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Study to Evaluate the Freeform Feature in PTC Creo Parametric 2.0

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Abstract

This study is mean to evaluate the freeform feature of PTC Creo Parametric by investigating its capabilities and advantages over the other modeling approach. To achieve the goals of the research, a thorough study of the available literature on freeform surface modeling concepts and geometric modeling. A heuristic evaluation and actual modeling of a case part (detergent bottle) was then carried out in PTC Creo Elements to determine the capability of the freeform feature of these CAD program. The paper revealed that the freeform feature in PTC Creo Parametric reduces modeling time, gives the designer more flexibility & control over the shape of the model and allows for creation of complex shaped models. However, its interface has some limitations. For example, right clicking while in the freestyle environment does not provide any feedback unless the button is held for a longer period. Nevertheless, the freeform feature in PTC Creo Parametric is a state of- the-art tool that is far ahead of its competitors.

Keywords: Freeform feature , PTC Creo , Parameters, available literature, surface modeling, geometric modeling, case part (detergent bottle).

I. INTRODUCTION

The emergence of computer aided technologies such as Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM) and other related tools has greatly revolutionized the world of engineering. Manufacturers all over the world are relying on these technologies in order to remain competitive and enhance innovative product development. With these technologies, manufacturers can create, adjust, evaluate and optimize their designs before actualizing them. CAD systems have enabled these manufacturers to design and manufacture complex parts quickly and accurately [1]. Freeform surface modelling is used to create aesthetic surfaces that have other functions. They are also used to design technical surfaces for various engineering components search as wind turbine blades. Consequently, most CAD software makers have incorporated the freeform feature in their software to remain competitive and meet engineer's requirements. Since the capability of this feature is different in different CAD programs, it is important to evaluate their capability in order to acquire the most appropriate CAD software. Freeform features offer a faster and a more intuitive modelling approach and guarantee a high quality design. Designers and manufacturers all over the world are currently relying on freeform modelling programs to create and manufacture outstanding products in a very short time.

II. RESEARCH METHODOLOGY

In this research, the factors to consider when selecting the most favorable freeform modeling software will be presented with emphasis on PTC Creo Parametric. The evaluation process will be based on available literature, heuristic evaluation and personal experience with each of the software . This will be accomplished by selecting a case part and modeling it in PTC Creo Parametric.

The work of this study also involved the following:

- Study the available literature on freeform surface modeling concepts.
- Study the capability and applications with emphasis on freeform surface modeling.
- Identify the case part that will be used to evaluate the capability of the freeform feature in PTC Creo Parametric.
- Evaluate the capability of the freeform feature in PTC Creo Parametric by relying on the studied literature.
- heuristic evaluation and the personal experience gained through the design process of the case part.

The findings of this study will help various CAD users in the selection process of the most suitable CAD software for a specific application. Designers and engineers in Small and Medium Enterprises (SMEs) that require complex surfaces will be the most obvious beneficiaries of this study.

III. LITERATURE METHOD

1. *Surface Modeling and Solid Modeling*

Solid modeling is used to generate solid components of a desired geometry. The solid modeling CAD software is used to create the virtual 3D image of the desired component. This is achieved by systematically joining or cutting a group of features until the desired model is complete. A solid model is a replica of the real component and can be rotated just like the real component [2].Solid modeling is applied in several industries including the automobile industry, material processing industry, and consumer products industry among others [3].

Surface modeling involves creating surfaces of a predetermined shape using various operations. Surface modeling is similar to solid modeling in the sense that the solid model is achieved when surfaces are connected to represent the object's boundary [3].

2. *Types of Surfaces*

Surfaces are mainly classified as either analytical or freeform (non-analytic/synthetic or sculptured surfaces) [4].Analytical surfaces are those surfaces that can be defined by mathematical equations in terms of X, Y and Z co-ordinates [5].On the other hand, freeform surfaces cannot be explicitly defined by a mathematical equation and are generated by spline curves in either one or both directions in a three dimensional space [5]. Analytical surfaces include plane surfaces, ruled surfaces, tabulated cylinders and surfaces of revolution (cylindrical surfaces, conical surfaces, parabolic surfaces, hyperboloid, and torus among others) [5].On the other hand, freeform surfaces include coon's surfaces, B-spline surfaces, NURBS surfaces, Bezier surfaces, and lofted surfaces among others. The general classification of CAD related surfaces is shown in figure 1.

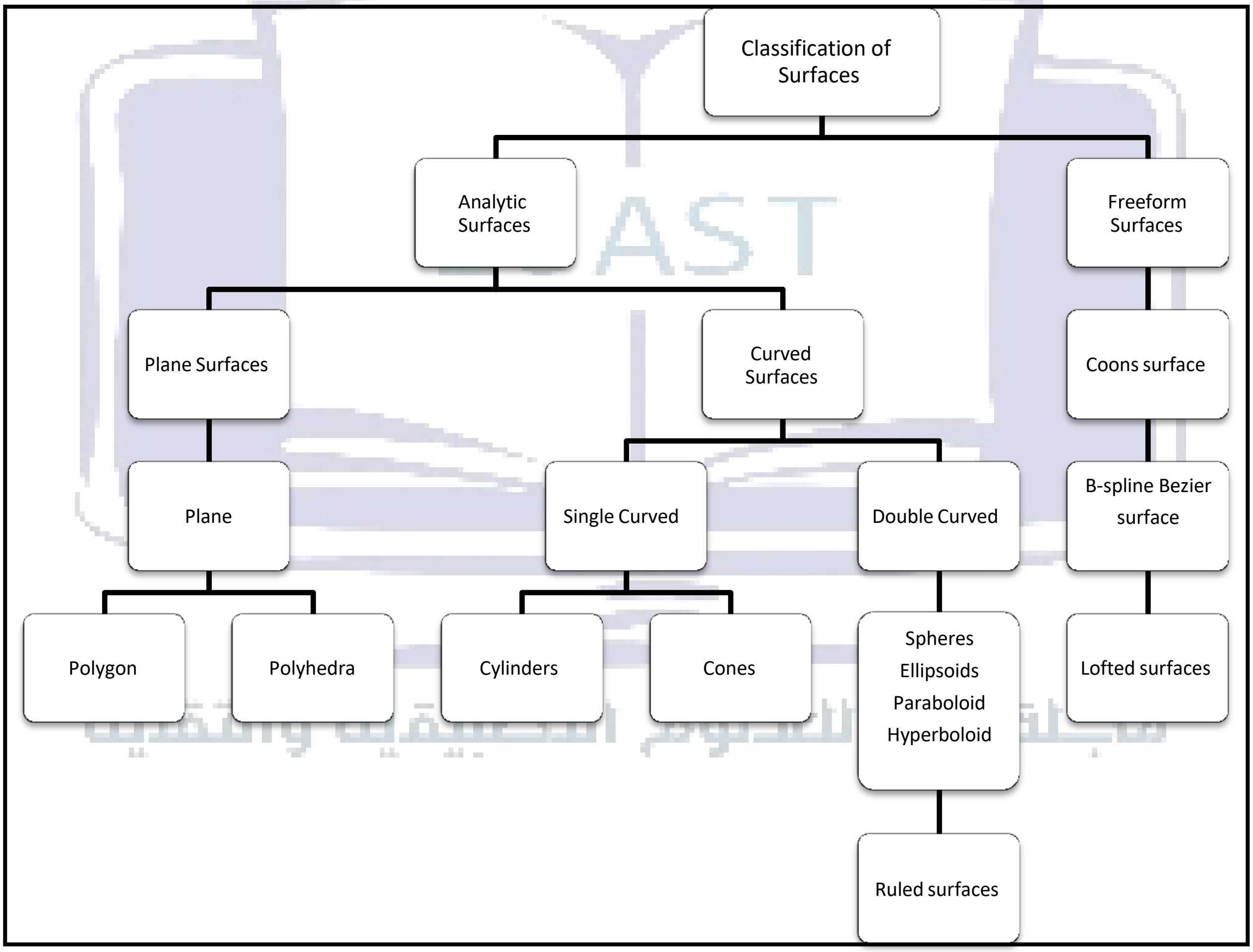

Figure 1: Classification of Surfaces [4].

3. *Parametric Representation of Analytical Surfaces*

Surfaces can be represented by using either parametric or non-parametric equations. When using parametric equations to represent a surface, the surface is described as the locus of points that comply with a constraint equation of the form of P(X, Y, Z) = 0 [4].In this case, the surface is described by the following equation:

$$P\ (u,v) = [x\ (u,v)\ , y(\ u,v)\ , z\ (u,v)]\ ,\quad u_{min} \leq u \leq u_{max}\ ,\ v_{min} \leq v \leq v_{max}\ .$$

Where X, Y and Z represent functions of u and v. Parametric representation of a surface is shown in figure 2.

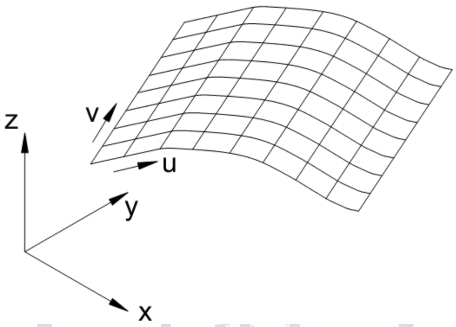

Figure 2: Parametric Representation of a Surface [4].

surfaces can be represented by non-parametric equations as shown :
$P(\ x,\ y,\ z) = [x,\ y,\ z\ (x,\ y)\ ]$. If z-values at all the points in the x-y domain are known the surface can be completely described.

3.1 Parametric Representation of Plane Surfaces

A plane surface defined by points P_0, P_1 and P_2 is represented by the following parametric equation:

$$P\ (u,V) = P_0 + u\ (P_1 - P_0) + v\ (P_2 - P_1)\ , 0 \leq u \leq 1\ , 0 \leq v \leq 1$$

A plane surface is shown in figure 3 below with the three non-coincidental points P_0, P_1 and P_2 clearly shown.

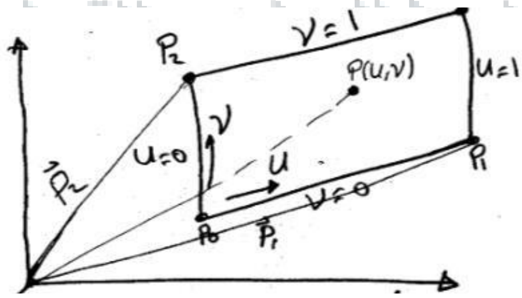

Figure 3: A plane surface.

3.2 *Parametric Representation of Ruled Surfaces*

A ruled surface is a linear surface and it is created by joining corresponding points on two space curves using straight lines [6].The two space curves are the boundary curves and are used to define the surface. Ruled surfaces are recommended for representing surfaces that are not characterized by any coils or kinks [7].If the two boundary curves are:

$G(u)$ and $Q(u)$, a ruled surface can be parametrically represented by the following equation :

$$P(u,v) = (1-v)\,G(u) + vQ(u)\,, \qquad 0 \le u \le 1, \quad 0 \le v \le 1$$

From the above equation it is clear that by keeping **u** constant, the rulings will be in the **v** direction of the surface. On the other hand, keeping **v** will produce curves in the **u** direction.

Parametric representation of a ruled surface is shown in figure 4 below.

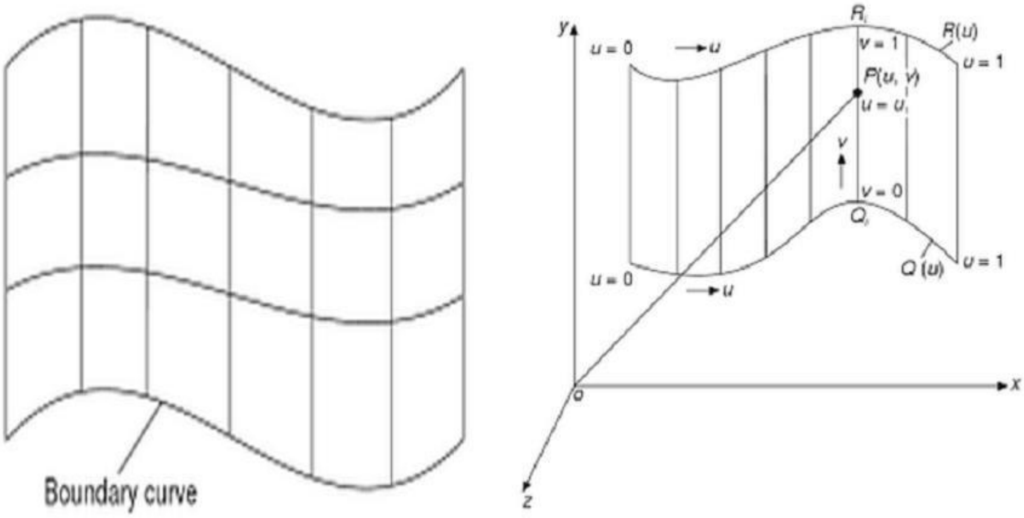

Figure 4: Parametric representation of a ruled surface [1].

3.3 *Parametric Representation of a Tabulated Cylinder*

A tabulated cylinder is a surface that is generated by moving a planar curve through a certain distance along a space curve [8].The axis of a tabulated surface is normal to the plane of the curve. A tabulated surface can be parametrically represented by the following equation:

$$P(u,v) = G(u) + v\vec{n} \qquad 0 \le u \le u_{max} \qquad 0 \le u \le u_{max}$$

In the above equation, G (**u**) is a wireframe entity, **v** is the length of the cylinder and **n** is the cylinder axis. The process of formation of a tabulated cylinder is shown in figure 5 below.

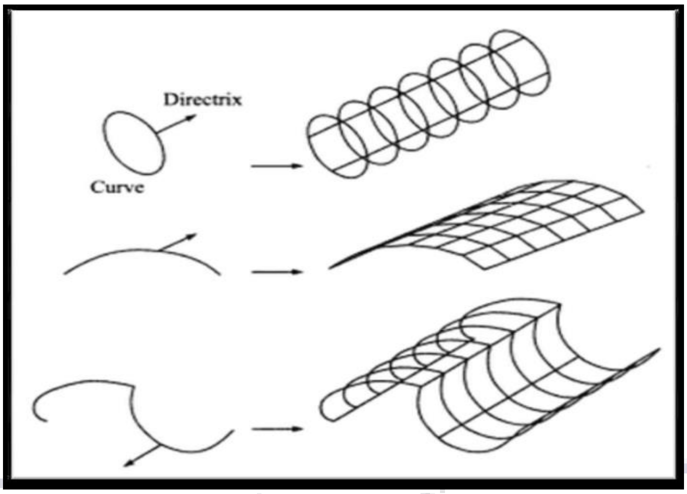

Figure 5: Formation of a Tabulated Cylinder [8].

3.4 Parametric Representation of a Surface of Revolution

A surface of revolution is formed by rotating a planar curve about the axis of symmetry at a given angle. The resulting surface is symmetrical. Therefore, this technique is usually used when modelling components that have axial symmetry [8].Generally, any space curve can be rotated about a fixed axis at a particular angle to form a surface of revolution. Examples of surfaces of revolution include cylindrical surfaces, spherical surfaces, ellipsoidal surfaces, torus, paraboloid, hyperboloid, and cones among others. Each of these surfaces hasitsown parametric equations but the general parametric equation for a surface of revolution is shown in the equation below:

$$P\,(u, v) = r_z(u)\,Cos\,[v\boldsymbol{n}_x] + r_z\,(u)\,Sin\,[v\boldsymbol{n}_y] + z\,(u)\,\boldsymbol{n}_z,$$
$$0 \le u \le 1, \qquad 0 \le v \le 2\pi$$

it is assumed that Z-axis is the axis of rotation. The formation of a surface of revolution is illustrated in figure 6 below.

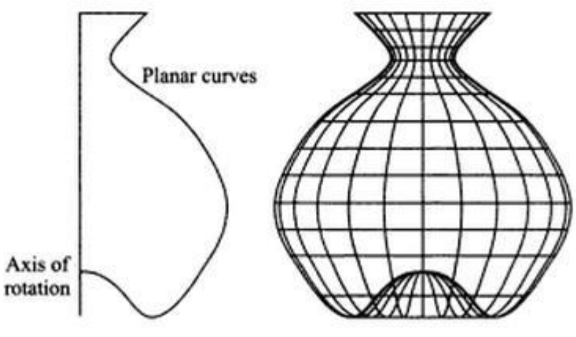

Figure 6: Formation of a Surface of Revolution [8].

4. *Parametric Representation of Freeform Surfaces*

Freeform surfaces are usually described by a rectangular set of control points and a mathematical model that defines the surface formation [9].In general, freeform surfaces can be modeled by either interpolation or approximation. When modeling a surface by interpolation, the surface passes through the control points. In this study, the surface does not necessarily pass through all the control points.

4.1 Parametric Representation of a Hermite Bi cubic Surface

A hermite bicubic surface is generated using hermite cubic splines going in two separate directions [9].These splines interpolate to finite number of control points to generate the surface. These surfaces are very useful in finite element analysis as well as image processing.

The parametric equation of a hermite bicubic surface is shown below.

$$P(u,v) = \sum_{i=0}^{3} \sum_{j=0}^{3} Cij\ ui\ vj\ ,$$
$$0 \le u, v \le 1$$

The hermite bicubic surface is illustrated in figure 7 below.

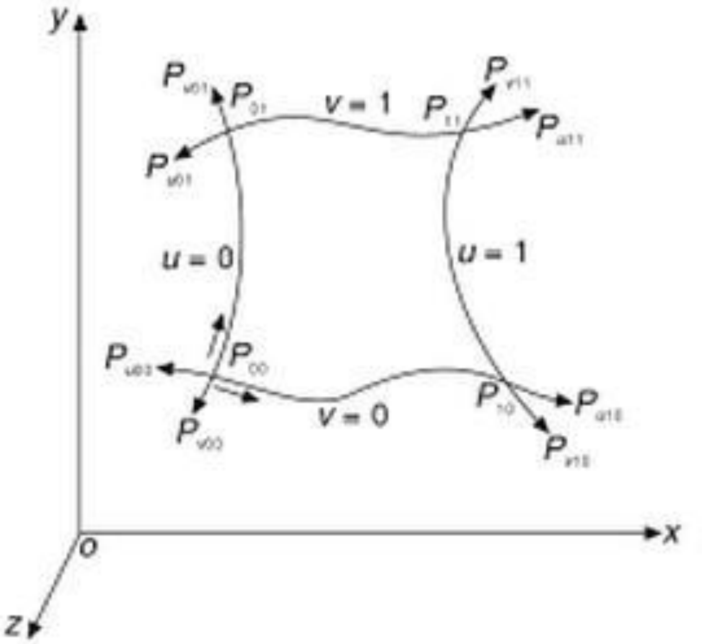

Figure7: Parametric Representation of a Hermite Bicubic Surface [9].

4.2 Parametric Representation of a Bezier Surface

A Bezier surface is a transformation of a Bezier curve. It allows twists and kinks in the surface [9].A Bezier surface has a set of 2-D control points denoted as $P_{i,j}$. in this study ,**i**' lies between **0** and **m** while , **j**' lies between **0** and **n**. The parametric equation of a Bezier surface is :

$$P\,u,v = \sum_{i=0}^{m} \sum_{j=0}^{n} B_{m,i}(u)\, B_{n,j}(v)\, P_{i,j}\,,$$

$$0 \le u, v \le 1$$

P (u, v) is any point lying on the Bezier surface while $P_{i,j}$ are control points. The main advantages of Bezier surfaces are that they are easy to use and can be generated using any order of the Bezier curve. A Bezier surface is illustrated in figure 8 below.

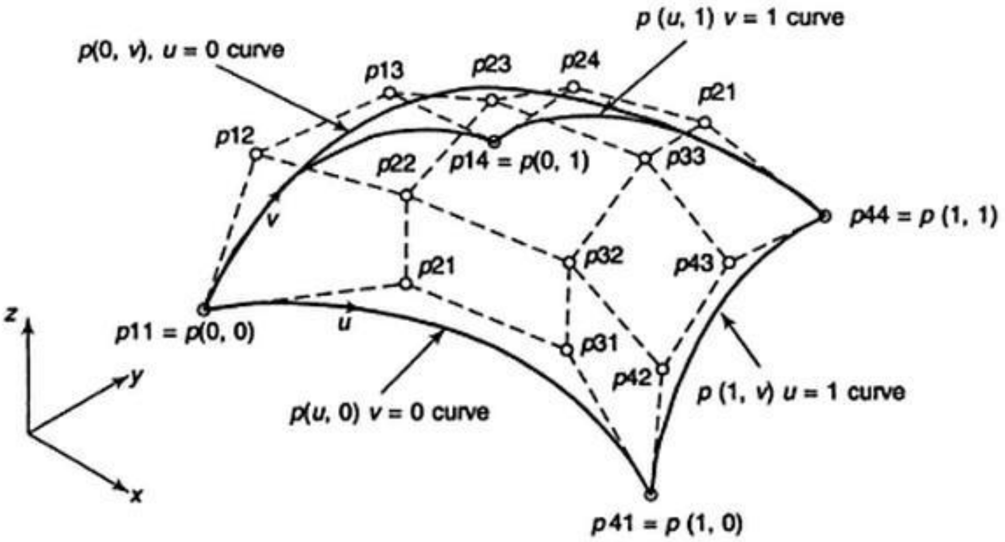

Figure 8: A Bezier Surface Patch [4].

4.3 Parametric Representation of a B-Spline Surface

B-spline surfaces are generated from B-spline curves. This surface does not pass through all data points and has the capability to yield smoother contours than Bezier surfaces. Furthermore, B-spline surfaces allow for local control of the surface [10].A B-spline surface is described by (m+1) x (n+1) set of control points and its equation is shown below.

$$P\,(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{n} P_{ij}\, N_{i,k}\,(u)\, N_{j,L}(v)$$

$$0 \le u \le u_{max}\,,\ 0 \le v \le v_{max}$$

In the above equation , **P (u, v)** is any point lying on the B-Spline surface, **K** defines the degree in u-direction while **L** defines the degree in v-direction. A B-Spline surface is shown in figure 9 below.

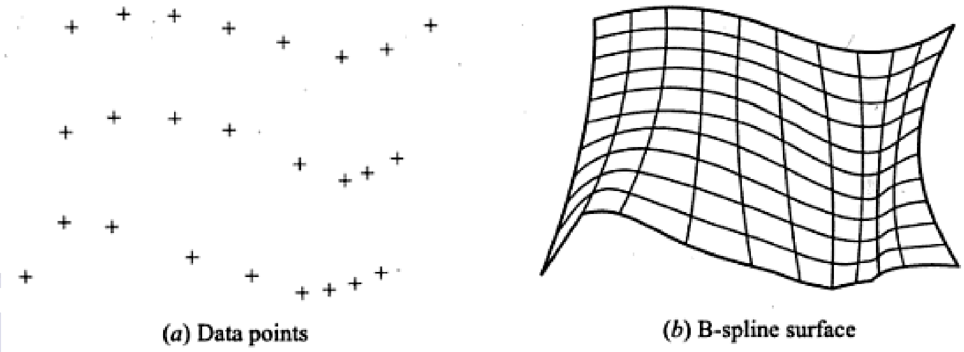

Figure 9: B-Spline surface [11].

4.4 Parametric Representation of a Bilinear Surface

A bilinear surface is generated by linear interpolation of four corner points in two separate directions (u, v) [12]. The points may either be in the same plane or in different planes. The **u** and **v** make lines at certain intervals hence producing surface visibility of a bilinear surface shown in figure 10 below.

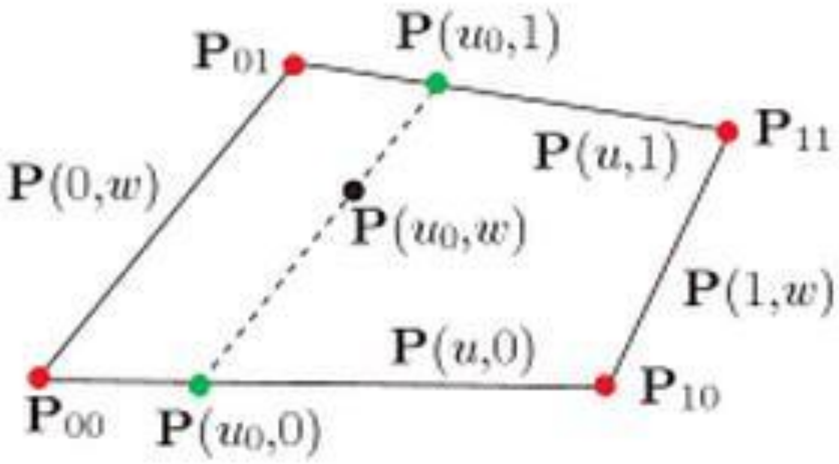

Figure 10: A Bilinear Surface [12].

This surface is very useful in 2-D finite element analysis. When carrying out finite element analysis, the component is defined by numerous bilinear surfaces known as the elements. These surfaces are formed after joining various points on the component's geometry. These points are referred to as nodes. It is important to note that bilinear surfaces have limited applications. This is due to their rigidness and limited smoothness. The parametric equation of a bilinear surface is:

$$P\,(u, v) = (1 - u)\,(1 - v)\,P\,(0{,}0) + u\,(1 - v)\,P\,(1{,}0) + (1 - u)\,P\,(0{,}1) + uvP\,(1{,}1)$$

This equation is valid for… $0 \leq u, \quad v \leq 1$

4.5 Parametric Representation of a Coons Patch

A coon's surface or coons patch is created by interpolating four bounded curves [13].Coon's surfaces can be easily created and they follow boundary curves. Because of their simplicity, they are used in many two dimensional CAD software like AutoCAD for creating surfaces between four boundaries. However, they are limited in the sense that they are unable to control internal shape, they are inflexible and cannot be used to produce very smooth surfaces. For instance, it is almost impossible to model an aero plane fuselage using coons patch.

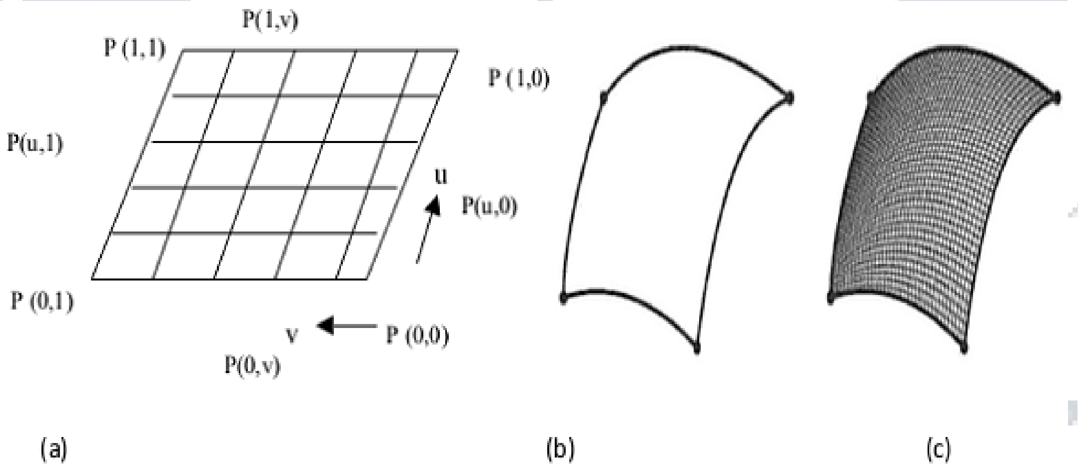

Figure 11: Coons patch [13].

The parametric representation of Coon's patch is shown in the following matrix equation.

$$Q(u, v) = [(1-u)\;u\;\;1]\begin{bmatrix} -P(0{,}0) & -P(0{,}1) & P(0, v) \\ -P(1{,}0) & -P(1{,}1) & P(1, v) \\ P(u, 0) & P(u, 1) & 0 \end{bmatrix}\begin{bmatrix} 1-v \\ v \\ 1 \end{bmatrix}$$

4.6 Parametric Representation of NURBS (Non-Uniform Rational B-Splines) Surface

NURBS can be used to describe any shape ranging from two dimensional shapes to extremely complex three dimensional freeform surfaces and solids [14].The NURBS geometry is usually defined by four main parameters namely: degree, knots, control points and an evaluation rule. The degree refers to a positive integer. The degree of NURBS curve or surface determines its shape. The parametric equation of NURBS surface is given below.

$$P(u,v) = \frac{\sum_{i=0}^{n}\sum_{j=0}^{n'} W_{i,j}\, B_{i,d}(u) B_{j,d'}(v) P_{i,j}}{\sum_{i=0}^{n}\sum_{j=0}^{n'} w_{i,j}\, B_{i,d}(u) B_{j,d'}(v)}$$

5. PTC Creo Parametric Features

PTC Creo Parametric has a high reputation for its capability for creating complex models. PTC Creo Parametric has significantly simplified freeform modelling and has enabled designers to quickly create freeform models using sub-divisional modelling [15].Freeform surface modelling in PTC Creo Parametric is done in the Style and Freestyle environments. The style and freestyle environments are grouped together to form the freeform surfacing environment. Freestyle modelling environment enables multilevel sub divisional modelling which gives the designer more control over the surface [15].Therefore, the designer is able include finer details on the surface without changing the original shape.

IV. ANALYSIS METHODS

In order to carry out a thorough evaluation of the freeform feature of PTC Creo Parametric adopted two different analysis methods were used. The first evaluation method was a Heuristic Evaluation. This analysis identified the weaknesses and strengths of the user interfaces of the selected software. The second evaluation technique involved modeling of a detergent bottle in the selected software. In order to understand how the heuristic evaluation is conducted, an overview of this evaluation technique was provided .

1. Heuristic Evaluation

A heuristic evaluation of a CAD system is usually carried out by having an experienced CAD user looking at the interface of the selected software and identifying the weaknesses and strengths of the interface. Heuristic evaluation is the best tool to analyze CAD software when time is limited. There are developed a general checklist with guidelines that can be followed to easily carry out a heuristic evaluation on the user interface of any software.

These guidelines are usually regarded as rules of thumb when conducting a heuristic evaluation of an interface. The main guidelines are briefly described below.

A. Provide Feedback (Visibility of System Status)
B. Match between System and the Real World (Speak the Users' Language).
C. User Control and Flexibility.
D. Consistency and Standards.
E. Recognition Rather Than Recall.
F. Flexibility and Efficiency of Use.
G. Aesthetic and Minimalist Design.
H. Provide Sufficient Error Messages.
I. Error Prevention.
J. Help and Documentation.

2. *Evaluation of the Freeform Feature in PTC Creo Parametric 2.0*

The freeform features in PTC Creo Parametric 2.0 were evaluated using heuristic evaluation, personal experience, available literature and by actual modeling of a detergent bottle. In PTC Creo Parametric 2.0, freeform modeling begins from a primitive shape. In this case, a bottle image was imported into the sketch and used to provide the outline for the desired bottle shape. After inserting the image, a sphere was selected to serve as the primitive shape. The image and the sphere are shown in figure 12 below.

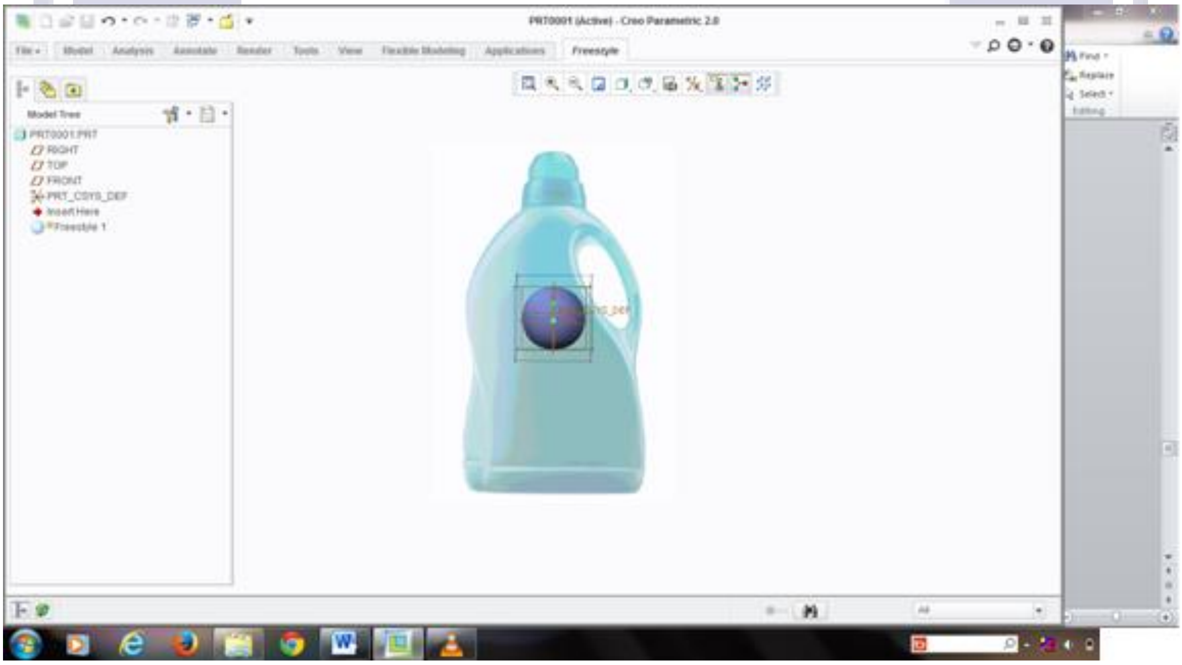

Figure 12: Initial step in Freeform Modelling in PTC Creo Parametric

Using the control meshes, edges, faces and vertices were selected appropriately to manipulate the entire shape. Some of the manipulations used include extruding of faces, dragging of faces and edges, connecting faces, planar zing faces, and scaling among others. various steps are shown in figures 13, 14, 15 and 16 below.

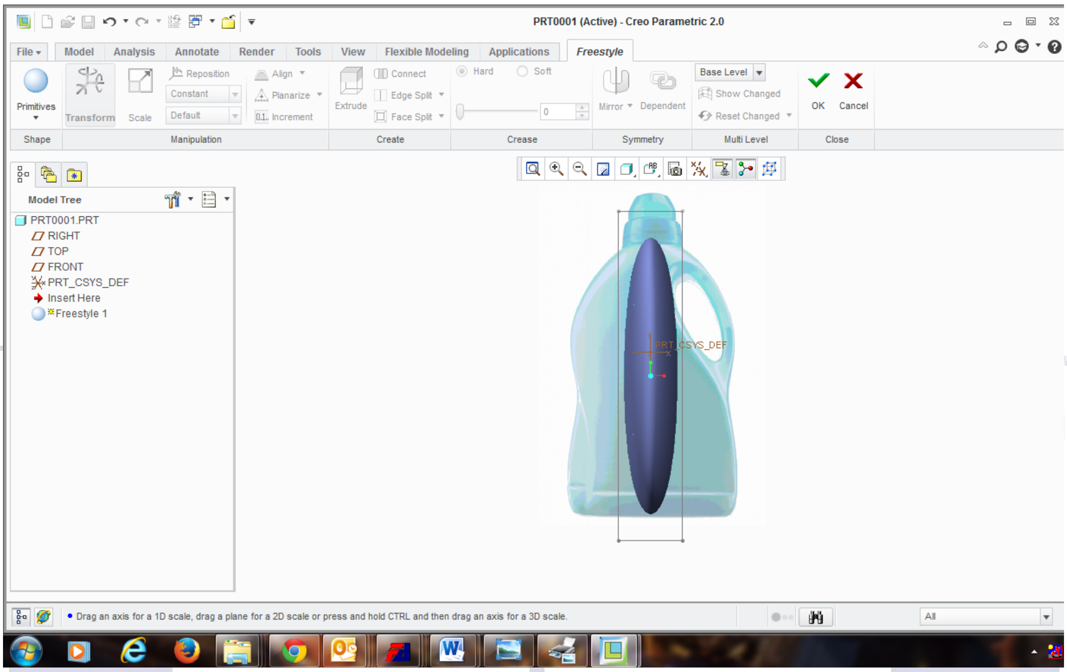

Figure 13: A scaled Primitive Feature (Sphere)

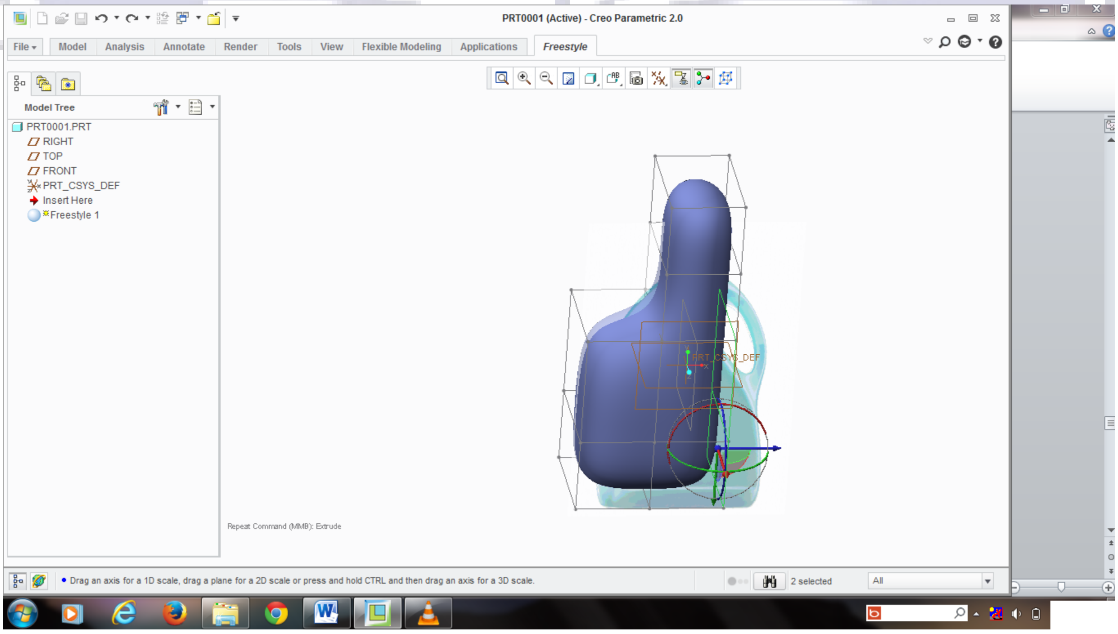

Figure 14: Freeform Modelling Process

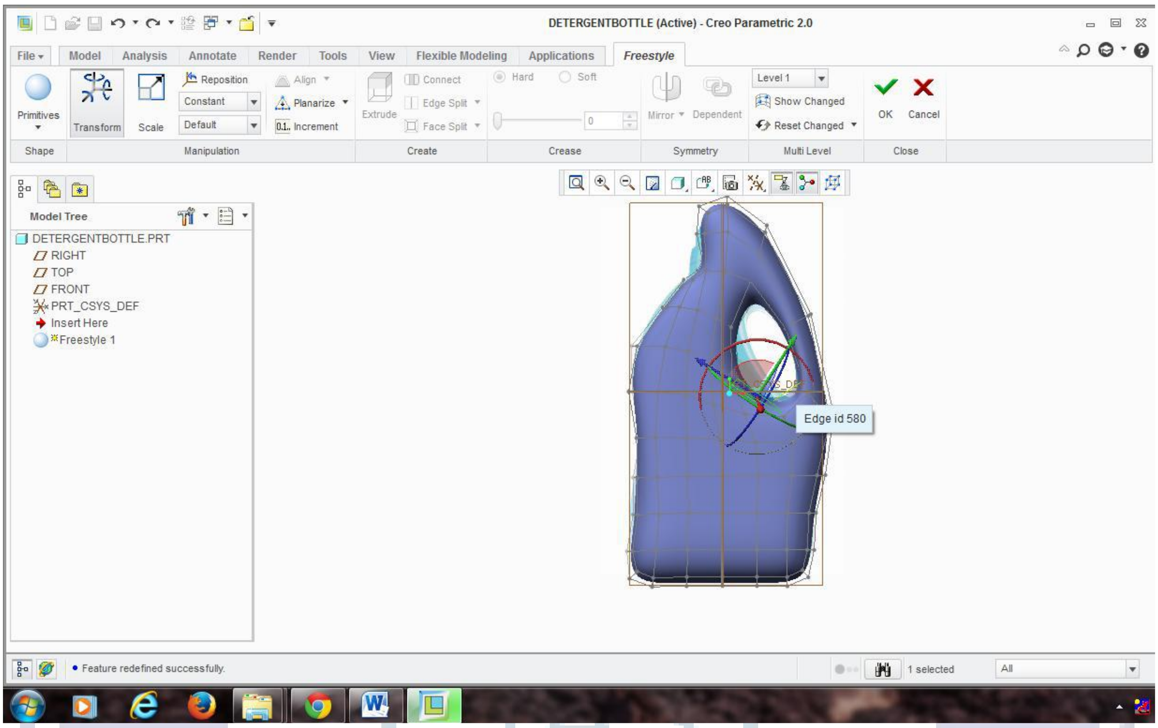

Figure 15: Partly Modelled Bottle

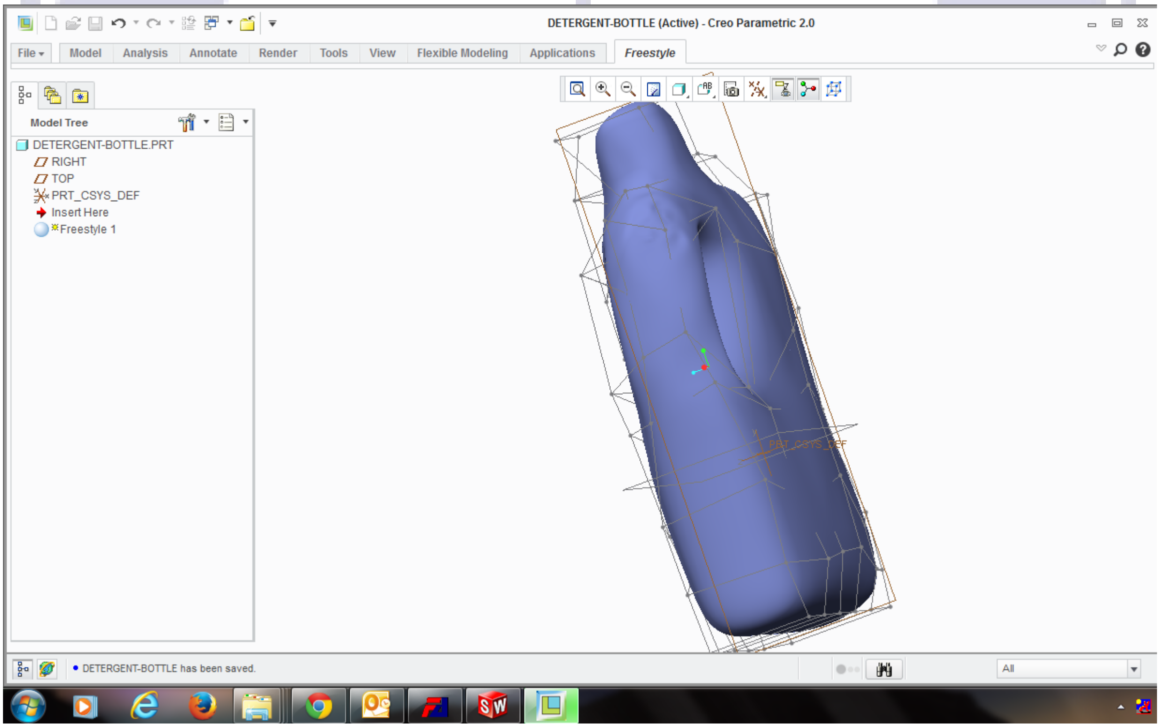

Figure 16: Final Model of the Bottle

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I. RESULTS AND DISCUSSION

These are the results for both heuristic evaluation and actual modeling of the detergent bottle.

1. *Heuristic Evaluation of the Freeform Feature in PTC Creo Parametric*

A. ***Provide Feedback (Visibility of System Status):*** When opening a model in PTC Creo Parametric within the freestyle environment, the system provides feedback to indicate that there is an operation going on. However, the feedback is not accompanied by text message to indicate the specific process in progress. There is also no indication of the approximate time remaining to open the model. Nevertheless, there are instances when the system provides sufficient feedback information. For example, when the system fails to import an image, the system displays that it could not load the sketch image as shown in figure 17 below.

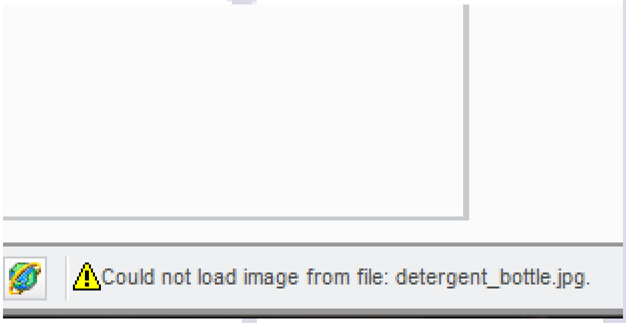


Figure 17: Feedback in PTC Creo Parametric

It is also important to note that right clicking on the model while in the freestyle environment does not give any feedback. Feedback is only provided when the right hand button is held for about 2 seconds. Instead of informing the user that the action is not supported and provide alternative actions, it gives no feedback. The overall feedback in the freestyle environment of PTC Creo Parametric 2.0 is poor.

B. ***Match between System and the Real World (Speak the Users' Language):*** When a function has been selected, the system displays text in English at the bottom left corner explaining the next step to perform. The description of the icon is only given in English and it cannot be edited to any other language. Although this is a weakness, there is a fair match between the system and the real world.

C. ***User Control and Flexibility:*** The style and freestyle environments are excellent in terms of user control and flexibility. These environments have clearly marked „do‟ and „undo‟ icons and they provide clearly marked exits. These exits points can easily be identified by a novice user.

D. ***Consistency and Standards:*** Words, phrases, actions and appearance of icons in the style and freestyle environments conform to the industry's standards. Moreover, each icon on the toolbar has a unique function. This consistency characterizes all the other modules in PTC Creo Parametric which are useful in facilitating a complete product development.

E. ***Recognition Rather Than Recall:*** The style and freestyle environments in PTC Creo Parametric are well designed to reduce the user's memory load. This is evident from the fact that all the icons are self-explanatory. icons also have pictures that are easy to remember and provide a hint about the function of the icon. This is illustrated by the scale, mirror and extrude icons shown in figure 18.

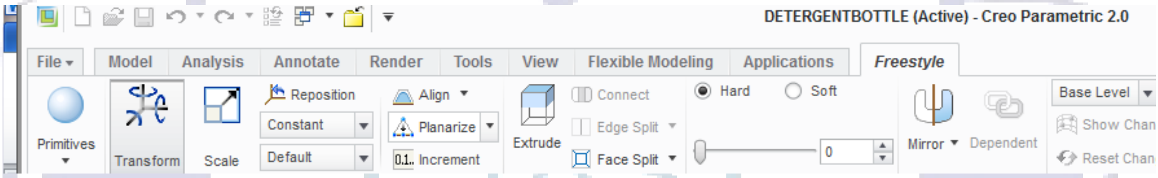


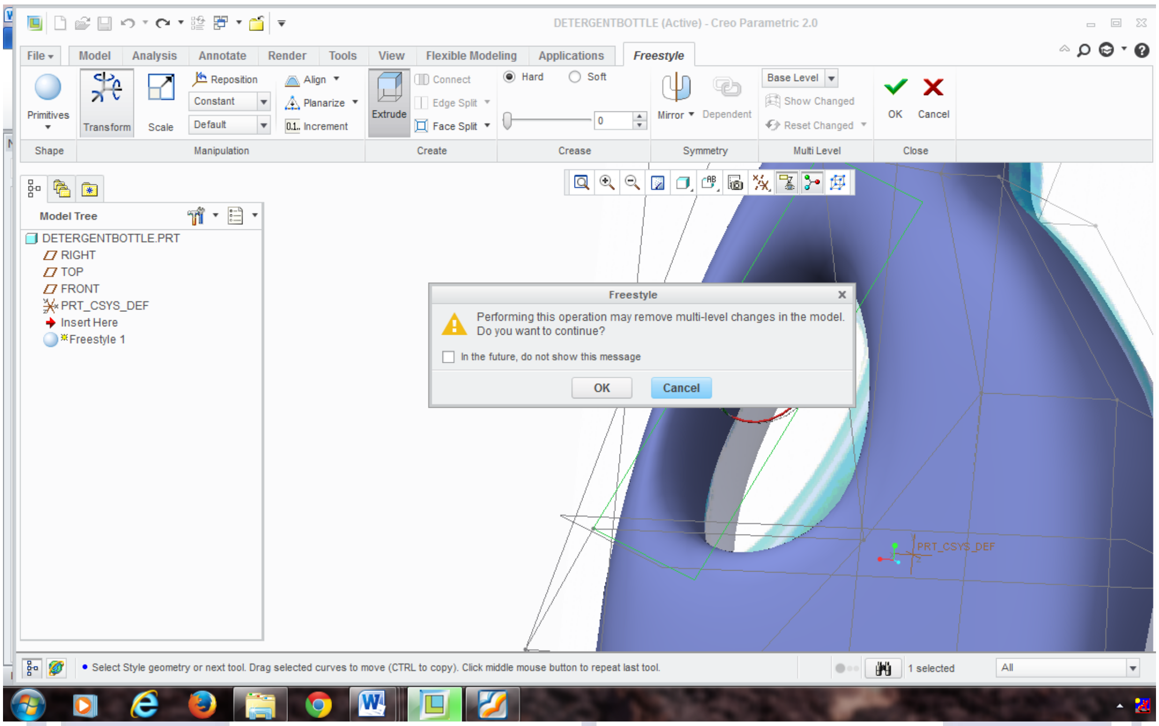
Figure 18: Simplicity of Icons in the Freestyle Environment of PTC Creo Parametric

F. ***Flexibility and Efficiency of Use:*** The freestyle and style environments of PTC Creo Parametric can accommodate different levels of skill. Novices can find the freeform feature easy to use because there are self-explanatory icons on the toolbar. The environment allows for stepwise execution of various functions.

G. ***Aesthetic and Minimalist Design:*** The freeform environment in PTC Creo Parametric is well designed to ensure that only important information is displayed. The messages below the icons are also as short as possible. The function of the icon is further explained in a text message when a curser is passed over the icons. The interface is also compact and aesthetically sound.

H. ***Provide Sufficient Error Messages:*** In case of errors, PTC Creo Parametric provides sufficient errors messages. The error messages are able to help the user to identify the errors, diagnose them and recover from them. The error messages are usually expressed in a simple language and mentions the specific error and suggest the best solutions.

I. ***Error Prevention:*** The freeform environment in PTC Creo parametric has the ability to prevent frequent occurrence of errors. Error-prone conditions are also reduced. If execution of a certain function has the potential of severely distorting the original model, a warning message is provided before the function is executed. This is evident from the error message generated when the user attempts to extrude inappropriate faces. The system displays a message that reads, performing this operation may remove multi-level changes in the model. Do you want to continue?" The message is shown in figure 19.



19: Error prevention in PTC Creo Parametric

J. ***Help and Documentation:*** Freeform environment in PTC Creo parametric has an effective help function that not only addresses functions that can be executed in this environment but also in other environments within this software. In addition to the help function, there is also online help via the Learning Connector.

VI. CONCLUSION

The main aim of this study was to evaluate the freeform feature of PTC Creo Parametric. A comprehensive literature review was carried out to understand freeform modelling concepts. A detergent bottle was selected as the case part and was modelled in PTC Creo Parametric. There was also a heuristic evaluation of the interfaces of these CAD program. The freeform feature in PTC Creo Parametric gives the user more flexibility and control over the shape of the model, hence allows for easy creation of complex-shaped models. The freeform feature in PTC Creo Parametric is the best tool when creating complex-shaped models from scratch. PTC Creo parametric require improvements in order to make freeform modelling more attractive. The freeform feature of PTC Creo Elements

2.0 significantly reduces the time required to create a model, it cannot work in isolation. For instance, some of the surface details on the original bottle could not be easily introduced on the CAD model using the freeform feature in PTC Creo Parametric. To include these details, other surface modelling operations must be performed.

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