A Preliminary Scheme for Automated Grading and Instantaneous Feedback of 3D Solid Models

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Abstract

A scheme for the grading of CAD solid model files is presented. The method rests on the original drawing's relationship to the design intent. By testing whether the solid model's parameters agree with the original drawing dimensional values in a one-to-one correspondence, the changeability and robustness of the model is quickly ascertained. The method is currently used manually but will be tested in a computer application in the future. The method will allow consistent, non-subjective, and repeatable scoring and fast turnaround of feedback.

Introduction

With some basic training and enough time, today's CAD packages allow most anyone to create a 3D solid model that appears to look like some specific object. At our university, we are seeing more and more first-year students that have quite a bit of experience in one or more CAD packages and can seemingly reproduce some requested geometry quite well. However, even though the various solid models may all look the same at first glance, major differences result when one or more parameters of the model are altered. When the design intent of the original drawing is not successfully transferred into the 3D solid model, the model will break or unexpected results will occur when a specific solid model parameter is changed.

For instance, Figure 1 shows nine student-created solid models that closely resemble the requested part. A few students got the view orientation incorrect and the bottom center model has an oversized center boss, but basically the geometry looks correct in all nine models. If the three parameters controlling the thickness, length, and width of the base plate are changed, we expect to see what is shown in Figure 2. In this case, the end brackets travel with the ends of the revised base plate and stay centered. The center boss and pattern of threaded holes travels with the top surface of the base plate and stays centered. This type of change is a valid real-world occurrence and is a test of model robustness and changeability. Others have called it "model flexing" (Ault, 2013) or "dynamic modeling" (Wiebe, 2003).

However, when the three parameters are changed in the set of nine student-created models, we see many issues (Figure 3), including: end brackets failing to stay with the ends of the base plate (2X), end brackets failing to stay centered (4X), center boss failing to stay centered (4X), hole pattern not staying centered (6X), disappearing center boss (1X), and the appearance of an extra threaded hole (1X). Depending on the drawing specifications, some of these behaviors could be correct – but not by the particular drawing that was provided.

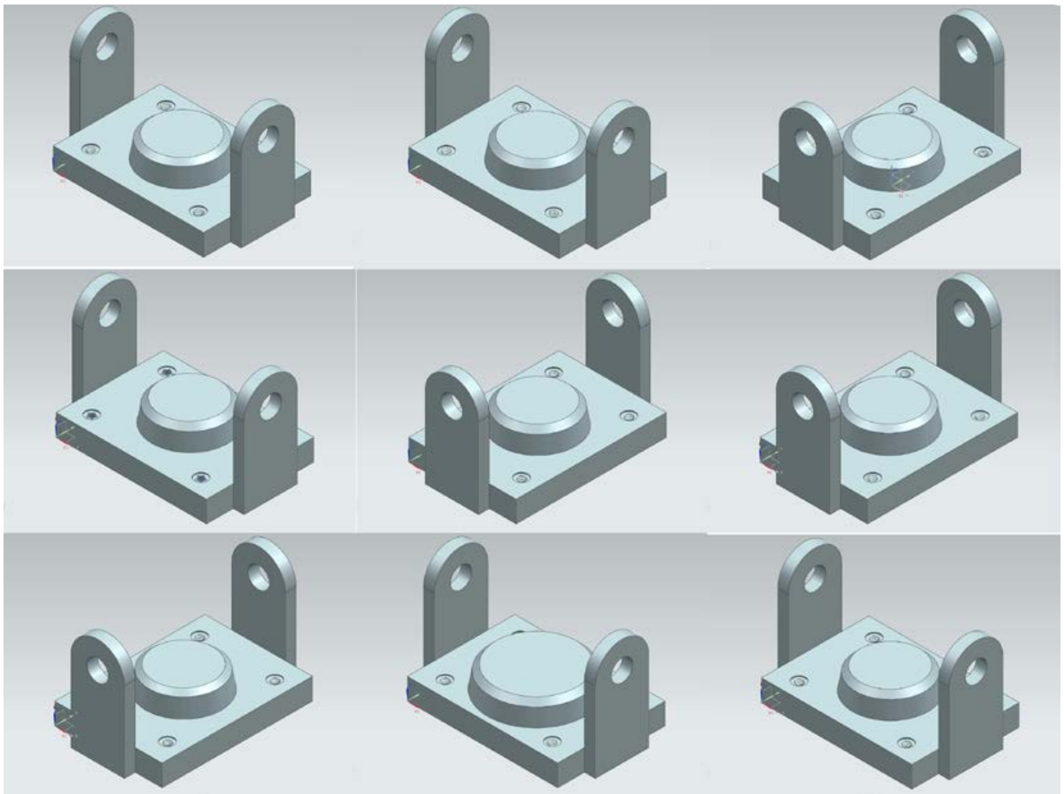

Figure 1. Nine student-created solid models that closely resemble the requested part.

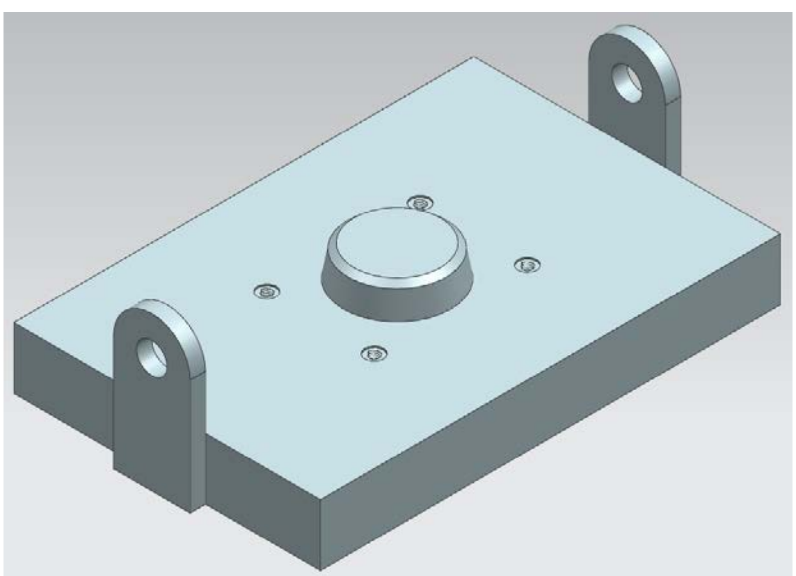

Figure 2. Desired result if the base plate is made thicker, longer, and wider.

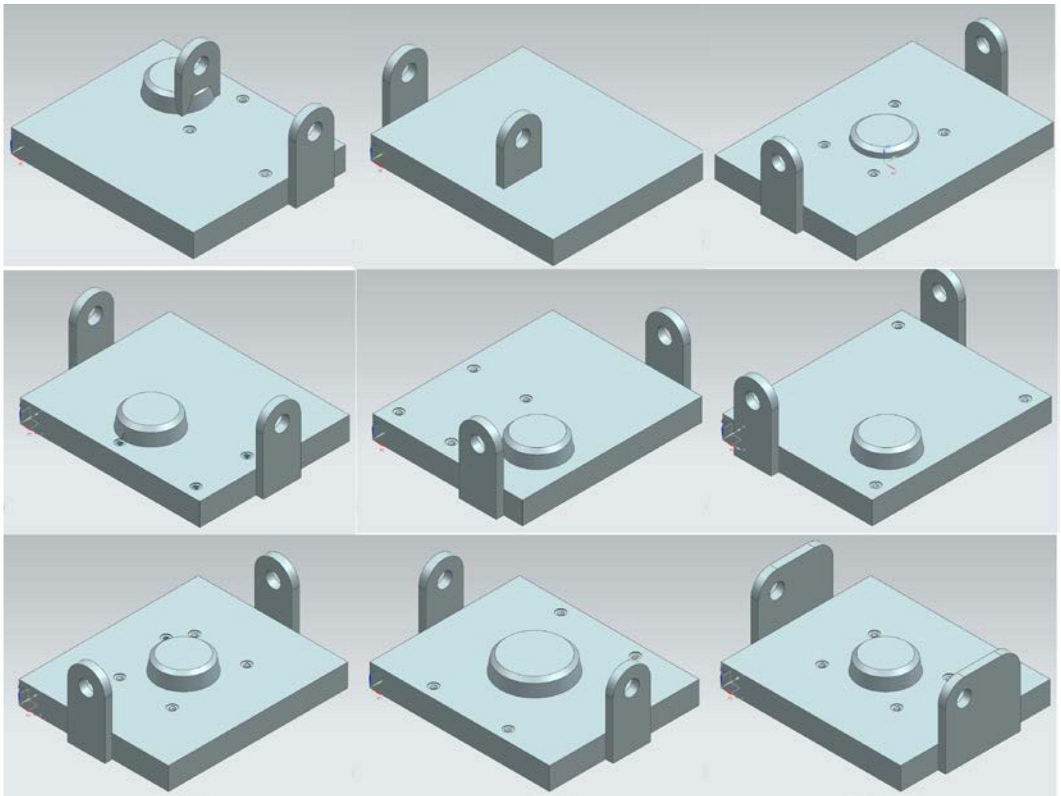

Figure 3. The same nine student-created models collapse during base plate alteration.

The Original Drawing Controls the Design Intent

In Figure 4, the same geometry is specified in two different ways. The left sketch shows the top view of the Chapter 8 Tutorial 2 part from Tickoo's NX 6 book (2009) and the right sketch shows the same part in his NX 7 book (2010). The left sketch communicates that the 80x40 hole spacing is important, while the right sketch communicates that all four holes are 10 mm from the adjacent corners. Also, in the left sketch the brackets are centered by default, while in the right sketch the brackets are 50 mm from the right edge (centered now, but not necessarily after changes in the base plate). While they produce the same static geometry, changes in base plate size will cause dramatically different results in models based on these two drawings. Neither drawing is necessarily incorrect: either drawing may be valid for a particular design intent.

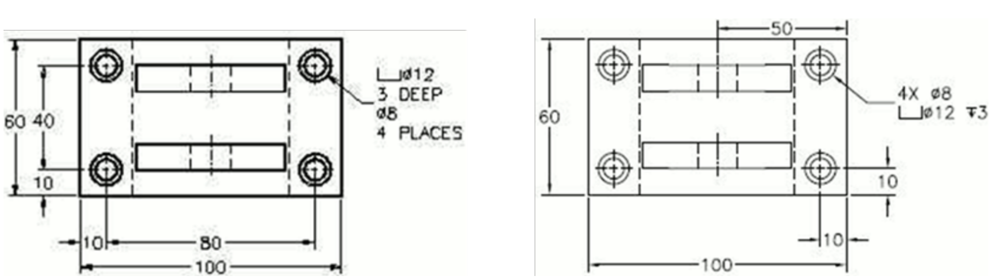

Figure 4. Two different specifications of the same static geometry.

The successful transfer of design intent from original drawing to solid model means that the solid model is changeable and robust. Some simple guidelines can be useful in specifying what makes a robust, changeable solid model.

Guidelines for transferring design intent from drawing to solid model

- Use only dimensions that come directly from the original drawing. For instance, if a diameter is specified, use it; if a radius is specified, use that. In this way there will be a one-to-one correspondence between all the parameters in the original drawing and those in the solid model.
- If extraneous dimensions were provided in the drawing, then over-constrained sketches will result. In this case, the design intent may be ambiguous and the drafter will have to make some choices. At first glance, reference dimensions can appear to be extraneous dimensions, but they are generally ignored in the creation of a solid model and they will resurface when a drawing is produced from the solid model.
- The creation of new dimensions that are not on the original drawing are not usually required if the design is non-ambiguous. Computing dimensions that are not on the original drawing requires mathematics, which is rarely needed or wanted in solid modeling when provided with a clear, non-ambiguous drawing of a part. Usually nothing more than the original drawing dimensions and properly selected geometric constraints are all that is needed. In the rare instances when math is needed, perhaps as in specifying the angular spacing of holes in a circular pattern, let the CAD software do the math by entering an angular pitch of 360/5 (if permitted) rather than entering 72 degrees. In this way should the design need to be changed to support six uniformly spaced holes, the 5 just needs to be changed to 6, rather than a new math computation being carried out. Surprisingly, the math computation is too often incorrect and the hand entering of a number can lead to confusion about where the number came from.

Proposed Scheme for Automated Grading

Students can have difficulty in grasping the concept of design intent. Frequent and clear feedback from the instructor appears to be the best method for guiding the student into the habit of creating robust solid models that contain the design intent of the original drawing. A significant issue is that manual evaluation of a moderately complex part may require examination of the part tree and several fully constrained sketches. The time spent evaluating the model and then writing up some useful feedback for the student has been reported to be as little as six minutes (Ault, 2013), but even after teaching our solid modeling course ten different times, I find that providing a grade and useful feedback can take two to three times longer than that. Additionally some homework assignments can involve up to three different models. As others have noted (Ault, 2013 and Baxter, 2003), the automated grading of digital CAD models can eliminate the variability and subjectivity of individual graders and offer feedback very quickly, perhaps in real time. But before moving to computer-assisted grading we need to define exactly what we are looking for. Although it can process instructions very fast, the computer can only do what we tell it.

The scheme rests on the importance of the dimensions in the original drawing to define design intent. All the key dimensions of the model are "parameterized", or set as "driving dimensions". Early in the semester, the models are quite simple with perhaps just a few individual parameters. Towards the end of the semester, models can contain up to 30 individual parameters.

For any assessment, the instructor creates a solid model and from it a drawing that shows all critical parameters. It is advantageous that each parameter value is a unique numerical value. In evaluating student work, the set of student parameters is examined. All parameters equal to zero are ignored. We also ignore the "2" in parameters showing a divide by 2 (such as p5=225/2), likely to represent a radius when diameter was provided on the drawing (not ideal but acceptable: the diameter dimension would be greatly preferred), or used to center objects (geometric constraints would be preferred), or to create half lengths. In rare cases, issues arise to confound this proposed method. For instance, sometimes NX converts to intermediate variables, such as angular pitch when count and span were provided. The sorted student's list of parameters is compared to the sorted set of instructor parameters. There should be a one-to-one correspondence between the two parameter sets.

Model Scoring

In general, all models start with a perfect score of 100 and deductions bring the score down. The deduction scheme proceeds as follows:

- Every repeated parameter is given a weight of 2. Repeated parameter usually occurs when insufficient geometric constraints are applied. Repeated parameters limit the changeability of the model and the model will break or do unexpected things upon alteration.
- Dimensional parameters used in the model but not from the original drawing are given a weight of 1. This occurs when insufficient geometric constraints are applied. Alternatively, it may come from specifying a radius when a diameter was specified.
- Dimensional parameters that are in the original drawing but absent in the model are given a weight of 2. When parameters are absent, they are impossible to change.
- Additional deductions occur if there are any unconstrained sketches, errors or conflicts in the part tree, or unnecessary complexity in the model.

The grade is computed by deducting from 100 the three products of the sums with the corresponding weight factors and a scaling value:

$$\text{Grade} = 100 - \text{val}\ [\ \text{nRepeats} \times 2 - \text{nNew} \times 1 - \text{nAbsent} \times 2\ ] - \text{otherDeducts} \qquad (1)$$

where,
nRepeats is the total number of repeated parameters
nNew is the total number of parameters that were not in the original drawing
nAbsent is the total number of parameters that are absent the original drawing
otherDeducts represents other deductions based on visual inspection of model or part tree

For complex models, val may be a low number in the range of 2 points. For simpler models, the deductions can be scaled up by setting val to a larger number.

Conclusions

The general scheme is independent of CAD software used. While most schemes verify a subset of included parameters or test the model robustness with just a few parameter changes, this scheme checks that all parameters are present. If all parameters are present in a one-to-one mapping between drawing and model, then the model is almost certainly robust and changeable. Without examination of the actual model geometry, comparison of parameter sets is all that is needed to evaluate the models in the bulk of the cases. An important distinction of this approach is that a model is not judged by the modeling approach. Models can be created by many different techniques and are all good as long as there is a one-to-one correspondence between the parameters in the original drawing and those in the model.

Future work will involve implementing this scheme in a computer program. Ideally, this work would involve direct reading of the NX file with the prt extension. More likely, it will require access to the NX program. A center of gravity check will be easy to do when interacting with an application programming interface (API) and will be useful in determining if the proper orientation of the part was provided.

References

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