

## Hybrid Algorithm for Automatic Processing of 3D Models in STEP-File form

E. Varitis<sup>1,\*</sup>, K. Rinos<sup>1</sup> and D. Sagris<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, University of Western Macedonia, Kozani 50100, Greece.

<sup>2</sup>Mechanical Engineering Department, Laboratory of Manufacturing Technology & Machine Tools, International Hellenic University, GR-62124 Serres Campus, Greece.

Received 6 July 2020; Accepted 10 December 2020

### Abstract

In the attempt to restrict the impact of data exchange issue in the processing of 3D neutral models (STEP, IGES, etc.), modern CAD systems provided the users with commands-tools, which are capable to directly modify the geometry of the model, without interfering with their design history. Nevertheless, the implementation of these tools in complex geometries requires expertise from the user, and their repeated use even for simple modifications leads to counter-productivity. The purpose of this paper is to introduce an algorithm as a method for automation of processing 3D models in native and neutral form, based on the technology of hybrid modeling. The function of this algorithm enables the user to separate the model into sub-bodies, define the new position of them (translate and/or rotate) and combine them by creating an intermediate volume (lofting and combination). Furthermore, to demonstrate its capabilities, the proposed algorithm is implemented to a variety of 3D models and assemblies in STEP-File format. The experimental results of this research clarify the efficiency of the algorithm's use and give prominence to its impact on the user's productivity, utilizing the modification moves as a measure of comparison.

**Keywords:** STEP-Files, Hybrid Algorithm, 3D Model Transformation, Volume Division, Hybrid Modeling and Direct Editing.

### 1 Introduction

The continuous development of industrial productivity leads to the creation of more accurate and more efficient tools and methods for the improvement of every associate process. In the field of computer-aided design (CAD), modern software provides engineers with capabilities, which enhance every process, from the creation and validation of a model to the transformation of its data to neutral form for later use. Nevertheless, the industry still faces many difficulties, which in most cases, lead to counter-productivity or design errors. These limitations depend on the format of the model data, the complexity of its geometry, the duration of its creation, etc., and they are the point of interest in many types of research over the last decades.

One of the most common problems in CAD is the model data exchange between software packages with different data manipulation methods [1]. To eliminate this problem and to improve the interoperability of the CAD software, the industry turned to the creation of a variety of Product Data Exchange (PDE) standards. Specifically, one widely used format is STEP (Standard for the Exchange of Product Model Data), which is standardized by ISO-10303, and it is used to transfer necessary data related to the geometry and the creation of the 3D model [2]. However, STEP-Files do not support the exchange of information such as design history, standardized features, etc., which results in the deterrence of the use of traditional modeling methods (parametric, feature-based, etc.) [3]. Consequently, the lack of this information renders the modification of three-dimensional models complicated or even impossible.

For the enhancement of the processing models in STEP-File form, both the CAD software industry and research community developed a variety of technics and digital tools over the last years. Specifically, technologies such as Direct Editing modeling enable the user to directly interact with the geometry of the model, using Puss-Pull techniques [4]. These techniques provide the capability of recording the changes in the geometry to the current design history or the generation of a new one in the case of neutral models for effective feature management. Moreover, the new Direct Editing technics allow the insertion of parameters during the geometry processing, introducing this way a Hybrid modeling method, which unites the capabilities of both Direct and Parametric modeling and simplifies the future processing of the model due to the given parameters [5]. Moreover, CAD software (SOLIDWORKS, PTC CREO, CATIA, etc.) includes hybrid commands with different capabilities, such as the division of model's geometry and translation or/and rotation of specific surfaces or the entire model. Therefore, the implementation of these commands-technics is useful and rapid for small changes in the geometry of the neutral STEP models or for modifications on their outer boundaries or surfaces. Nevertheless, the use of the existing technics for changes in the internal geometry of the model is complicated, non-standardized, and repeated. Consequently, there is a necessity for advanced knowledge in design and programming, which render the implementation of hybrid commands counterproductive.

This paper presents an algorithm as a tool for the automation of processing native and neutral 3D models based on hybrid modeling technology and direct editing commands. Its application enables the modification of the internal geometry of the model by creating and adding new intermediate volume. Specifically, the user can split the

\*E-mail address: evaritis@uowm.gr

ISSN: 1791-2377 © 2020 School of Science, IHU. All rights reserved.

doi:10.25103/jestr.136.07

model into subsystems (bodies), translate and rotate the preferable body, and result in a new geometry by reuniting them with the creation of intermediate volume using three different processes. Furthermore, the algorithm developed using the Application Programming Interface (API) of SOLIDWORKS, but due to its structure, it can be implemented in a variety of CAD software for different applications. Additionally, this paper is structured as follows. The next section includes information about the literature overview of previous research related to the creation of algorithms for the automation of processes implemented in

native or STEP-Files, for the generation of new 3D models or the modification of the existing geometry. The second section includes the function and the structure of the algorithm, while the third section contains the mathematical template of the automatic hybrid processes. For the illustration of the algorithm's capabilities and efficiency, the fourth section includes case studies of its implementation to 3D neutral models, one for each provided intermediate volume creation process. Finally, conclusions and future work are included in the fifth section.

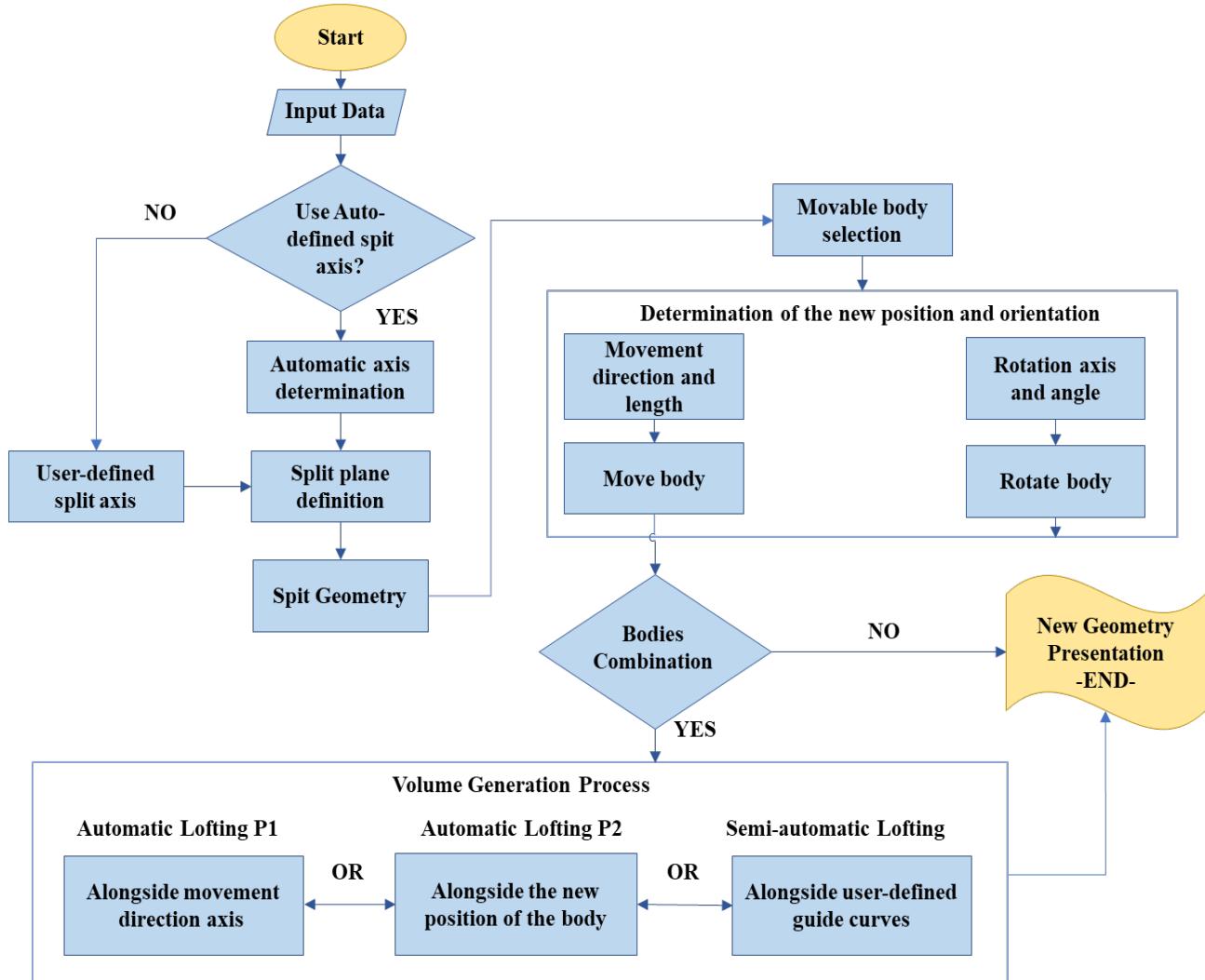


Fig. 1. Flowchart of the algorithm's individual steps.

### 1.1 Related works

The last decades have been published a lot of researches, which present the creation and implementation of algorithms, as applications-tools for the automation of product development processes. Specifically, the benefits originated from the use of algorithms in processes such as design, assembly, manufacturing, documentation, etc., of 3D models; give prominence to their impact on industrial productivity and operation accuracy, as well as to the elimination of unnecessary repeated processes. Kyratsis et al. developed an application, called Cylin3Der, using the CAD Application Programming Interface (API) of SOLIDWORKS, to automate the design and manufacture of an ISO15552 double-acting pneumatic cylinder [6]. With the intention of automatically generate every part of the cylinder, the

application provides the user with a form, demanding the specification of every necessary parameter. Afterward, the application automatically assembles the parts to the final model and generates some useful documents, which contain information for the simplification of the manufacturing process. The function of this tool clarifies the impact of the automation algorithms in the user - software interaction as well as in the improvement of processes included in the product life-cycle.

Zbiciak et al. developed an application as a tool for the automatic generation of helical and spur gears [7]. The function of this application demands only the specification of the values of some mandatory factors (e.g., tooth module ( $m$ ), teeth number ( $z$ ), etc.), which describes the form of the gear and are necessary for the design process. The rest of the

factors are calculated automatically with the use of different calculation algorithms. Using the API of the CAD software Siemens NX (Simple NX Application Programming or SNAP) for the creation and implementation of the application, the authors achieved to eliminate all the repeated design routines of the supported gears.

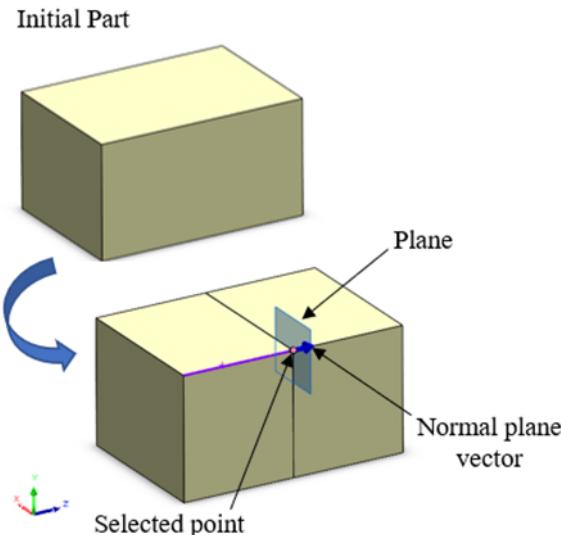
Haag and Anderl presented a method for the automated generation of an as-manufactured representation of digital twins in neutral form [8]. This method relies on two processes, the translation of the model's data to STEP-File format and the creation of 15 different modification algorithms. In order to illustrate the function of this method, the authors created an application called GEMINI, using MATLAB, and implemented it to the design environment of Siemens NX 12.

## 2. Methods

### 2.1 Function of the algorithm

The structure of the Automatic Hybrid Processes Algorithm (AHPA) is divided into three discrete areas. Fig. 1 illustrates the flowchart of the algorithm, where the processes of geometry division, the transformation of the model's position, as well as the creation of intermediate volume, are distinguishable.

The operation of the AHPA starts with the selection of a point on one of the model's edges. This point constitutes the input data of the algorithm, and it is considered the benchmark for the implementation of the automated processes. Afterward, the separation of the geometry can be achieved with the creation of a plane parallel and coincident to the selected point [9]. The orientation of the plane can be defined automatically as perpendicular to the edge, where the selected point belongs or manually. The second option provides the user with the capability to choose any edge of the model as the main reference for the orientation of the plane. Fig. 2 depicts the initial model and the two individual bodies separated by the plane perpendicular to the edge of the object, passing through the selected point.



**Fig. 2.** The model before and after the implementation of the separation process.

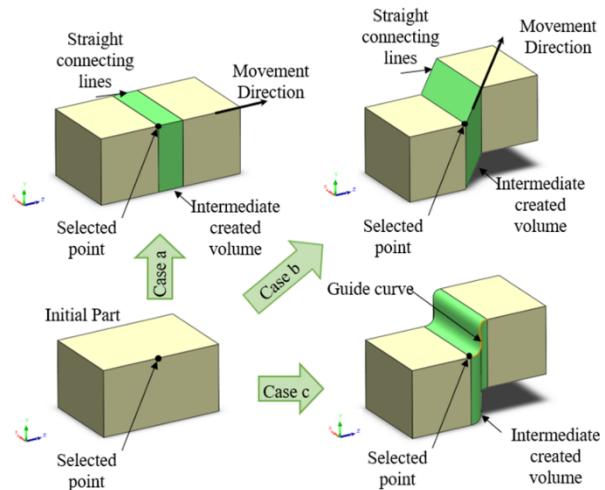
The next step of the algorithm includes the definition of the final position and orientation of the moveable body. The user selects one of the resulted bodies and defines the direction and the length of the movement. Otherwise, he can

rotate the moving body by defining the rotation axis and the angle. The direction of the movement and rotation of the body is defined automatically from the coordinate system of the design environment or manually from the user, with the selection of an edge. The final step of the algorithm includes the creation of intermediate volume for the combination of the divided bodies. The volume generation process can be achieved with the selection of one of the three different processes depicted in Fig. 1 and Fig. 3.

The first process, depicted in Fig. 3 Case a, is implemented in cases where the direction of the body's movement is the same as the direction of the edge, where belongs to the selected point. Also, all the necessary information about the initial and final position of the divided points is provided from the previous processes, hence the generation of the intermediate volume occurs automatically, and the combination of the resulted bodies is achieved with straight lines.

The second process is implemented in cases where the movement of the selected body is towards a new position in three-dimensional space defined by the user. Moreover, Case b of Fig. 3 illustrates that the generation of the intermediate volume and the combination of the bodies occurs automatically in the same way as Case a.

In the third process (Fig. 3, Case c), the movement of the selected body is the same as Case b, but for the generation of the intermediate volume, the user should define a number  $n$  ( $n \neq 0$ ) of guided curves for the combination of the divided bodies [10]. In all three cases, the volume generation process is followed by an optional combination process, which results in the new geometry representation.



**Fig. 3.** Different cases for the generation of the intermediate volume, according to the movement of the selected body.

## 3. Theory

### 3.1 Basic Automatic Processes

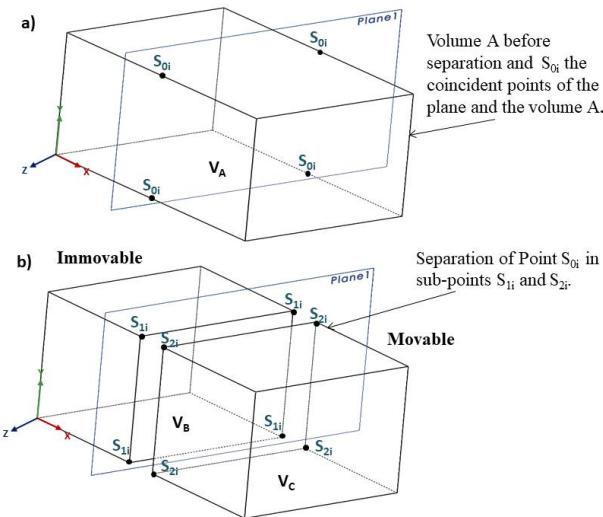
The function of AHPA lies in the cooperation of five processes Separation, Translation, Rotation, Lofting, and Combination. The basic theory behind the process of Translation and Rotation comes from linear algebra [11] and especially from the theory of Transformations [12]. The processes of separation, lofting, and combination, which implemented in the boundary represented models, use the operators of Boolean algebra [13] and the Set Theory [14]. Furthermore, the representation of a three-dimensional model

in computer-aided design software is achieved with a set of points arranged at different planes. Therefore, several sets of points structure a 4x4 algebraic matrices, such as the C [15] (Eq. 1).

$$C = \begin{bmatrix} x_1 & x_2 & x_3 & t_1 \\ y_1 & y_2 & y_3 & t_2 \\ z_1 & z_2 & z_3 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

### 3.2 Separation

In the first step of the algorithm, the user chooses a point  $S_{0i}$ , where the vertical plane is coincident. With the intention of separate the model into two different bodies, the dividing method utilizes between the coincident points  $S_{0i}$  (when  $i=1, 2\dots n$ ) of the plane and the volume of the model Fig. 4.a. The volume  $V_A$  of the model comprises of a set A of points. After the separation of the merged volume  $V_A$ , the two outcome volumes  $V_B$  and  $V_C$  consist of the different subsets of points B and C, whose intersection is an empty set  $B \cap C = \emptyset$ , when  $B \neq C$  [13,16]. To summarize, Fig. 4.b depicts the separation process, which divides the coincident points  $S_{0i}$  of the plane and the model into two different sets of points  $S_{1i}$  and  $S_{2i}$  (when  $i=1,2,\dots,n$ ). These sets of points represent the subsets B and C of volumes  $V_B$  and  $V_C$ , respectively.



**Fig. 4.** (a) Volume A before separation, (b) Separation of Point  $S_{0i}$  in sub-points  $S_{1i}$  and  $S_{2i}$  in order to create two different volumes  $V_B$ ,  $V_C$ .

### 3.3 Translation and Rotation

The processes of Translation and Rotation derive from linear algebra and specifically from the theory of Transformation [12]. This theory represents these transformations as matrixes, which in cooperation with the correct mathematical equations can lead to several changes to the position of the model in the Euclidean space. Furthermore, a transformation of a matrix C to another form C' (according to the process) lies in the equation  $C'=R*C$  [17] (where R is the transformation matrix). The translation of an object [17] in three-dimensional space uses the matrix  $R_s$ , where the points  $x'$ ,  $y'$ , and  $z'$  symbolize the new coordinates of the model. During the operation of the AHPA, the user defines these coordinates for the distance of the two bodies.

The equation for an object, which is moved, can be expressed as  $C'=C*R_s$  (Eq. 2).

$$R_s = \begin{bmatrix} 1 & 0 & 0 & x' \\ 0 & 1 & 0 & y' \\ 0 & 0 & 1 & z' \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

In the case of the Rotation process, there is a type of matrix for every axis x,y,z [17]. Significantly, the transformation matrices  $R_x$  (Eq. 3),  $R_y$  (Eq. 4),  $R_z$  (Eq. 5) can change the angle  $\theta$  of the object (C to C') through the General equation  $C'=C*R_n$  (where  $n=x$ ,  $y$  and  $z$ ).

The equation for an object, which is rotated about X-axis, can be expressed as  $C'=C*R_x$ , and the matrix:

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The equation for an object, which is rotated about Y-axis, can be expressed as  $C'=C*R_y$ , and the matrix:

$$R_y = \begin{bmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The equation for an object, which is rotated about Z-axis, can be expressed as  $C'=C*R_z$ , and the matrix:

$$R_z = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

In more complex cases, where the final position and orientation of the rigid body result from several translations or rotations, the final transformation matrix called "Homogenous transformation matrix" [18,19] derives from the multiplication of the intermediate transformation matrices ( $R_s$  or  $R_x$  or  $R_y$  or  $R_z$ ). The matrix of Eq. 6 illustrates the general form of the 4x4 Homogenous transformation, which consists of four individual vectors ( $n$ ,  $s$ ,  $a$ , and  $d$ ). The vectors  $n$ ,  $s$ , and  $a$  represent the direction of  $x'$ ,  $y'$ , and  $z'$  respectively with reference in the initial frame  $o, x, y$ , and  $z$ . The vector  $d(dx, dy, dz)$  is an equation, which represents the distance of the new axis origin  $o'$  respectively on the initial origin  $o$ , with reference in the initial frame  $o, x, y$ , and  $z$ .

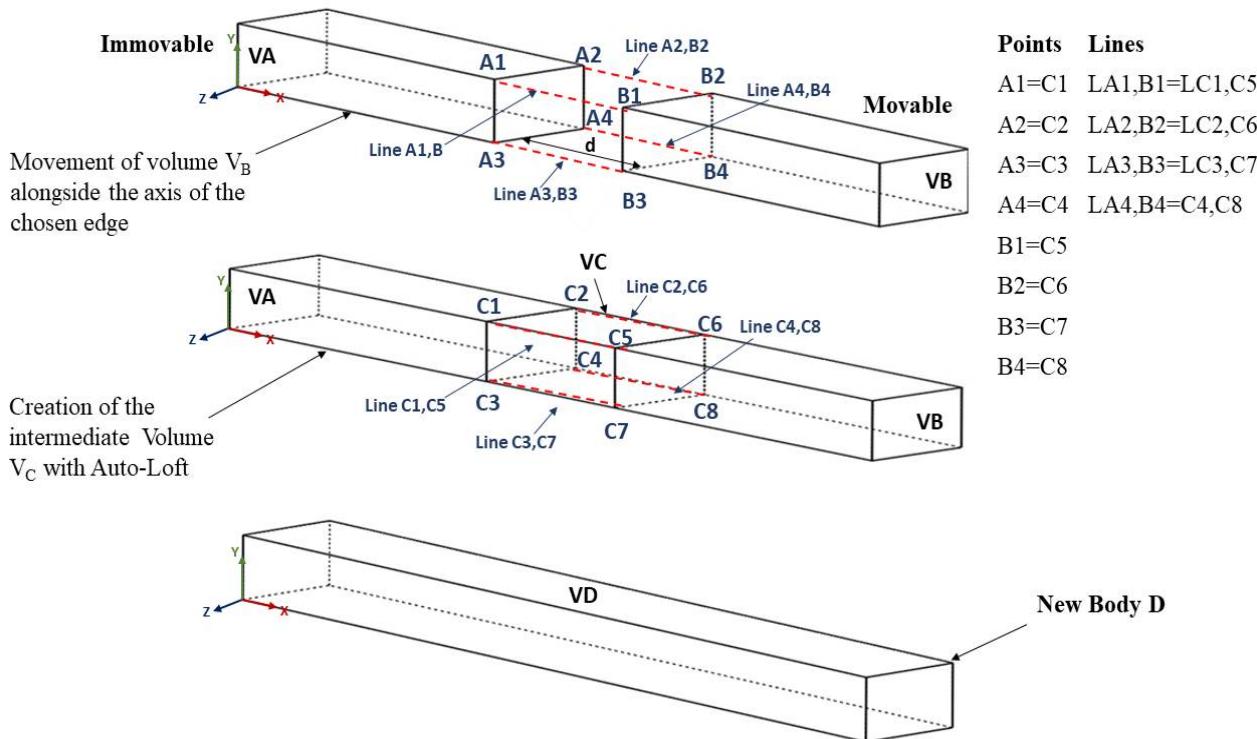
$$H = \begin{bmatrix} nx & sx & ax & dx \\ ny & sy & ay & dy \\ nz & sz & az & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

### 3.4 Volume Creation and Combination

The volume-creation processes derive from the operations of the Boundary Representation (B-rep) [13] method. This method represents the solid geometry of the model as a collection of connected points, lines, and surfaces (limits), and uses different operations (lofting, extrude, sweeping, drafting, etc.) depending on the procedure. The function of this algorithm includes the use of the lofting process [16], using as volume-creation guides, lines, or curves, which depends on the movement of the body and the geometry of the intermediate volume. Moreover, the combination [16] of the two bodies lies in the Boolean operation of conjunction (sum or + or U), where the set of points A of a body  $V_A$  and the set of points B of a body  $V_B$  are combined to form a body  $V_C$ , with a set of points C ( $A \cup B = C$ ).

#### 3.4.1 Automatic Lofting P1

The process of Automatic Lofting 1 is implemented in case of the body's movement alongside the axis of the edge, (volume  $V_B$  Fig. 5). The algorithm uses Lofting operation [16] to create an intermediate volume  $V_C$  to combine the bodies of  $V_A$  and  $V_B$ . This process does not require a guide axis or a distance of operation because the algorithm uses the parameters and the axis of the translation process. Furthermore, the points  $C_i$  ( $i=1,2,3,4$ ) and the lines  $LC_i,C_i$  ( $i=1,2,\dots,8$ ), which determine the geometry of volume  $V_C$ , are known. Points  $C_i$  ( $i=1$  to 4) are derived from the initial position before the division, and points  $C_i$  ( $i=5, 6, 7, 8$ ) are calculated by the Homogenous Matrix (3.6). In the final step, the algorithm applies the process of combination  $V_A \cup V_B \cup V_C = V_D$  and create the new body  $V_D$ .



**Fig. 5.** Intermediate volume creation with the Automatic Lofting P1 alongside the axis of the edge, where the chosen point tangents, and combination process for the new body creation  $V_D$ .

#### 3.4.2 Automatic Lofting P2

The process of Automatic Lofting P2 is implemented when the user moves one of the bodies alongside the axes x,y,z to a new position in three-dimensional space. Specifically, during the translation of the body  $V_B$  Fig.6, alongside the axes, y, and x, the user sets the parameters of distance  $dy$  and  $dx$  and the direction of the process. The algorithm uses these parameters (guide axis and distance) for the creation of the intermediate volume  $V_C$  and the combination of the divided bodies  $V_A$  and  $V_B$ , in the same way as case 1, points  $C_i$  ( $i=1,2,3,4$ ) and lines  $LC_i,C_i$  ( $i=1,2,\dots,8$ ) determining the geometry of volume  $V_C$ , are known. Points  $C_i$  ( $i=1$  to 4) are derived from the initial position before the division, and points  $C_i$  ( $i=5$  to 8) are calculated by Homogenous Transformation Matrix (3.6). Finally, the algorithm applies the process of combination  $V_A \cup V_B \cup V_C = V_D$  and create the new body  $V_D$ .

#### 3.4.3 Semi-automatic Lofting

The Semi-automatic Lofting process is implemented in cases where the user wants to shape a complex geometrical intermediate body and especially when the translation and the rotation of the body are alongside the axes x,y,z to a new position in three-dimensional space. Through this process, the algorithm enables the user to design guide curves (paths) 2D or 3D splines (Fig. 7) in order to determine the shape of the intermediate body  $V_C$  and to set the construction path of the process [10]. The guide curves are polynomials and their functions are defined by the user or automatically by the software during the design. In this case, the topology of the intermediate volume derives from the guide curves. The lofting operates between two solid bodies with known topologies, and therefore there are not any discrepancies in the geometry during the construction of the surfaces, which consist of the intermediate volume. In the final step, the algorithm uses the relations between the points  $A_i$ ,  $B_i$ , and  $C_i$

to apply the process of combination  $V_A \cup V_B \cup V_C = V_D$  and create the geometry of the new body  $V_D$ .

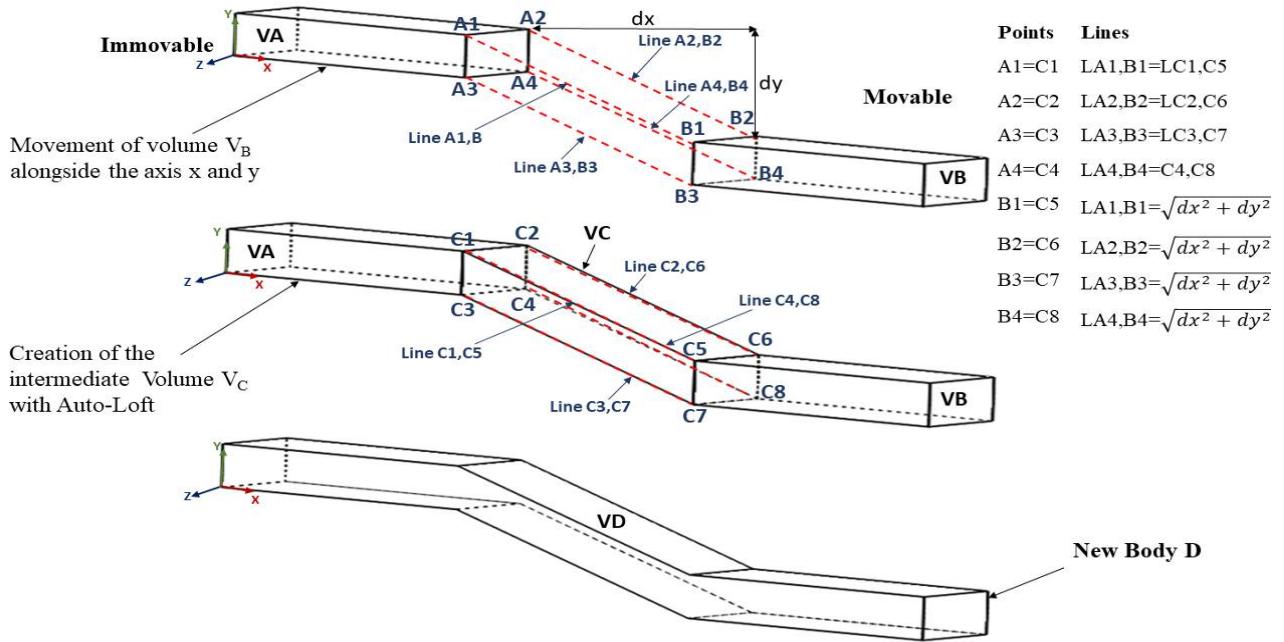


Fig. 6. Implementation of the Automatic Lofting P2 process alongside the axis derived from the new position of the volume  $V_B$ , and combination of the bodies for the creation of new body  $V_D$ .

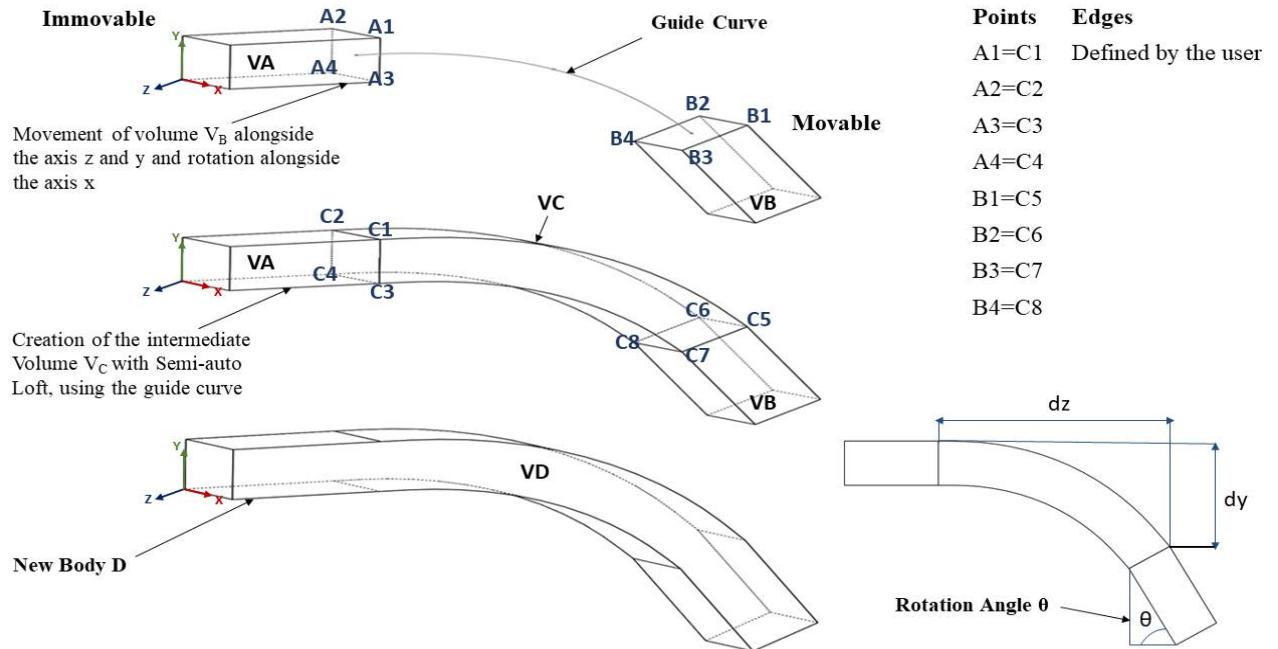


Fig. 7. Implementation of the Semi-automatic Lofting process alongside the path of the curve, which is designed by the user for the creation of new volume  $V_D$ .

#### 4. Examples

The main purpose of the following section is the illustration of the use and the capabilities of the algorithm, which is implemented in the C++ language in an Integrated Development Environment (IDE). The algorithm operates in the STEP-Files' design environment of the software of SOLIDWORKS, through a communication protocol API (Application Programming Interface) [20]. Furthermore, the following examples are divided into three categories based on

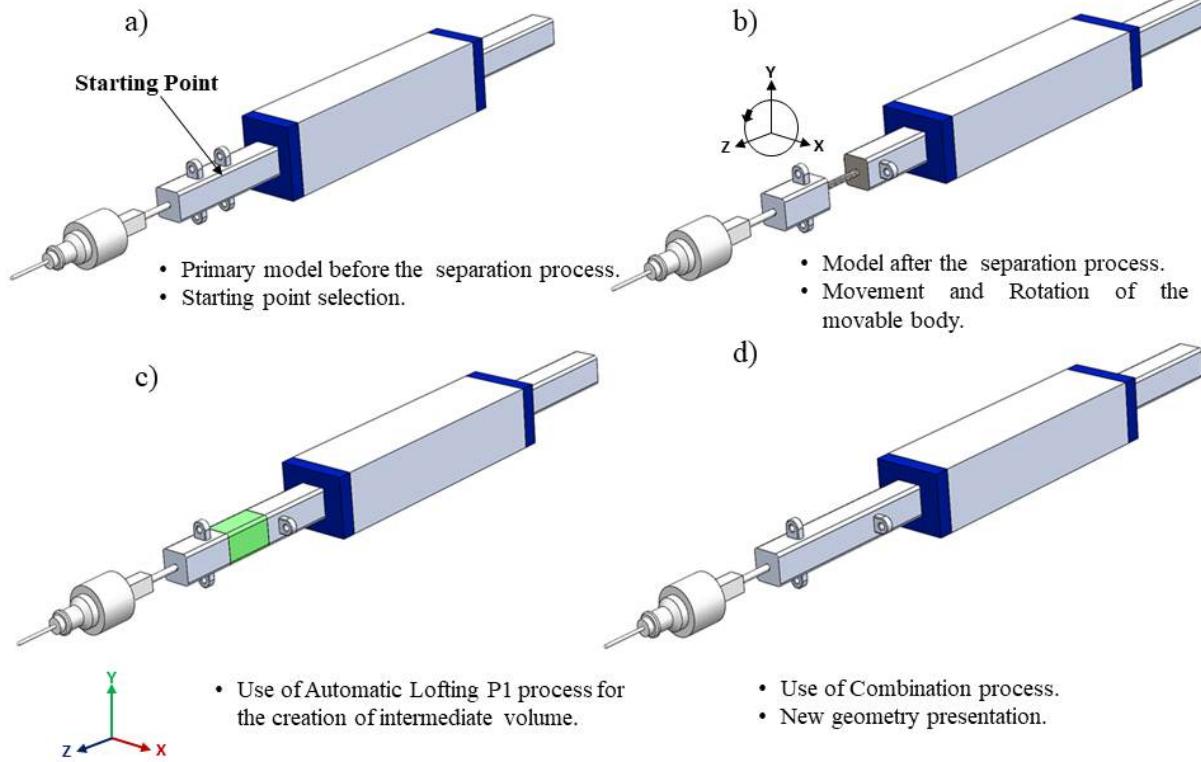
the different capabilities of the algorithm. Specifically, the models, Picker Nozzle (Fig. 8), Gripper's Part (Fig. 10), and Industrial Hanging Conveyor (Fig. 12) are in the form of Step-Files and, depending on their geometry; they cover all the three cases of intermediate volume creation.

##### 4.1 Single axis movement-rotation and use of Automatic Lofting P1 process

The Picker Nozzle example (Fig. 8) represents a three-dimensional model in the STEP-File format, which illustrates

the use of AHPA for the modification of the central axis' geometry. The operation of the algorithm starts when the user chooses the starting point (Fig. 8.a) on one of the edges of the Nozzle's central axis. Afterward, the algorithm automatically applies the separation process on the auto-created plane, which is coincident to the starting point. Moreover, after the selection of one of the two resulting bodies, the user defines the parameters of the distance  $d_z$  and the angle of rotation  $\theta = 90^\circ$  (along the z-axis), and the algorithm automatically applies the translation and the rotation processes (Fig. 8.b). Furthermore, due to the translation of the body across the z-axis, which is parallel to the edge (where the chosen point

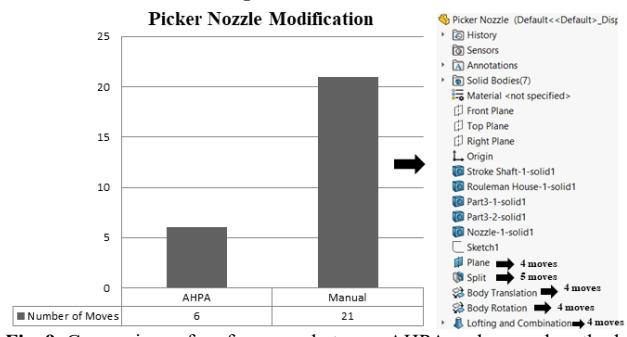
tangents), the algorithm allows the user to create automatically an intermediate volume (Fig. 8.c) with the selection of the Automatic Lofting P1. This process is suitable for that model-case due to the translation of the divided body. In the final step of the algorithm, the user chooses the process of combination (Figure 8.d), which results in the creation of a merged body with new geometry. Nevertheless, it is remarkable that the algorithm applies the automated processes without interfering with the external (Fillet) or internal (Bores) configurations (Fig. 8.c), which exist in the model unless this action is pretentious.



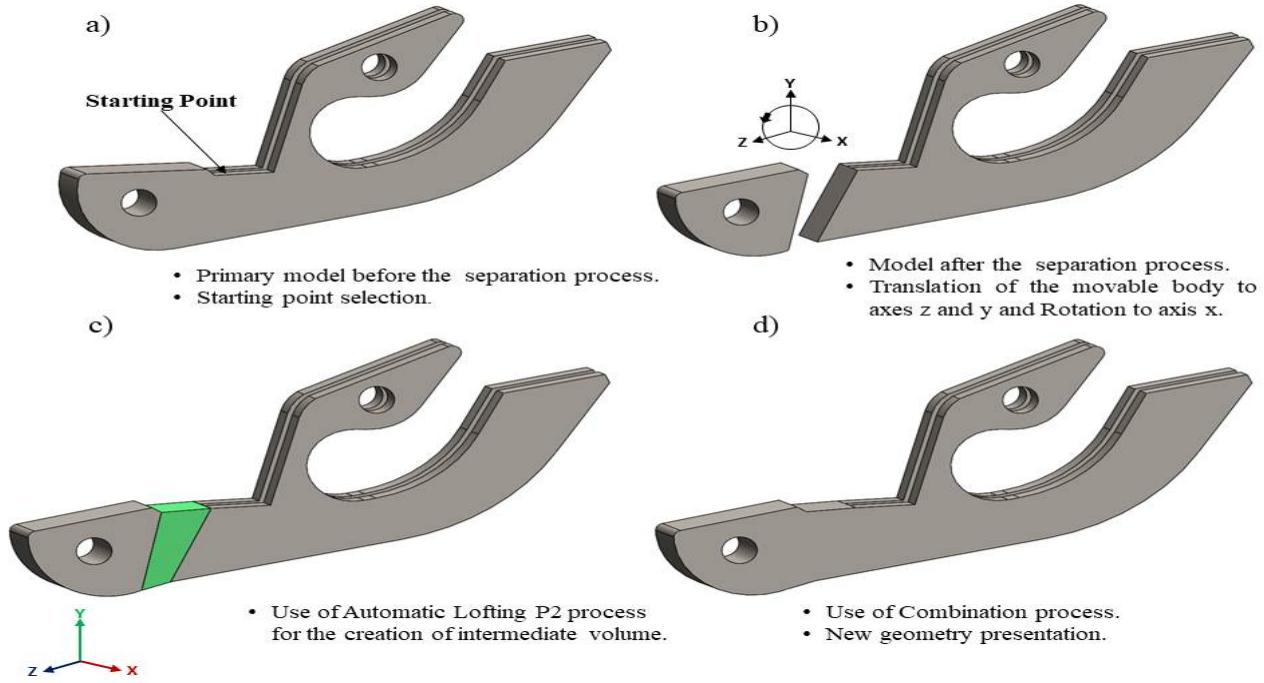
**Fig. 8.** Application of Automatic Lofting P1 process for the modification of a picker nozzle's geometry.

The example of Fig. 8 demonstrates the impact of the algorithm's implementation to models in STEP-File form, which have to be modified (separate and translate) across a single axis. In contrary to the function of direct editing commands, the use of the Automatic Lofting P1 process automates the creation of the intermediate volume and eliminated unnecessary time-consuming moves. Furthermore, to validate the performance of the algorithm, the column chart of Fig. 9 compares the number of user's modification moves, which have been counted when he uses both the AHPA and manual method for the modification of the picker nozzle. Specifically, the design tree of Fig. 9 includes an average of moves for every necessary command (Plane, Split, Body Translation, etc.) for the manual modification process. A comparison of these numbers (6 and 21 moves) indicates that the use of the AHPA leads to the reduction of the modification moves at a percentage of 71,43% (15 moves). Besides that, the performance of the algorithm can be maximized when the

automated processes are applied repeatedly in long-length models with exterior configurations, where the modification routine is known and repeatable.



**Fig. 9.** Comparison of performance between AHPA and manual method, utilizing the user's moves during the modification of the Picker Nozzle as the measure of comparison.



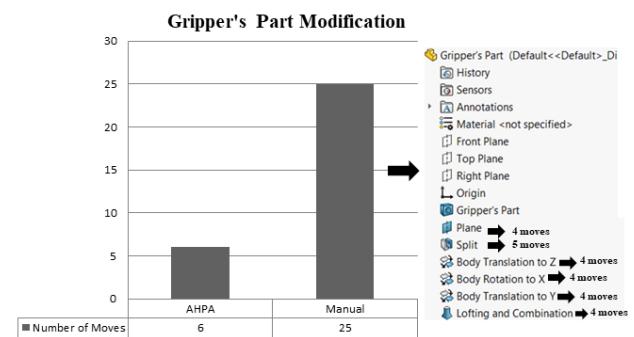
**Fig. 10.** Application of Automatic Lofting P2 for the modification of a gripper's part geometry.

#### 4.2 Multiple axis movement-rotation and use of Automatic Lofting P2 process

The Gripper's Part example Fig.10 represents a three-dimensional model in the STEP-File format, where the user applies the AHPA to modify its geometry by placing the feature from the left side in a horizontal position. In the first step of the algorithm, the user determines the starting point on one of the model's edges, and the algorithm applies the separation process on the auto-created plane Fig. 10.a. Furthermore, choosing one of the resulted bodies and defining the distance parameters  $d_z$  and  $d_y$  as well as the rotation angle  $\theta$ , the algorithm applies the processes of translation and rotation. As a result the body is translated along the axes z and y, and it is rotated along the axis x Fig. 10.b. Moreover, after the selection of the Automatic Lofting P2 process, the algorithm uses the parameters of the translation and rotation processes from the previous step as well as the resulted geometry of the separated points to create the intermediate volume Fig. 10.c. In the final step of the algorithm, the user chooses the process of combination Fig. 10.d and creates the final geometry form of the model, which includes the required modifications.

The model of Fig.10 belongs in the cases of neutral models where the translation and rotation of the selected body are towards a defined position in three-dimensional space. The implementation of the Automatic Lofting P2 process provides the user with the capability to increase his efficiency

during the modification of the neutral model by automating all the repeated moves. Specifically, a comparison between the use of AHPA and the direct editing commands is illustrated in the column chart of Fig. 11. Choosing the number of modification moves as the measure of comparison, it is deduced that for the modification of the gripper's part, the use of AHPA demands 6 moves, and the use of the manual method demands 25 moves from the average user. Consequently, the use of AHPA reduces the moves at a percentage of 76% (19 moves), while at the same time; it simplifies future processing by attributing parameters to the model with the use of hybrid modeling.



**Fig. 11.** Comparison of performance between AHPA and manual method, utilizing the user's moves during the modification of the Gripper's Part as the measure of comparison.

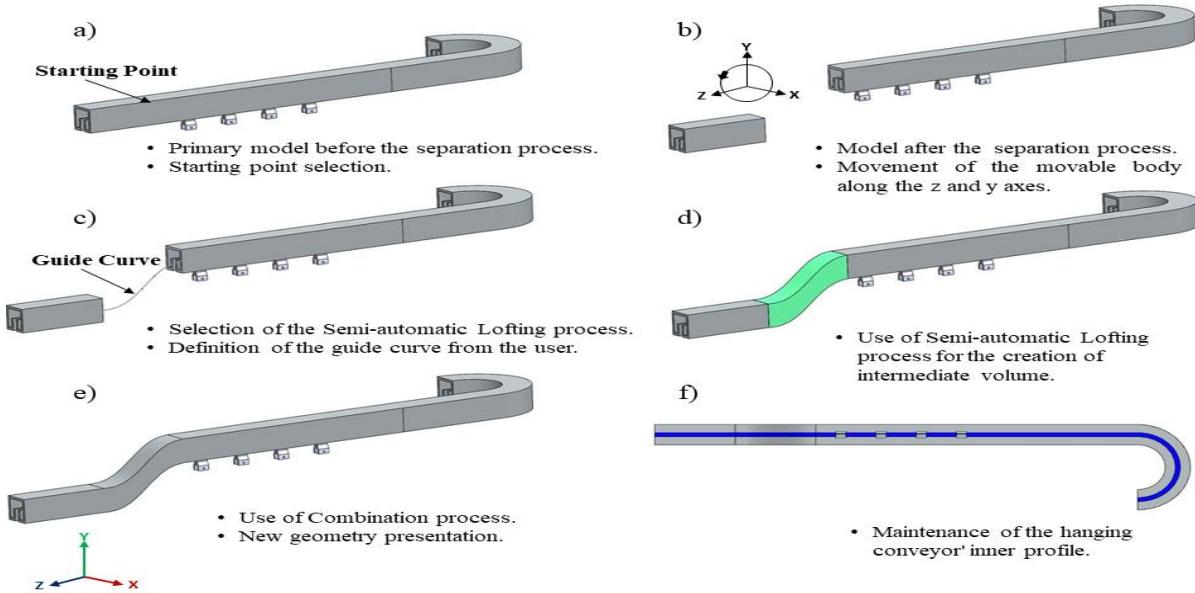


Figure 12: Application of the Semi-automatic Lofting process for the modification of the hanging conveyor's geometry.

#### 4.3 Multiple axis movement-rotation and use of Semi-automatic Lofting process

The Industrial Hanging Conveyor example Fig. 12 represents a three-dimensional model in the STEP-File format. The AHPA creates an intermediate volume with complex geometry and modifies the path (change of the transport height), where sliding the hanging receptors. After the activation of the algorithm, the user determines a starter point on one of the model's edges to generate the auto-created plane and the separation process is implemented automatically to divide the model into two different bodies Fig. 12.a. The next step of the algorithm includes the selection of one of the bodies and the definition of the proper parameters of distance  $dz$  and  $dy$ , which leads to the translation of the body along the axes  $z$  and  $y$  Fig. 12.b. Furthermore, the user chooses the Semi-automatic Lofting process to attribute curvature in the geometry of the final body and defines the necessary guide curve Fig. 12.c, which operates as the leading path for the creation of the intermediate volume Fig. 12.d. Finally, the user chooses the process of combination Fig. 12.e to create a uniformed body with new geometry and dimensions. It is obvious that the operation of the algorithm does not influence the geometry of the inner profile of the conveyor and maintains its standardization Fig. 12.f.

The model of Fig. 12 demonstrates the impact of the Semi-automatic Lofting Process on modifications, which demand a customized inner or/and outer geometry for the creation of the intermediate volume. The example of Hanging Conveyor as other manufacturing structures in neutral form, which include conveyors or beams with a variety of cross-sections, demand several modifications across their path, something complicated and time-consuming for the average user due to the absence of the design tree. Hence, the use of AHPA automates the repeated moves while it simplifies the implementation of the modification processes. Furthermore, comparing the number of necessary modification moves for each method (12 for AHPA, and 28 for the manual), depicted in the column chart of Fig. 13, it is deduced that the use of AHPA leads to the reduction of the modification moves at a percentage of 57,14% (16 moves).

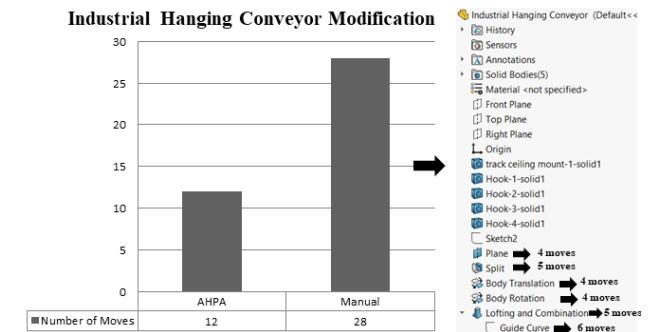


Fig. 13. Comparison of performance between AHPA and manual method, utilizing the user's moves during the modification of the Industrial Hanging Conveyor as the measure of comparison.

#### 5. Conclusion and Future Work

The algorithm presented in this paper developed to automate the processing of 3D models in native or STEP-Files form. Its function enables the user to automatically modify the internal geometry of the model by adding new intermediate volume, based on three provided processes. Moreover, the function of the algorithm does not require the existence of the design history, the relations between the parts of the model, and other data, which are not supported by the STEP-Files. Therefore, it can be implemented directly to the geometry of the model, regardless of its complexity or the format of the file. Furthermore, due to its structure of the workflow, this algorithm consists of an integrated template for the standardization of neutral 3D model processing, which is crucial for the improvement of the current use of individual direct editing processes.

The examples presented in this paper illustrate the impact of the algorithm in the elimination of repeated and time-consuming processes. Using the number of user's moves as a measure of comparison between the current method and the use of AHPA, it is demonstrated that the automatic hybrid processes increase the productivity of the user while it facilitates the modification process. Additionally, the use of hybrid technology as the principal modeling method of the automatic processes enables the user to use both the capabilities of the direct and parametric modeling during the

modification. Consequently, the proposed algorithm eliminates the difficulty of the user to modify and configure the geometry of neutral and native models by establishing parameters for further processing. Last but not least, the user can rapidly and accurately modify the model without interfering with any configurations (bores, threads, chamfers) present in the surface geometry.

The present paper provides many opportunities for further research. The absence of automated processes in neutral file formats (STEP, IGES) compared to the impact of this algorithm on the modification of three-dimensional models necessitates the creation of different hybrid algorithms for the automation of design commands and processes. These

algorithms will be implemented immediately in several design processes (Part modeling, Assembly, Mold tools, etc.) and file formats. Moreover, the cooperation of these algorithms can lead to the creation of a standardized software-toolbox, which can be the fully-automated package of processes with application to several file formats and applications.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License



## References

1. McKenzie-Veal D. An Analysis of STEP, JT, and PDF Format Translation Between Constraint-based CAD Systems with a Benchmark Model. Purdue University; 2012.
2. H.J.Helpenstein. CAD Geometry Data Exchange Using STEP. CAD Geom. Data Exch. Using STEP, Aachen: Springer Science & Business Media - Verlag; 1993, p. 3–30.
3. Tornincasa S, Torino P, Torino P. THE FUTURE AND THE EVOLUTION OF CAD II-1 II-2. 14th Int. Res. Conf. "Trends Dev. Mach. Assoc. Technol. TMT 2010, Mediterr. Cruise, 11-18 Sept. 2010, 2010, p. 11–8.
4. Zou Q, Feng HY. Push-pull direct modeling of solid CAD models. *Adv Eng Softw* 2019;127:59–69. <https://doi.org/10.1016/j.advengsoft.2018.10.003>.
5. Wypysiński R. Hybrid modeling in CAD. *Adv Technol Mech* 2015;2:15. [https://doi.org/10.17814/atim.2015.1\(2\).14](https://doi.org/10.17814/atim.2015.1(2).14).
6. Kyrtatsis P, Tzotzis A, Tzetzis D, Sapidis N. Pneumatic cylinder design using cad-based programming. *Acad J Manuf Eng* 2018;16:107–13.
7. Zbiciak M, Grabowik C, Janik W. An automation of design and modelling tasks in NX Siemens environment with original software - Generator module. *IOP Conf Ser Mater Sci Eng* 2015;95. <https://doi.org/10.1088/1757-899X/95/1/012117>.
8. Haag S, Anderl R. Automated Generation of as-manufactured geometric representations for digital twins using STEP. *Procedia CIRP* 2019;84:1082–7. <https://doi.org/10.1016/j.procir.2019.04.305>.
9. Stouffs R. The Algebra of Shapes. Carnegie Mellon University University Pittsburgh, 1994.
10. H. Toriya H. Chiyokura. FREE-FORM CURVES. 3DCAD Princ. Appl., Springer-Verlag Berlin Heidelberg; 1993, p. 51–69. <https://doi.org/10.1007/978-3-642-45729-6>.
11. Gentle JE. Matrix Algebra. 2nd ed. Springer International Publishing; 2017. <https://doi.org/10.1007/978-3-319-64867-5>.
12. Mortenson ME. Mathematics for computer graphics applications: an introduction to the mathematics and geometry of CAD/CAM, geometric modeling, scientific visualization, and other CG applications. 2nd ed. New York: Industrial Press Inc.; 1989.
13. Christofer M. Hoffman. Geometric and Solid Modeling: An Introduction. vol. 66. Morgan Kaufmann Pub; 1989.
14. Jech TJ. Set theory. 3rd ed. Springer-Verlag Berlin Heidelberg New York; 2002.
15. Angel.E S. Geometric Objects and Transformations. In: Horton M, editor. *Interact. Comput. Graph. - A Top-Down Approach*. 6th ed., Pearson Education; 2012, p. 115–64.
16. Stroud I. Boundary Representation Modelling Techniques. Springer-Verlag London; 2006. <https://doi.org/10.1007/978-1-84628-616-2>.
17. Elias R. Transformations in 3D Space. *Digit. Media A Probl. Approach Comput. Graph.*, Springer International Publishing; 2014, p. 143–95. <https://doi.org/10.1007/978-3-319-05137-6>.
18. Ude, Matjaž Mihelj, Tadej Bajd A, Stanovnik, Jadran Lenarčič A, Šlajpah, Marko Munih, Jure Rejc S. Homogenous Transformation Matrices. Robotics. 2nd ed., Springer International Publishing; 2019, p. 11–9. <https://doi.org/978-3-319-72911-4>.
19. Díaz EO. Rigid Motion. 3D Motion Rigid Bodies A Found. Robot Dyn. Anal., Springer International Publishing; 2019, p. 147–60. <https://doi.org/https://doi.org/10.1007/978-3-030-04275-2>.
20. Luke Malpass. SolidWorks API Series 1: Programming & Automation. AngelSix; 2014.