly thus becomes a fundamental operation for the recovery of raw materials and components expanding the sole changing in functionality for the maintenance or replacement of parts.
For an EOL product to be disassembled effectively, careful disassembly sequence planning is required, allowing optimal resource recovery based on specific criteria such as less time or minimum disassembly cost. For these reasons, the study of the sequence of operation must be taken into account already at the design stage of a product.
This led to the birth of the concept of Design for Disassembly (DfD), that is, a design aimed at simplifying the assembly and disassembly phases of an industrial product, for example by reducing the number of components of the same.

1.1 Objectives
This paper aims to identify the optimal disassembly sequence of a screw reducer, through the application of specific algorithms, taking as an evaluation criterion the time taken to complete the disassembly.
First of all, the object was drawn using a CAD (Solidworks v2017). The screw reducer (Figure 1) was prepared for the study and its general principles of operation to understand which parts should move first in a standard sequence of disassembly. Finally, the Design for Disassembly sequence was developed, and two different algorithms were analyzed to the screw reducer in order to minimize the time of operation for each component and more in general, the time of operation of the whole disassembly sequence.

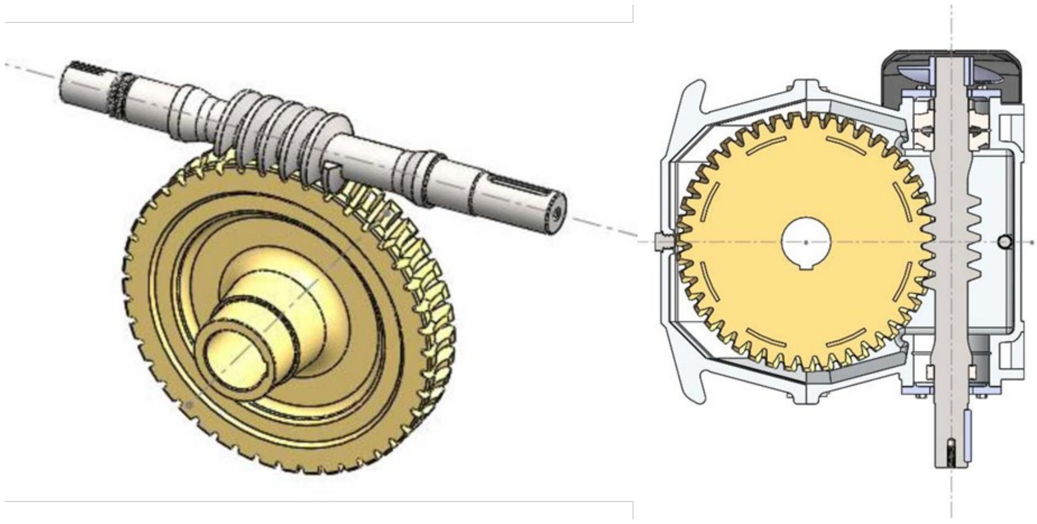

Figure 1. Screw reducer and section

The goal of this paper is to get an optimal disassembly sequence, using time as the most important evaluation criterion.

2. Literature Review

The Design for Disassembly is growing fast due to its wide applications. If Design for Assembly was the first goal to achieve in a good design path, today it is no more sufficient. The main difference between the two approaches is their application during the lifecycle of the product. As explained in (Boothroyd and Alting 1992), both methodology are necessaire to caver and optimize the product's life. In fact, living in the era of the mass production, it is impossible to rely only on Design for Assembly to achieve good results because the importance of wasted material related to their production, usage and disposal have become a priority. Because of that, DfD approaches are today widely used and relevant in the design process (Desai and Mital 2003). This lead to a sequence of disassembly that can be calculated both for reducing times and costs of maintenance, than to achieve environmental solution (Harjula et al. 1996) (Rios, Chong, and Grau 2015). There isn't a straight forward path to follow in the DfD methodology and many solution have been thought based on different principles (Anon n.d.). In this paper two different algorithms are presented: the first one (Wang et al. 2017) is based on a series of matrices build on constraints and priority, while the second (Mitrouchev et al. 2015) is a methodology based on a graphical approach. Both solutions deal with selective disassembly, so they have been applied choosing the same target component in order to evaluate which produce the optimal sequence. The paper aims to find, through a practical case study application, the limits and the advantage of both algorithms and provide the best one for the proposed problem. Among all, the disassembly problem remains one of the most important in the design phase of our century (Lowe and Bogue 2007) and must be tested and studied in the industry 4.0 context.

3. Methods

3.1 First Sequence

This methodology addresses the problem of sequence planning as a mathematical problem, it also has as its basic principle the non-destructiveness of parts and connections, except where this is inevitable (rivets, welds, etc.). Operations should be bypassed, or otherwise kept to a minimum. Before applying the phases of the algorithm, one has to determine the target component and check for any subassembly in which it is positioned.

Constraint graph (AND/OR):

The first part of the method consists in generating an AND/OR graph (Figure. 2), necessary to represent the product. The graph consists of a series of nodes and arcs: the nodes represent the various components, while the arcs reproduce the disassembly operations. The connection between two parts can be of three types: a simple arc implies that the two parts have equal precedence in the sequence and can be removed indifferently one before the other.

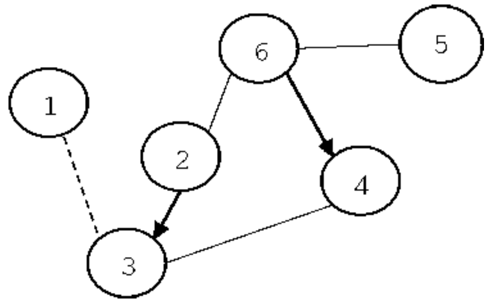

Figure 2. Example of constraint graph

If the arc has an arrow at one end ($x \rightarrow y$) it means that the two components have an already predetermined order of priority (in the example, component 4 cannot be disassembled until part number 6 is assembled). Finally, if the link can only be removed destructively, the arc is composed of a dashed line.

Multilevel array of constraints:
The assembly of the product and its subassemblies can be imagined as a "tree" where the hierarchy between the parts is determined by the bill of product. Planning the disassembly, each operation is represented as a translation, so in a Cartesian coordinate system the translation directions can be ($\pm X, \pm Y, \pm Z$). The constraint matrix represents the limitations between two parts along the latter directions. For an assembly $A = \{A1, A2, \dots, A_n\}$, composed of n objects, a matrix of n times n dimensions can be build, in which each element corresponds to a series of 6 digits. The a_{ijd} element describes the constraint relationship between part i and part j in the direction of d. When $a_{ijd} = 1$ it means that component j blocks the movement of component i along the direction d. If $a_{ijd} = 0$, part j does not interfere with the translation of component i along the direction d. The various components can only be removed in the direction in which there are no obstacles. The equation for evaluating whether an element i is removable along direction d is:

$$a_{id} = a_{i1d} + a_{i2d} + \cdots + a_{ind} = 0$$

Only when $a_{ijd} = 0$, component i can be removed along the d direction. When all the items in the first column are 000000, the column itself can be cleared. Similarly, the first row of the array is deleted after the component has been removed. This operation decreases the size of the matrix and reduces the computational complexity.

Fastener-Component Matrix:
It represents the relationships that the various components have with the liaison bodies (fasteners). The rows in the array represent the components, while the columns represent the fasteners. When the intersection of the elements between rows and columns is one, it means that the component is constrained by a non-destructive removable link. If is 0, there is no link between the component and the fastener. Finally, when the value is equal to 2 it indicates that a destructive operation is required to separate the two elements. Connecting elements should always be removed before components.

Sequence planning algorithm:
The target component and its subassembly are identified and this one must be considered separately from the whole product. Series planning starts with the target component. Analyzing the graph it is possible to identify a probable $S(i)$ sequence; the first component $S(1, i)$ in the sequence $S(i)$ is analyzed through the multilevel matrix of constraints. If $S(1, i)$ can be removed, an additional control on the matrix of the fastener-component must be performed determining the connecting organs to be removed before disassembling the component. If it is impossible to disassemble the piece from the first matrix, then the sequence is not feasible, and it is necessary to start the algorithm again. The sequences determined for each subassembly are then combined to schedule the complete disassembly sequence. This system allows to determine multiple sequences for the same target component comparable to each other through, for example, time, to obtain the optimal disassembly sequence.

3.1 Second Sequence

This method aims to provide a selective disassembly sequence, already optimized by the algorithm itself. As well as the first case, non-destructive solutions for the removal of connecting organs should be preferred. The concept of the *Gaussian Sphere* is used in determining the possible directions for the disassembly of a part (Set of Directions of Removal - SDR).
Before implementing the algorithm, the CAD reproduction is analyzed and the collisions between the projections of the components are determined. In addition, it is possible to group up components into a subassembly, to reach the target solution without disassembling all the parts of the subassembly. In this case, grouping is treated as a single component.

Geometric feasibility:
From a geometrical point of view, feasibility is defined as the possibility of disassembling two parts (or subassemblies) without collisions in order to identify the path and direction of disassembly. Figure 3 is a typical problem of direction limitations.

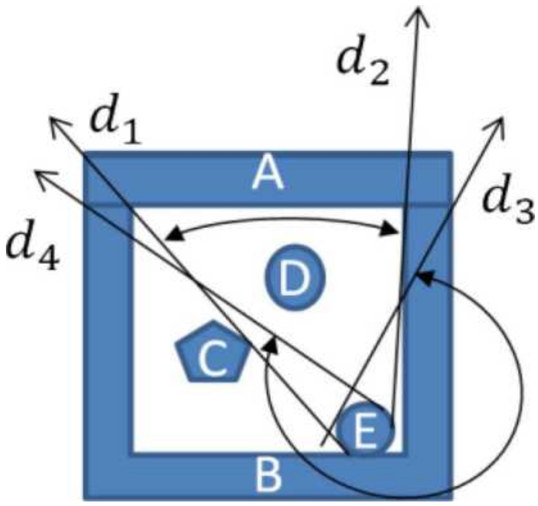

Figure 3. Direction and constraint graph

The arrows indicate the limits of the possible direction of disassembly of one-part respect to another. The assembly consists of parts A (lid), B (body), C, D and E, which define $N = (A, B, C, D, E)$ and the limit directions d_1, d_2, d_3, d_4 from which calculate the final disassembly direction.

Collisions:
The projection calculation method is used to represent possible collisions between the components. It consists in projecting the volume (3D) of the test part in a chosen direction (2D), if the projection of the piece does not intersect the projection of another component along the path, it means that there is no collision between the considered objects in that direction.
In general, a component may not be removed for two reasons: the first is that it has no SDR i.e., possible directions for disassembly; the second is the presence of collision with other parts. For example, to calculate the SDR of part E in Figure 3 are consider only the constraints imposed by the parties in contact with E. So, the limits CD_{EB} are calculated as SDR while CD_{EA} is the collision between component E and A.

Disassembly geometry contacting graph – DGCD:
The algorithm is divided into two steps: the first consists of the construction of the geometric disassembly graph of the product (DGCG), then the disassembly sequence is generated. The DGCG aims to divide the components related to the target part into different levels of disassembly, depending on their characteristics. Components that can be removed directly, without breaking others, are the first level of disassembly. Considering the total assembly defined by "m" parts, for each component is determined its SDR and the collisions for each level. The construction of the graph ends when the target component is reached. The chart specifies why a part cannot be removed in the upper layers, through the following notations:

- If component i cannot be disassembled in level n due to a collision with part j, Cn^{ij} is written.
- If component i cannot be disassembled in level n because it does not have SDR available, NSn^{i} is written.

To simplify the model, the connecting organs can only be removed along the direction of their axis. In addition, fasteners can generally be removed already at the first level of disassembly, otherwise there is a collision. The algorithm can be summarized in the following steps:

1. Analyze the 3D model of the assembly and verify the geometric feasibility for each part;
2. Analyze the type of component and any collisions. If a part is not a connecting organ, look for its SDR, if it is (0.2π), detect collisions.
   a. If the collision is present, plot its arc.
   b. If both conditions are absent, the part may be disassembled at the level under consideration.
3. Remove parts in the studied layer and delete arcs with other components.
4. Search for SDRs and collisions for the remaining components and restart the algorithm

4. Data Collection

For both methodologies studied, component number 15 (the screw) was chosen as the target component. Figure 4 shows an exploded view of the reductor reproduced with the CAD as well as the bill of materials of the same assembly (Table 1). The bill of material has an important role since defines all components with their quantities and it underlines the target object for the disassembly sequence.
For the disassembly times of the connecting bodies see (Desai and Mital 2003).

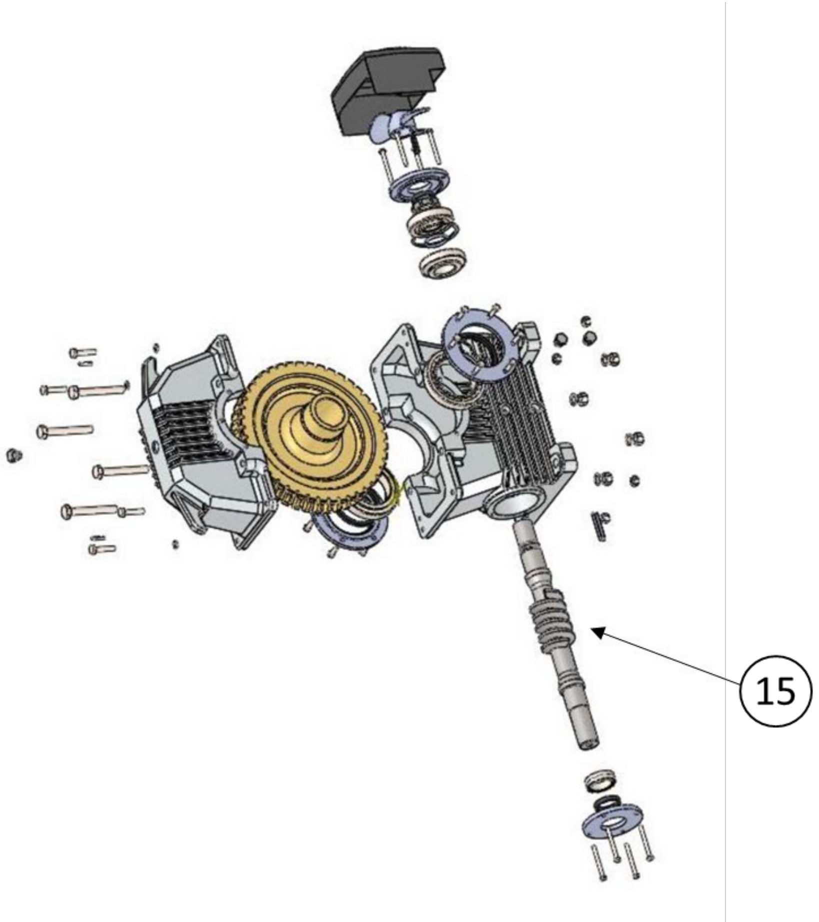

Figure 4. Exploded view of the reducer

Table 1. Bill of materials

No.	Component	Q.y.
1	Carcass	1
2	Flange No. 1	2
3	Screw wheel	1
4	Bearing 120 KB 20 UNI 6042	2
5	Cover	1
6	Loading cap G 3/4	1
7	Gasket No. 1	2
8	Flange lid	1
9	Gasket no.2	1
10	Exhaust cap G 3/4 No.1	4
11	Fan	1
12	Flange #2	1
13	Bearing 60 KD 23 UNI 4222	2
14	Spacer	1

15	Lives screw	1
16	Bearing 60 RF 3 UNI 4214	1
17	Gasket No. 3	1
18	Flange #3	1
19	Plug 10 x 40 UNI 6873	2
20	Screw M14 x 65 UNI 5737 - 8.8	4
21	Rosette A 14 UNI 1751	4
22	Nut M14 UNI 5588	4
23	Screw M12 x 40 UNI 5739 - 8.8	12
24	Tab B 12 x 9 x 50 UNI 6604	1
25	Ring M60 x 2 DIN 1804 w	1
26	Ring 130 UNI 7437	1
27	Screw M10 x 100 UNI 5739 - 8.8	8
28	Tab A 16x 12 x 90 UNI 6604	1
29	Nut M20 UNI 5588	4
30	Rosette A 20 UNI 9195	4
31	Screw M20 x 150 UNI 5738 - 8.8	4

5. Results and Discussion

5.1 Graphical Results

First method:

The screw reducer under study consists of 31 different parts that have been divided into components (Figure 5), from number 1 to number 18, and fasteners, from number 19 to number 31 to simplify the reading of the methodology.
In accordance with CAD playback, the assembly has been divided into two subassemblies and the target component (No.15) is in the Sub. 1.

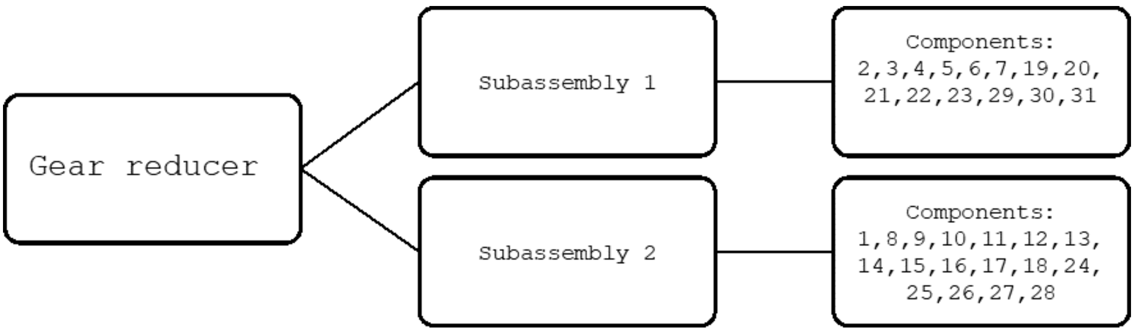

Figure 5. Subassemblies subdivision

Figure 6 shows the constraint graph for this specific application. If two components are in contact with each other they are connected by a straight line. If there is also an arrow, it means that to disassemble the two parts a pre-defined precedence should be respected. Finally, if the line is dashed, the two components can only be separated by destructive operations and this should be avoided.

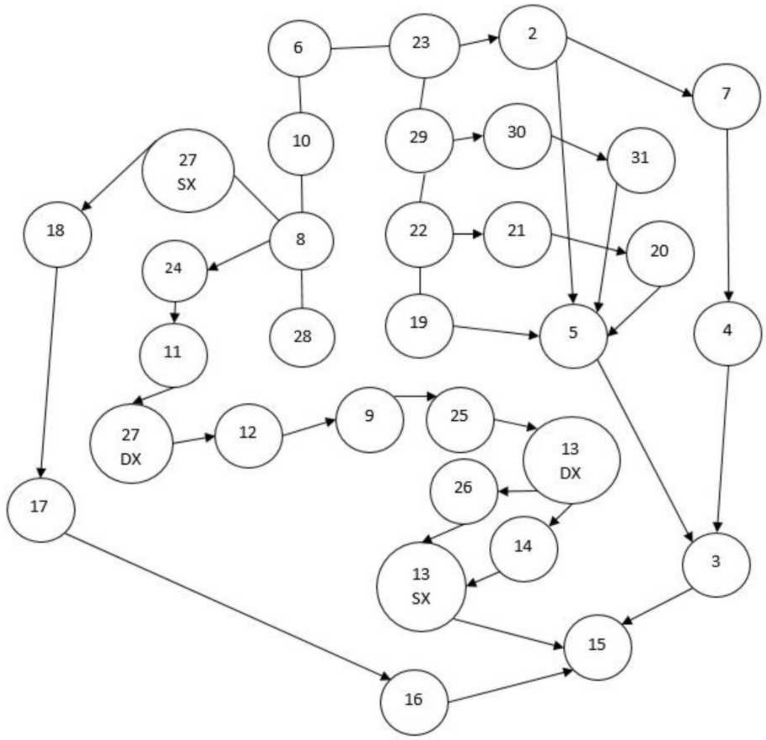

Figure 6. Constraint graph for the case study

The construction of the graph allows to compile the three multilevel matrices of the constraints that represent the limits deriving from the constraints along the six directions $(\pm X, \pm Y, \pm Z)$. In particular, in the columns and rows are reported the same components in the same order meaning that the diagonal of the matrix represents the constraint relation between the object and itself and it has indeed value 0 for all linear degree of freedom. In these matrices no rotations are considered.

The first matrix (Table 2) refers only to the two subassemblies and it shows the possible constraint combinations between them. It is possible to note that the two subassemblies are constrained one with respect to the other along the Y-direction since the matrix results to be symmetric. It is easy to note that if a general component A has a freedom in a (+) direction respect to B, B will have the same freedom respect to A but in the opposite (-) direction.

The second and the third matrices refer respectively to subassembly 1 and subassembly 2. In particular Table 3 shows the constraints between component in subassembly 1 while Table 4 shows the constraints in subassembly 2.

Table 2. Constraint matrix for the entire assembly

	Sub. 1	**Sub. 2**
Sub. 1	000000	001000
Sub. 2	000100	000000

Table 3. Constraint matrix for subassembly 1

Sub. 1	**2 R**	**2 L**	**3**	**4 R**	**4 L**	**5**	**6**	**7 R**	**7 L**
2 R	000000	010000	011111	010000	010000	011111	000000	001111	000000
2 R	100000	000000	101111	100000	100000	101111	000000	001111	001111
3	101111	011111	000000	101111	011111	111111	000100	101111	011111
4 R	100000	010000	011111	000000	010000	001111	000000	100000	010000

4 L	100000	010000	101111	100000	000000	001111	000000	100000	010000
5	100111	010111	110111	000111	000111	000000	001000	000000	000000
6	000000	000000	000100	000000	000000	110111	000000	000000	000000
7 R	001111	000000	011111	010000	010000	000000	000000	000000	010000
7 L	000000	001111	101111	100000	100000	000000	000000	100000	000000

Table 4. Constraint matrix for subassembly 2

Sub. 2	**1**	**8**	**9**	**10 R**	**10 L**	**11**	**12**	**…**
1	000000	111111	000000	101111	011111	000010	111110	…
8	111101	000000	111101	000000	000000	111101	111101	…
9	000000	111110	000000	000000	000000	000010	111100	…
10 R	011111	000010	000000	010000	010000	000010	000010	…
10 L	101111	000010	000000	100000	000000	000010	000010	…
11	000001	111110	000001	000000	000000	000000	000001	…
12	111101	111110	111101	000001	000001	000010	000000	…
13 R	111101	000010	000010	000000	000000	000010	000010	…
13 L	111101	000010	000010	000000	000000	000010	000010	…
14	111100	000010	000010	000000	000000	000010	000010	…
15	111100	111110	111110	100000	010000	111110	111110	…
16	111110	000010	000010	000000	000000	000010	000010	…
17	000000	000010	000010	000000	000000	000010	000010	…
18	111110	000010	000010	000000	000000	000010	000010	…

…	**13 R**	**13 L**	**14**	**15**	**16**	**17**	**18**
…	111100	111100	111111	111100	111100	000000	111101
…	000001	000001	000001	111101	000001	000001	000001
…	000001	000001	000001	111101	000001	000001	000000
…	000000	000000	000000	000000	000000	000000	000001
…	000000	000000	000000	000000	000000	000000	000001
…	000001	000001	000001	111101	000001	000001	000001
…	000001	000001	000001	111101	000001	000001	000001
…	000000	000001	000001	111101	000001	000001	000001
…	000010	000000	000010	111101	000001	000001	000001
…	000010	000001	000000	111101	000001	000001	000001
…	111110	111110	111101	000000	111101	111101	111101
…	000010	000010	000010	111110	000000	000001	000001
…	000010	000010	000010	111110	000010	000000	111100
…	000010	000010	000010	111110	000010	111100	000000

Subsequently, the fastener-component matrix was defined in Table 5, and each column represents a fastener while each row is a component, so it resulted in a 18x13 matrix. Each element of the array represents the connection state between a part and a connecting organ: if the element $a_{i,j} = 0$ it means that component *i* is not in contact with fastener *j;* if $a_{i,j} = 1$ the two elements are in contact and disassembled by a non-destructive operation.
For all components, their fasteners must be dismantled before being removed.

Table 5. Fastener-component matrix

	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28	F29	F30	F31
C1	1	1	1	1	1	0	0	1	0	0	1	1	1
C2	0	0	0	0	1	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	0	0	0	0	0	0	0
C5	1	1	1	1	1	0	0	0	0	0	1	1	1
C6	0	0	0	0	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	1	0	0	0	0	0	0	0
C12	0	0	0	0	0	0	0	0	1	0	0	0	0
C13	0	0	0	0	0	0	1	0	0	0	0	0	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	1	1	0	0	1	0	0	0
C16	0	0	0	0	0	0	0	0	0	0	0	0	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0
C18	0	0	0	0	0	0	0	0	1	0	0	0	0

In accordance with the equation:

$$a_{id} = a_{i1d} + a_{i2d} + \cdots + a_{ind} = 0$$

where $i, j = 1,2, \dots, n$ and $dE(\pm X, \pm Y, \pm Z)$, it is possible to schedule the disassembly sequence. Table 6 shows the guessed sequence in the first method underlying the number of the operation, the component taken into account for that operation, the direction of removal, the time (in seconds) for the operation and a short description.

Table 6. Disassembly sequence for method 1

Sequence	**Component/Fasteners**	**Direction**	**Time [s]**	**Description**
1	6	Y	12	Removal of load cap
2	10 R	X	24	Removal of no. 2 exhaust caps
3	10 L	-X	24	Removal of no. 2 exhaust caps
4	28	Y	9,5	Tab extraction
5	23	±X	48	Remove 12 M12 side flanges
6	2 R	X	12,3	Remove flange on the right side
7	2 L	-X	12,3	Remove left side flange
8	29	-Y	46	Remove No. 4 Nut M20
9	30	-Y	33,2	Remove no. 4 rosette A 20
10	31	Y	32	Remove No. 4 M20 screws
11	22	-Y	46	Remove No. 4 Nut M14
12	21	-Y	33,2	Remove No. 4 rosette A 14
13	20	Y	32	Remove No. 4 M14 screws
14	19	Y	24	Remove No 2 plug 10 x 40

15	5	Y	26,1	Remove Top Cover
16	7 R	X	18,2	Remove right seal
17	7 L	-X	18,2	Remove left gasket
18	4 R	X	21,8	Remove bearing 120 right
19	4 L	-X	21,8	Remove bearing 120 left
20	3	Y	14,5	Remove screw wheel
21	8	Z	21,3	Side flange cover removal
22	17	-Z	18,2	Remove left gasket
23	24	Z	10,3	Tab extraction
24	11	Z	13,5	Remove fan
25	27 R	Z	23	Remove No. 4 screw M10 right
26	12	Z	12,3	Remove right-side flange
27	9	Z	18,2	Remove right seal
28	25	Z	36,3	Remove locking ring
29	13 R	Z	21,8	Remove bearing 60 left
30	26	Z	19,7	Remove elastic ring
31	13 L	Z	21,8	Remove bearing 60 right
32	15	Z	16,3	Extracting screws
			741,8	Total Time [s]

Second method:
This methodology allows to group up components to speed up disassembly as these are not separated from each other. The determination of the subgroup must obviously not include the target component and should allow the disassembly of the selected part. For this reason, components 3, 4, 5, 6, and 7 were grouped into the subgroup $S_i = (3,4,5,6)$, which in the sequence is then considered as a single element, and therefore removed in bulk. The technique studied also allows the removal of multiple parts at the same time. Having assumed in the case study presented a manual disassembly, this possibility was considered only for the simultaneous disassembly of screws and rosettes (parts number 21-20 and 31-30), and for the removal of the flange with the gasket (parts number 9-12). Through the algorithm defined in methodology section, the DGCG graph was obtained (Figure 7), which divides the disassembly sequence into various levels. For each part there are notations $Cn^{i,j}$ or NSn^{i} whether the component can or cannot be disassembled in the upper disassembly levels.

The first disassembly-level is defined immediately, as it includes components that can be removed without having to remove others. In the DGCG the connecting organs are represented by squares, while the parts and subassemblies are

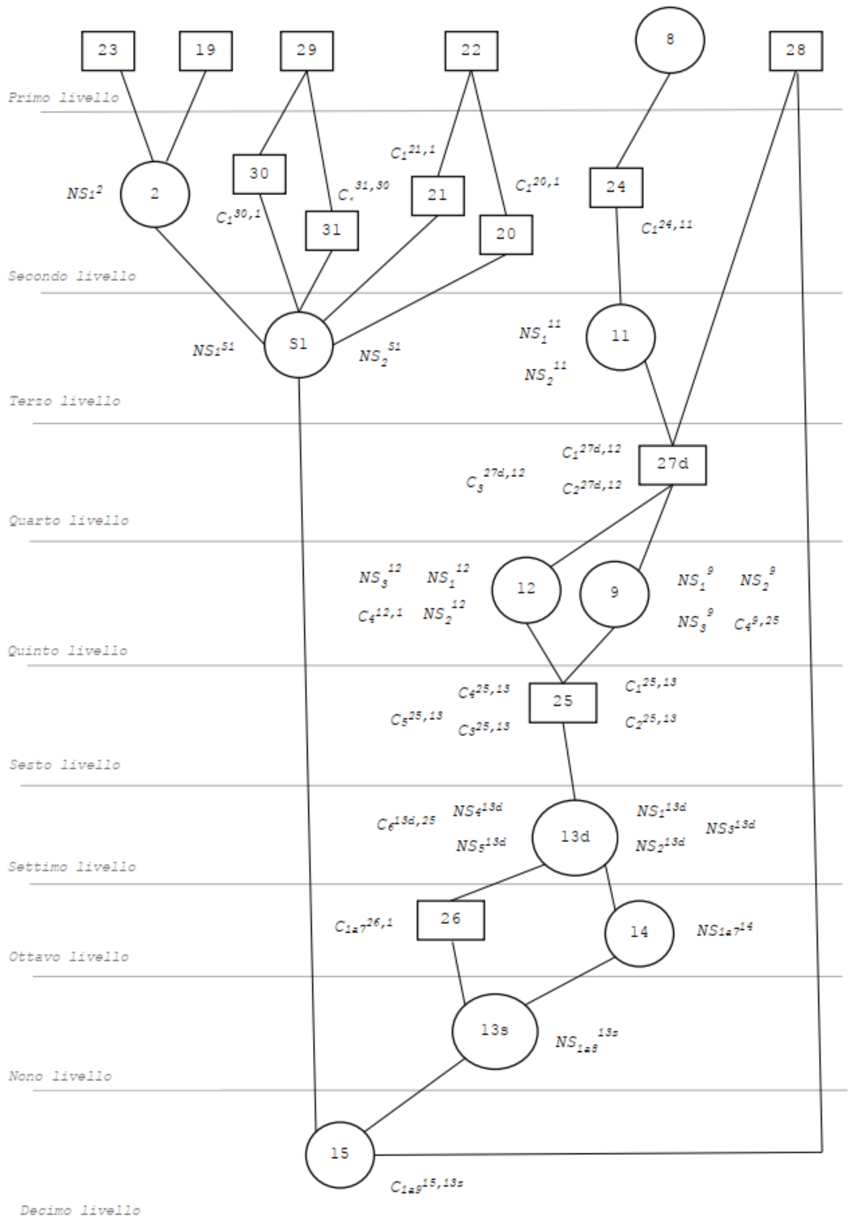

Figure 7. DGCG graph

described by a circle. In addition, the same components are distinguished by L (left), or R (right) which must be dismantled separately.

Starting from the target component in the DGCG graph, it can be seen that it collides with the 13L component in levels 1 to 9 ($C_{1-9}^{15,13L}$) the methodology in this case requires that the two components must be connected with the component 13L placed in the upper level (9). At this point part 13L becomes the "transient target" from which the algorithm will start again.

After a series of iterations of the method, the disassembly sequence shown below in Table 7 was obtained. The table shows again the number of sequence, the component involved, the time required for the disassembly and a short description of the operation.

Table 7. Disassembly sequence for method 2

Sequence	Component/Fasteners	Time [s]	Description
1	8	46,0	Remove flange cover
2	22	46,0	Remove No. 4 Nut M14
3	29	46,0	Remove No. 4 Nut M20
4	19	24,0	Remove No 2 plug 10 x 40
5	28	9,5	Tab extraction
6	21 - 20	33,2	Remove No. 4 rosette A 14 and No. 4 lives M14
7	31 - 30	33,2	Remove No. 4 rosette A 20 and n.4 screw M20
8	23	48,0	Remove n.12 screw M14 side flanges
9	2	24,6	Remove No. 2 side flange
10	S1	58,3	Remove subassembly S1
11	24	10,3	Tab extraction
12	11	13,5	Remove fan
13	27 R	23,0	Remove No. 4 screw M10 right
14	12 - 9	30,5	Remove flange and right gasket
15	25	36,3	Remove locking ring
16	15	48,7	Extracting screws
		531,1	Total Time [s]

5.3 Proposed Improvements

One of the main problems related to the Design of Disassembly is the difficulty in compare different methodology and different systems. Many strategies involving virtual CAD representation are important to reduce the times and costs of the analysis but remain a tool far from the real model designed. In particular, in order to study the maneuverability of each component for a maintenance purpose result complex since the CAD object isn't immerse in the real content of application. With the development of Virtual Reality and Augmented Reality solutions, the DfD could became easer and more realistic providing a true calculation of times because the component can be immersed in the real environment and the operator can see through the helmet if the operation suggested is possible or not (Chang, Ong, and Nee 2017) (Frizziero et al. 2019). In conclusion, a clear grouping of the methodology related to their principles and their field of application should be performed to simplify the analysis. In this paper, the choose of two comparable methodology was done aiming this result.

6. Conclusion

The study of the two methods reported different results for planning an optimal sequence. The first method used appears to be more immediate and simpler in application, but it may be too long and laborious for products with a large number of components since it needs the definition of various large matrices.

This algorithm obtained a sequence that can be developed in 741.8 seconds, which turns out to be a longer time than the one obtained with the second methodology. It is considered appropriate, however, that the first study allows less simplification of the product leading to a simple selective disassembly process which therefore provides less chance of error in the implementation of the process itself.

The second method leads to a disassembly solution in 531.1 seconds, which, as mentioned above, is less than the first case study. However, the simplifications implemented could be difficult in the implementation of the disassembly, and therefore the operator can make mistakes with consequent waste of time.
After these evaluations, the second methodology is considered more advantageous considering that it should be carried out by qualified operators who have adequate equipment at their disposal.
The goal of this work was to search for an optimal disassembly sequence of a virtual reducer reproduced at the CAD. During the study, it became apparent that the topic covered is still in develop. The number of papers and methods proposed is very high, but none of them have yet achieved an optimal planning model for all the possible applications. However, the numerous publications in the literature suggest that companies, designers, and others have developed a greater interest in this topic, including in their project's solutions for recycling, disposal and revitalization of products to minimize the waste of resources and raw materials. The CAD reproduction of the screw reducer has allowed to appreciate the enormous potential of 3D modeling, thanks to which products can be verified and tested in the design stage. This is in line with the principles of Design for Disassembly, since the construction of prototypes also leads to high resource consumption.

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