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INFLUENCE OF GEOMETRIC FEATURES ASSOCIATIVITY OF CAD CLASS MODELS ON THE PROCESS OF THEIR UPDATING – COMPARATIVE ANALYSIS

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Abstract

This article deals with the topic of one of the most important features of modern CAx class systems – associativity. The term refers to the ability to form relations (links) between two or more objects (in terms of their selected features), and with the consequence creating an associative (linked) three-dimensional model. The author pays special attention to the very process of creating relations between objects, as it has a key impact on the structural stability of CAD class models, and thus on their susceptibility to possible modifications. To show that not all associativity brings a positive effect, the author presents two examples of its implementation. In order to emphasize the influence of the method of linking individual elements, both examples are based on the same 3D model – a thin-walled part with a positioning pin. That means the geometric form of the default part is the same, whereas only relations of the individual objects of the 3D model change. In the first scenario, correctly defined relations between objects make that the positioning pin offset does not affect the initial design conditions. The second scenario shows an incorrect implementation of associativity, as a result of which the same operation of positioning pin offset gives non-compliance with the initial design conditions and with the consequence an undesirable change in its geometry.

The article is an attempt to draw attention to the fact that the associative structure of 3D models is not always equal to the optimal solution. Only the well-thought-out nature of associativity allows to use all its advantages.

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Introduction

The efficiency of application of CAx systems is a fundamental matter when considering on the topic of optimization of the design process. The choice of the right software and defining the methodology of work in this software can significantly contribute to accelerating the project implementation, reducing its costs, and increasing the quality of the final product. According to the author, it should be assumed that a modern CAx class system is an extensive tool that allows to create optimal engineering solutions. That means the sources of any difficulties and problems when creating 3D models and when implementing further changes to these models should not be attributed to the properties of the CAx system used. Moreover, the difficulties arising in the design process should not be excused by its limitations (WEŁYCZKO 2005). Assuming that the earlier mentioned selection of software was made in accordance with the nature of the designed products, the constructor of these models should be responsible for the cause of the vast majority of problems arising in working with CAD models. „The vast majority", because it should be also assumed a certain minimum margin of error on the software side. On the other hand, the optimal structure of the 3D model creates a kind of synergy with the individual geometric features from which it is created, which in turn harmonizes with the architecture of the CAx system in which it was created. As a result, the occurrence of a possible error should be an indication to the constructor that there is a possibility to optimize the „3D model structure tree".

At this point we begin to dive into more detailed construction terminology. Let us therefore focus on the most important issues from the point of view of the discussed topic.

Materials and Methods

To better understand what an associativity is and why CAD class models use it in a better or worse way, it is worth to explain two additional terms.

The first of them is – already mentioned in the previous chapter – the **3D model structure tree**. Each 3D model in the CAD environment consists of hierarchically functions following one after another, which are saved in the form of a "tree" structure during its creation (Fig. 1).

The tree in its intent is supposed to record the history of this process, and with the consequence, to help constructor to identify the way of creating 3D model. What is important, that the 3D model structure tree created in this way allows to modify this model by editing, adding, or removing selected functions which create that tree (ŚWIACZNY, WYLEŻOŁ 2020a, 2020b). The modification

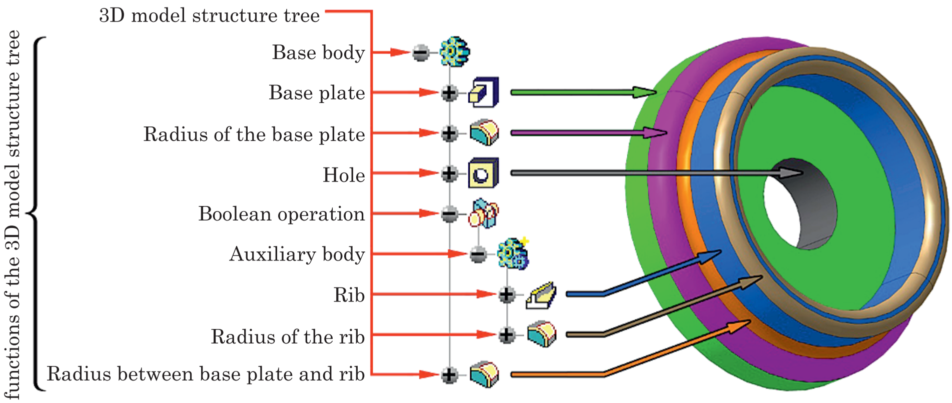

Fig. 1. An example of 3D model structure tree

process is laborious and error-prone because constructors have to repetitively edit and update CAD models. For example, the creation of cooling-holes/channels of injection mold entails several time-consuming and manual tasks, such as creating holes, maintaining the connections among them to form circuits. If these tasks can be partially automated, the design time can be reduced considerably and hence the productivity enhanced (MA, TONG 2003). The art of effective creation of CAD class models consists in preparing the structure tree in such a way that the modifications of these models, inevitable in the construction process, require a minimum involvement of the constructor (WEŁYCZKO 2005).

During adding further functions of the 3D model structure tree, the constructor uses the basic feature of the modern CAx class system – **parameterization** – to characterize them. Parameterization (which is the second term worth mentioning) is a feature of CAx systems that allows to define the created geometric objects by assigning them parameters such as dimension, logical value, material, or text. Modification of values of these parameters modifies the geometric objects to which they have been assigned. Moreover, by using these parameters, thanks to methodology implemented in modern CAx systems called Knowledge-Based Design (or Knowledge-Based Product Development), it is possible to create formulas, rules, checks, relations, and finally to create catalogs of 3D models (WYLEŻOŁ 2002). The term parametric design in engineering is a process of designing with parametric models in a virtual surrounding (a “parametric CAD system”) where geometrical and parameter variations are natural. In design a parameter is an entity that can hold a value to control geometrical components or relations between geometrical components. Parametric design implies the use of declared parameters to define a form (SALEHI, MCMAHON 2009).

The simplest example of using parameterization can be process of contour dimensioning. The rectangle shown in Figure 2 has a certain length and width. Their modification modifies the rectangle (Fig. 3).

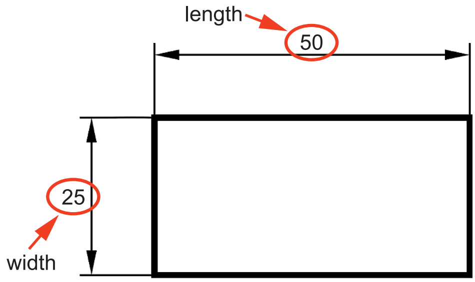

Fig. 2. Dimensioned rectangle as an example of using parameterization

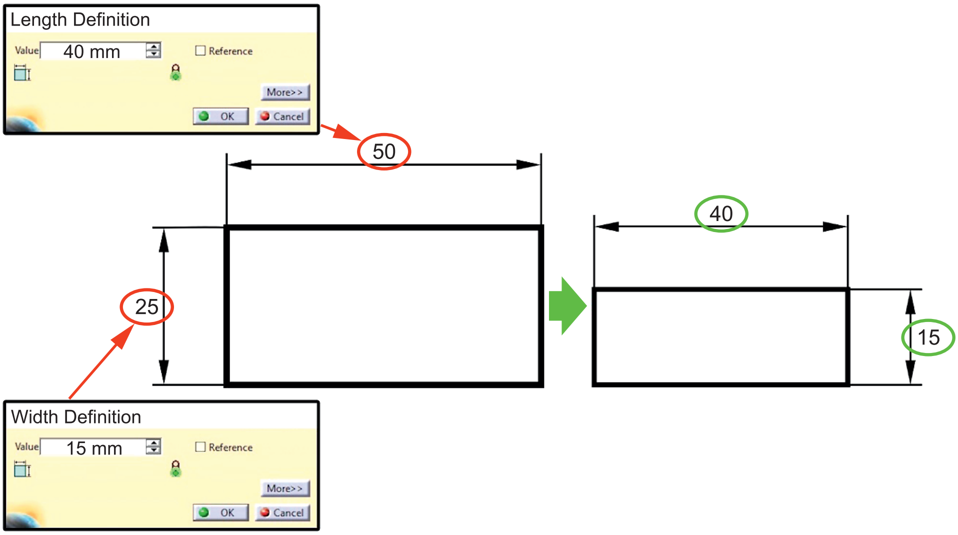

Fig. 3. Modification of rectangle parameters which causes the change of its geometry

What then is **associativity** itself? In most general, associativity connects the two functionalities described above and means the ability to create links between previously defined parameters, but also between individual geometric features, and even between individual 3D models or their assemblies. Related to the design process, associativity describes the fixed relationship between geometrical entities and objects (SALEHI, MCMAHON 2009). If, for example, the previously defined rectangle (Fig. 3) is used to create a cuboid, it will turn out that these two objects will be linked to each other in such a way that the rectangle will be superior to the cuboid, and the cuboid will be subordinate to the rectangle (Fig. 4). In the environment of constructors such relation has been adopted to be called as „Parent – Child", and the relation itself – as associativity. Associativity means that the modification of "Parent" causes the modification of his "Child (Children)" as well.

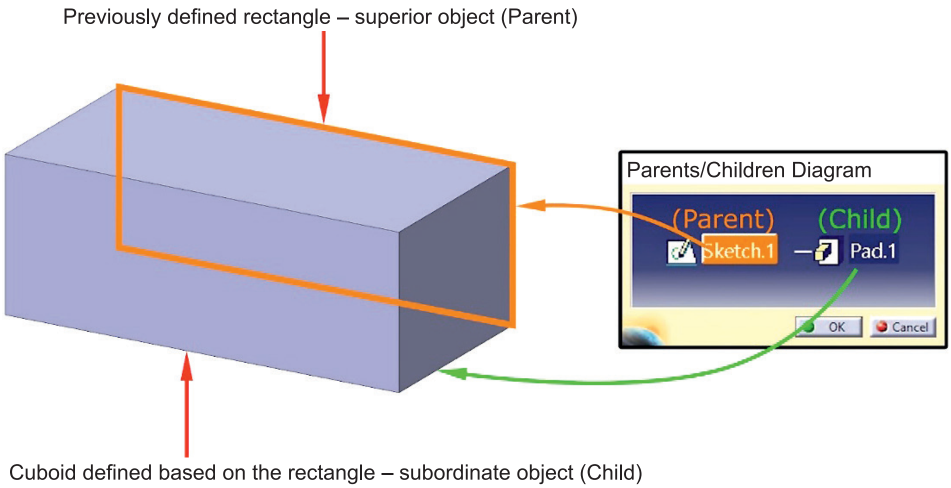

Fig. 4. Link between the superior rectangle (Parent) and the subordinate cuboid (Child)

Links can exist between two or more objects, which in the 3D model structure tree take the form of the previously mentioned functions. It causes, that with time they form a kind of net of connections (Fig. 5). It is important that the constructor is supposed to have full control over this net so that it forms a coherent and logical whole.

Thus, **parameterization** enables the characterization of the functions used to create the **3D model structure tree**, and **associativity** enables to assign relations between these functions and parameters by forming a net of connections. If the CAD system allowed only parametrization of single geometric elements without the hierarchical structure of 3D model and without „Parents/Children" links, propagation of construction changes from Parent elements to their dependent elements (Children) would not be possible. Therefore, subsequent geometric elements of the 3D model are created in relation to the elements defined earlier (WEŁYCZKO 2010). The availability of geometry associativities are a preliminary requirement for the effective support of the constructor (PÄTZOLD 1991). Let us see how two different nets of connections can affect the implementations of the same modification of an exemplary three-dimensional model.

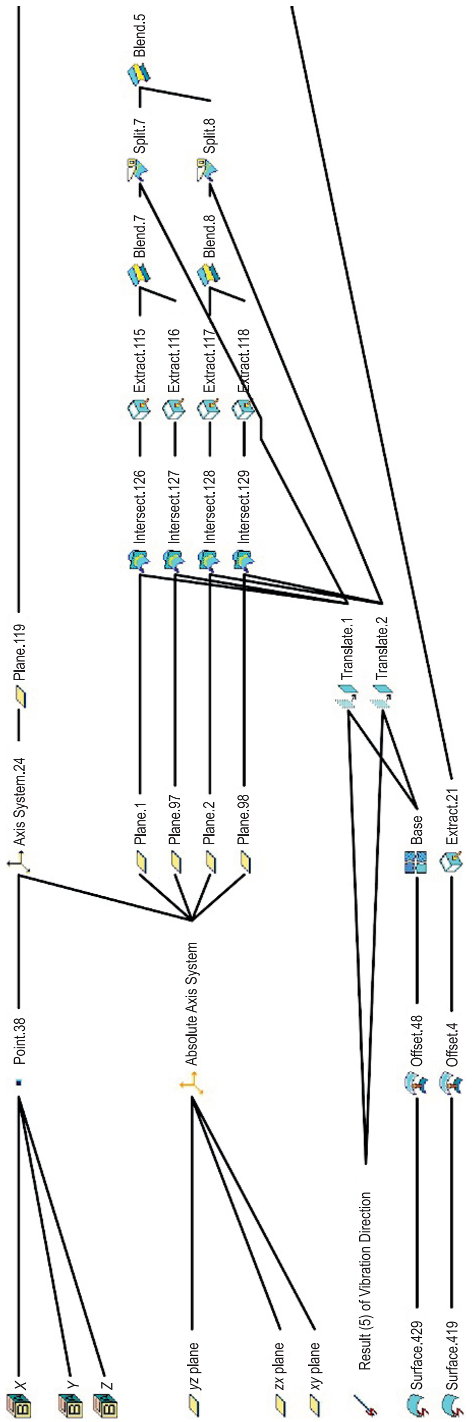

Fig. 5. The exemplary net of connections between functions of 3D model structure tree

Results

Let us imagine a situation in which constructor has a task to design a positioning pin of a thin-walled element (Fig. 6).

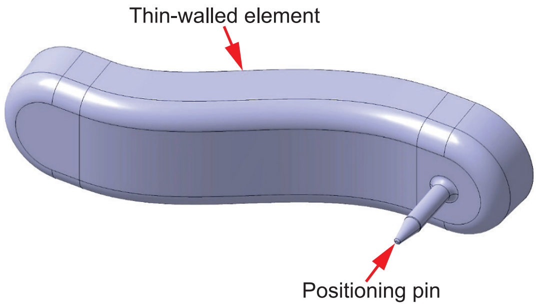

Fig. 6. 3D model of the thin-walled element with the positioning pin

The seemingly easy process requires a moment to think about how to connect the individual design features of the designed pin so that it meets the functional requirements, and its subsequent modification is as simple and short as possible.

The constructor defined the following initial **design conditions** (Fig. 7):

– the axis of the positioning pin is parallel to the mounting direction of its mating element;

– the height of the positioning pin (dimension *A*) is between the intersection of its axis with the front face of the base body at point *X* and its vertex;

– the length of the tapered pin head (dimension *B*) is measured from its top.

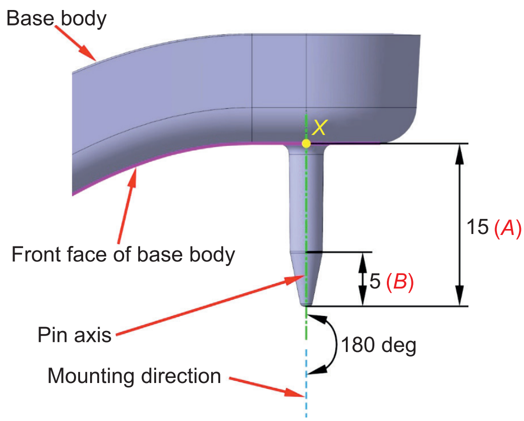

Fig. 7. The initial design conditions defined by the constructor

Scenario I

In Scenario I, the fulfillment of design conditions was achieved by the following links of geometric features:

– in the definition of the pin axis, the mounting direction has been indicated – link with the line „Mounting direction" (Fig. 8);

– the surface defining the height of the positioning pin has been defined by offset from the surface perpendicular to its axis formed at the point *X* of intersection of this axis with the front face of the base body – link with the surface „Extrude.3" (Fig. 9);

– the surface defining the length of the tapered head has been defined by offset from the surface defining the height of the positioning pin – link with the surface „Offset.1" (Fig. 10).

After completion of the work, the constructor received a request from the customer to move the positioning pin to the center of the designed element. Additionally, due to problems with the assembly of the mating element, a decision was made to extend the pin by 5 mm. The previously assigned associativity

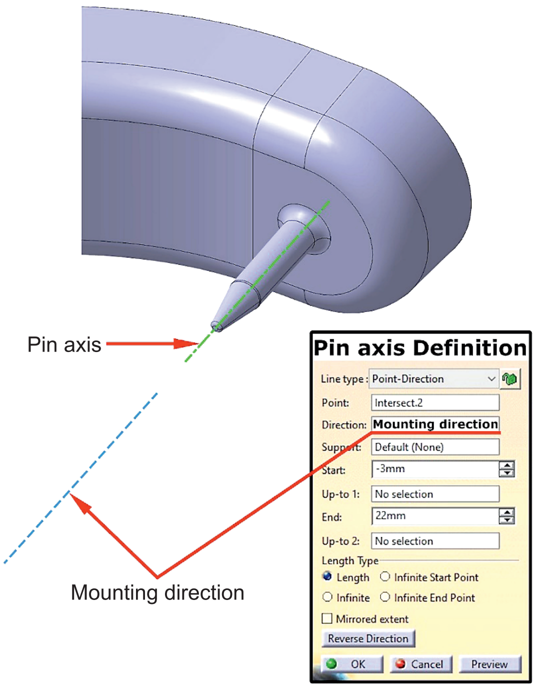

Fig. 8. Definition of the axis direction of the positioning pin

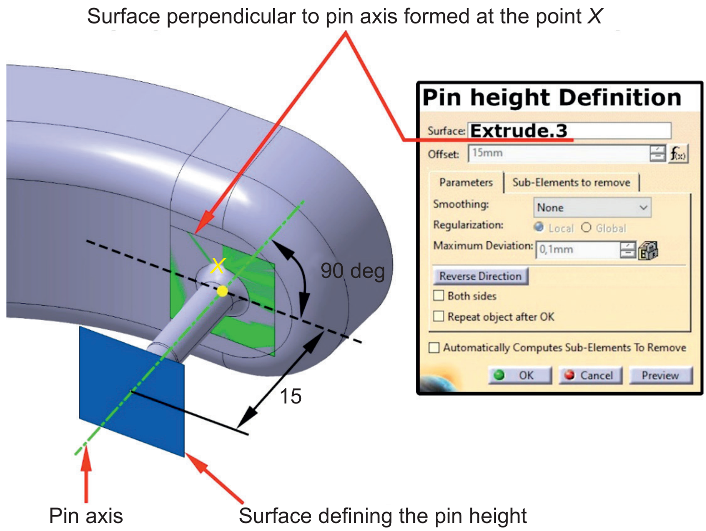

Fig. 9. Definition of the height of the positioning pin – Scenario I

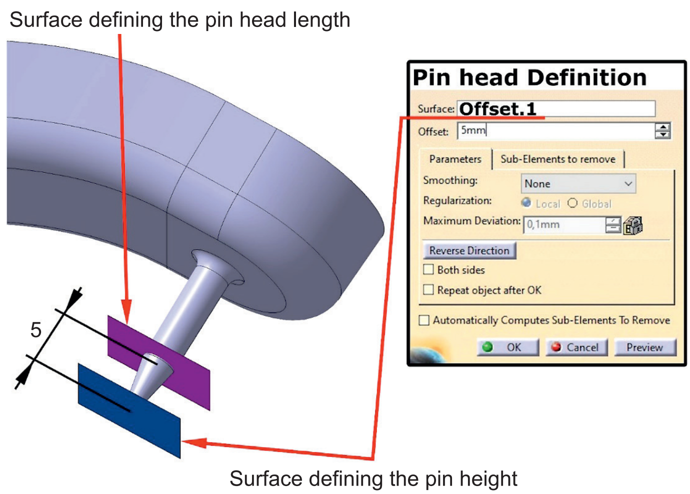

Fig. 10. Definition of the length of the tapered pin head – Scenario I

to the geometric features caused that the required modification came down to implementing new coordinates for the position of the pin and changing the parameter of its height. Properly created links ensured that the initial design conditions were maintained, and the time needed to implement the modifications was limited to a minimum (Fig. 11).

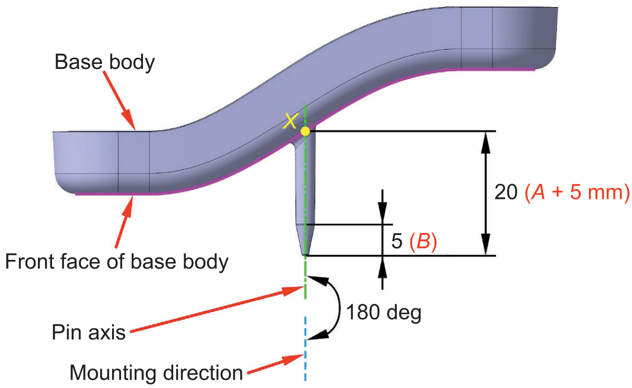

Fig. 11. Modification of the positioning pin that meets the initial design conditions due to properly created links – Scenario I

Scenario II

Now let us imagine an alternative scenario for the same task, in which the fulfillment of the last two design conditions was realized by assigning a different associativity to the geometric features:

– similar as before – in the definition of pin axis, the mounting direction has been indicated – link with the line „Mounting direction" (Fig. 8);

– the surface defining the height of the positioning pin has been defined this time by offset from the front face of the base body – link with the surface „Extrude.1" (Fig. 12);

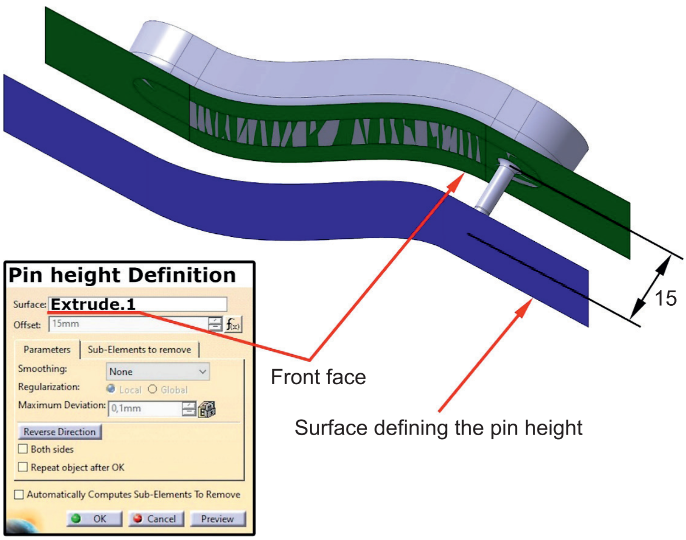

Fig. 12. Definition of the height of the positioning pin – Scenario II

– the surface defining the length of the tapered pin head has been defined this time by offset from the surface perpendicular to its axis formed at the point *X* of intersection of this axis with the front face of the base body – link with the surface „Extrude.3" (Fig. 13).

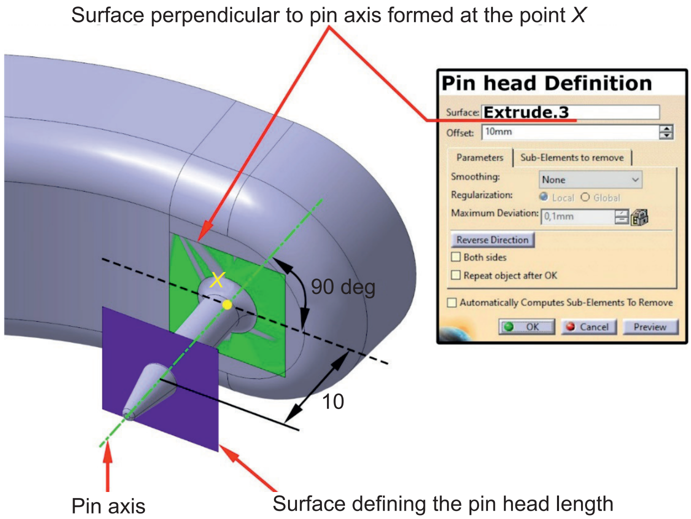

Fig. 13. Definition of the length of the tapered pin head – Scenario II

The positioning pin in the initial location maintains the same dimensions as in the original scenario, so it would have seemed that everything is fine, because the pin geometry meets the initial design conditions (Fig. 14).

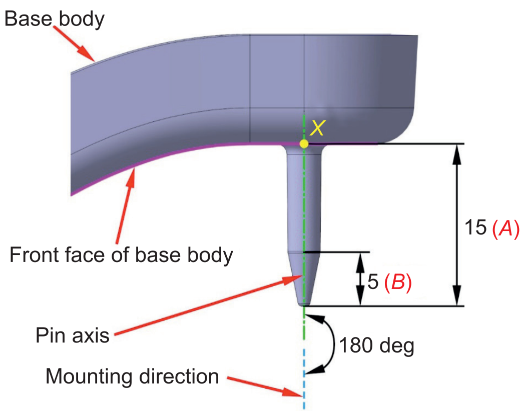

Fig. 14. The positioning pin built based on alternative links and meeting the initial design conditions – Scenario II

However, let us see what happens when the constructor receives the same request from the customer to move the pin to the center of the thin-walled element and to extend it by 5 mm.

After changing the coordinates for the position of the pin and its height, it turns out that:

– the pin axis is still in line with the mounting direction of the mating part – associativity correct (Fig. 15*a*);

– the pin height is different from its height in the original scenario. This is because of the link creating the height, which is based on the offset of the front face of the base body. This surface in the central region is not flat and is not perpendicular to the axis of the pin (which is parallel to the mounting direction). Although the Offset.1 is equal to the nominal height of the pin (15 mm), its curvature makes that the elongated pin (by 5 mm) is even longer – associativity incorrect (Fig. 15*b*);

– the length of the tapered pin head is different from its height in the original scenario. This is because of the link creating the length, which is based

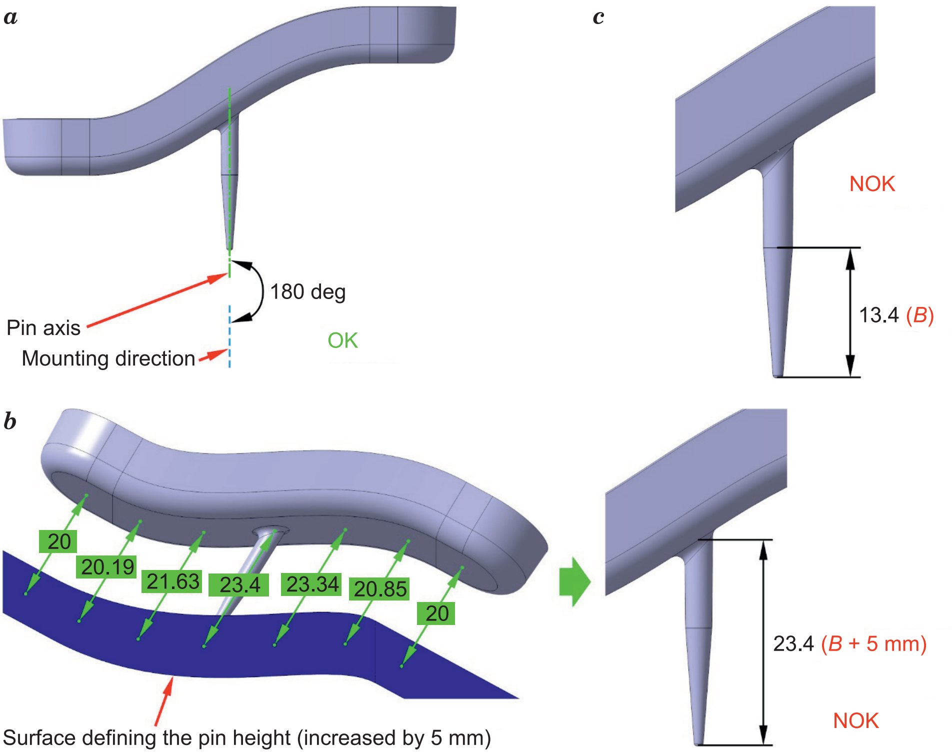

Fig. 15. The result of the positioning pin modification which does not meet all initial design conditions due to an incorrect selection of links – Scenario II: *a* – the pin axis is parallel to the mounting direction – associativity correct, *b* – wrong height of the positioning pin – associativity incorrect, *c* – wrong length of the tapered pin head – associativity incorrect

on a perpendicular surface created in point *X*. The link did not "react" to the elongation of the pin, the height of which was dependent on the other geometric feature – associativity incorrect (Fig. 15*c*).

As a result, the time needed to implement the customer's requests will extend, because the constructor must either "manually" modify the values of the parameters of individual geometric features to meet the initial design conditions (which is not recommended) or consider the optimization of the links that he implemented to the 3D model structure tree.

Discussion

The described scenarios revealed three guidelines that constructor should follow when creating associativity between elements:

– links should ensure the feasibility of the final product in terms of technology and assembly (**first design condition**);

– links should enable future design changes (**second design condition**);

– links should reflect the dimensions important from the technological and functional point of view (**third design condition**).

The capabilities of CAx systems in area of creating associativity between parameters, geometric features or individual three-dimensional models are very extensive. The links in the above example refer only to a few basic elements and certainly do not exhaust the possibilities of their further implementation. The net of connections of the same positioning pin could be defined in a number of other ways. Important is to choose the optimal one, considering the knowledge and experience of the constructor creating a given element.

According to the author, an apparently simple modification of the exemplary three-dimensional model shows the essence of the problem that may occur during the implementation of associativity in CAD class models. Interestingly, an experienced constructor, for example, by creating a complex 3D model structure tree of a car bumper, deals with issues related to correct or incorrect associativity, which are remarkably similar like those described above. It is obvious that as the structural complexity increases, the net of connections between the functions of such a tree also grows. However, contrary to appearances, the principles of its creation remain the same. Design intent captures the purpose of the modeling order and geometry chosen by the constructor. In modern parametric-based CAD systems, this is often stored within CAD features such as axis systems, planes, sketches, extrudes, revolves, and sweeps. It is also stored in the associations relating the CAD features together. By selecting features during the modeling process, an experienced constructor implicitly defines the important parameters of the model, which is extremely important to manufacturing and future updates to the design (Staves et al. 2017). So, does an experienced constructor always know the optimal system of links and relations, regardless of the complexity of the element he creates? The answer to this question is not as simple as might think. On the one hand, the design habits developed over the years of work significantly help to choose the most effective solutions. At a certain stage of his professional development, the constructor realizes that geometrical complexity of the designed element ceases to be relevant in the context of the difficulty of its creation. On the other hand, it should be remembered that 3D models in parametric systems are generated in a manner analogous to programming, in which we also have an ordered set of commands. Therefore, it can be said that the CAD system “triggers” a construction procedure that results in a geometric model (WEŁYCZKO 2011). That means there is almost always possibility of improving the “construction program”, and the “optimal solution”, in the case of the implementation of associativity, is a state to which the constructor should constantly strive.

Conclusions

1. An associative model is the model which is built of parameters and geometric features linked to each other. Not all connections have a positive impact on the efficiency of creating 3D models, and in extreme cases, they may prevent further work in their creation and lead to the need to rebuild them.

2. Only a well-thought-out and logically coherent set of links between elements creates a structure susceptible to easy and quick modification of the 3D model, and with the consequence contributes to the greatest extent to the effectiveness of its creation.

3. When starting work on a 3D model, the constructor should take into account the implementation of well-thought associativity from the very beginning so as to avoid unwanted complications in the structure of this model. Lack of an initial analysis of the created object in terms of its functional requirements or possible future changes and relying only on CAD modeling habits may hinder the associativity implementation at a later time.

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