Identifying and Quantifying Inefficiencies Within Industrial Parametric CAD Models

Andrew LINDSAY[1], Abby PATERSON and Ian GRAHAM
Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough LE11 3TU, UK.

Abstract. Parametric CAD software is the primary development tool for the design engineer during the product development process. However, industrial parametric CAD models are often constructed in a manner that leads to inefficiencies during subsequent product development activities. Despite the availability of Model Quality Tools (MQTs) these 'poor' quality models can currently only be accurately identified using time-consuming and subjective auditing from experienced users. The project aims to develop a more robust solution, using measurable part characteristics, to predict the efficiency level of these CAD files.

Keywords. Computer-Aided Design, Parametric Modelling, CAD Model Efficiency

1. Introduction

Since its inception in the 1970's, Computer-Aided Design (CAD) and parametric CAD in particular, has evolved into the principal tool of engineering design. PTC released the industry's first feature-based, constraint-based modelling product, Pro/ENGINEER[2], in 1991. This software type, now commonly referred to as 'Parametric CAD' and marketed by many different vendors, uses parameters, constructional features, and interdependent relationships (or constraints) to develop the form needed to satisfy the requirements of the part [1]. With continual development and integration of additional functionality concerned with Computer Aided Engineering (CAE) and Product Lifecycle Management (PLM) tasks, the digital 3D form generated within a CAD modelling package acts as the foundation for a growing number of product life cycle processes [2]. As the reliance on these files expands, their importance is set to continue and increase.

Parametric CAD can be identified as a type of 'indirect' modelling software in which the final form is constructed using sequential steps recorded in a history tree format, or Model Tree (MT). The MT allows the individual steps to be viewed, modified or rearranged by the user. Each modelling step will have a different, predictable effect on the geometry, indirectly affecting how it is presented in what we will call the Geometric Interface (GI). The responsibility of the parametric CAD user is to manage the cumulative effect of modelling steps required to produce the more complex final 3D form.

The CAD software presents the information to the user in an easily digestible format, but each chosen modelling operation defines a set of equations, with an associated

[1] Corresponding Author. a.lindsay@lboro.ac.uk
[2] Rebranded to PTC Creo in 2010

number of unknowns relating to feature size, shape and position. While some modelling steps will define primitive form features, in that their results are not decomposable into smaller units, other results will have a composite effect where a number of primitive shapes will be combined for the desired outcome [3].

A geometric entity relates to anything that can be represented in the GI, from datum points and planes to complex, freeform surface entities, both for inclusion in the final form or for assistance in this task. Each modelling step requires referencing to any existing geometric entity to be positioned in the 3D environment. Automatic or manual references to geometric entities will also be used to define the appropriate measurement origins for dimensions. Any remaining unknowns in equations presented by the modelling feature controlling the size, position and shape of the resultant form are represented by parameters. Parameters can be assumed to be a modifiable value, characterized by numerical, algebraic and non-numerical expressions, and both they and references can be driven from numerous sources, such as 2D sketches, across entities constructed via different modelling steps, or even to entities exhibited in external parts.

Thus it can be seen in the parametric approach there is a collection of 'Construction' data in the MT required to define the 3D 'Geometry' entities in the GI (See Figure 1).

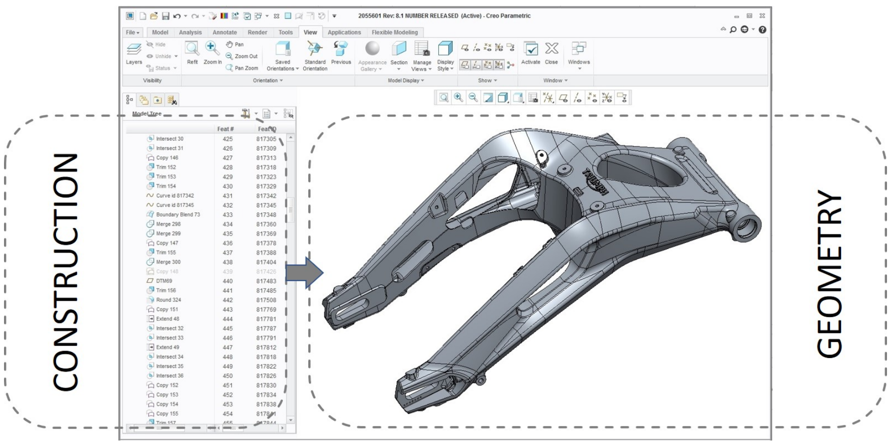

Figure 1. Parametric CAD.

It is the interdependent parameters, references and relationships that make parametric CAD so powerful. Changes to key parameters can be used to influence the entire form in a predictable and repeatable manner [4]. Therefore, we can define a robust parametric CAD model as one where construction has been carefully implemented to ensure changes occur without the need to 'fix' the model. This is an important characteristic during design development when many small changes are being implemented as the finer requirements of the design need to be balanced. However, it is especially important during design reuse when an existing model can be modified to a new design without developing a CAD model from scratch [5].

It is the powerful relationships in parametric CAD however, that are the source of its problems. Parametric CAD is a more labour intensive form of geometry creation than direct geometric manipulation, and as the complexity of the required 3D form increases, generally so do the number of modelling steps, parameters and interrelated references required to represent it. As the part becomes more complex in both 'construction' and 'geometry' data, it becomes harder to maintain its robustness and makes subsequent geometry updates difficult to predict. In a report investigating design reuse, 57% of organisations surveyed stated that model modification requires expert CAD knowledge, and 48% of organisations stated that models are inflexible and fail after changes [5].

To improve the quality of models, Model Quality Tools (MQTs) are marketed by several vendors. MQTs are powerful tools in highlighting generic mistakes, but their usefulness is limited to some more obvious errors and diversions from company standards [6]. There is currently no MQT that will analyse exactly how well a model has been constructed.

Currently a CAD model's effectiveness can only be identified by individual, time-consuming and subjective auditing from experienced users. The aim of this research is to develop a method which automatically identifies the efficiency levels of CAD models without relying on typical auditing methods. It is also proposed to examine the levels of inefficiency within a specific database of industrial parametric CAD models.

2. Defining an Effective CAD Model

Previously published works have defined the level of CAD model quality using a linguistic model [7]. The definition of morphological quality (geometrical and topological correctness) contains concepts that are measurable to specific industrial standards. However, syntactic quality (evaluating proper modeling conventions) will depend on the CAD platform being used, and semantic/pragmatic quality (considering the CAD model capable for reuse and modification) can only be measured against a specific methodology. Methodologies and strategies aimed at producing the highest quality model are continually being developed and evaluated [8], but the reality is that a 'one size fits all' approach is difficult to apply across all parametric CAD platforms, industries, companies, products and users. As the complexity of the part increases, strict adherence to methodology may actually introduce inefficiency to the part, as it is often the final geometry that will dictate the most effective constructional development.

The linguistic model is unarguably useful in pedagogical research when the route to the highest quality part needs to be evaluated. In this particular study however the author has decided to abstain from using these terms to ensure clarity for its primary industrial audience. It is the intention of this study to define the most *effective* CAD model as that which requires the smallest investment of time required to perform all design development tasks, irrespective of the route taken (i.e. is efficient).

The best CAD users have knowledge of many methodologies and strategies, and their relative merits, but also know when to deviate from a methodology when advantageous. Further, these users understand that the quality level of a CAD part is related to the requirements demanded of it. During the complete product development process there are often occasions when a high quality model is unnecessary, or provides minimal added value.

It is the assumption of this work that the users in an industrial setting are, broadly speaking, experienced enough to know the various methodologies, and take the route to producing models in a manner they feel the most effective.

3. Design development processes

With any design process using CAD, the goal is to produce a digital 3D form that satisfies the requirements in the specification. 3D parametric CAD activities can be characterized as those associated with Design Intent and Data Exchange.

3.1. Design Intent

The term 'Design Intent' is a broad one whose definition will depend on context. Often, even in a similar field of research, different definitions will exist for the same term. In general, design intent can be defined as the underlining reason for an object to exist. Intent justifies a design decision, but modern CAD applications have limited ability to allow the user to question design intent directly [9]. While it is true that there is no explicit definition of design intent within the CAD model, parametric history-based software will give some indication of the design decisions taken by the user in the construction of the model. The increased distribution of parametric CAD systems has modified the definition to a point where there is considerable overlap between the concept of design intent and design alteration. The most succinct description pertinent to this research then can be summed up by 'readability, alterability and usability of models' [10]

As the user directly interacts with a CAD model the influence of design intent will define how quickly they can perform a task in the modelling environment. A significant proportion of a design engineer's time is spent interacting with CAD models, so design intent level is critical to efficient working. Models with poor or ambiguous design intent might account towards 81% of respondents questioned in a survey agreeing that it is quite difficult to change CAD parts and assemblies created by other designers [11].

Unfortunately though, there is no metric that can be applied directly to design intent, meaning direct evaluation is troublesome. For any resultant form there are numerous constructional approaches. If two extremes are considered, then it is possible for an MT to exist with a single feature defining some very complex geometry. Conversely it is possible to have a complex MT that defines a relatively simple shape. In both cases it is possible to state that they do not contain a necessary level of design intent to allow efficient interactions with the model. In the first case the number of implicit indicators will be limited, in the second case it may be difficult to ascertain the design intent of the original user due to superfluous operations. Somewhere between these two extremes will lie a point where an ideal number of features will correspond to the equivalent representation of 3D form. Where this point exists though will depend on the requirements of the part and how those requirements affect the progress of CAD model development.

3.2. Data exchange

ISO 10303-1:1994 [12] defines data exchange as 'the storing, accessing, transferring, and archiving of data'. This describes the movement of data from one location (source) to another (destination). In most cases, all the information used in the construction and representation of the geometry, plus any additional proprietary information regarding the object, can be preserved and updated accordingly. Efficiency of data exchange therefore will be directly related to this data. Examples being, opening files into, and saving files from, the CAD software.

On diverse platforms an intermediate language will be necessary to translate the data; proprietary and constructional information present in the MT will be removed. Consequently, 'neutral' data exchange will be primarily concerned with the accurate representation of the *form*. This sort of information is often referred to as 'dumb data' as it does not convey any design intent and is difficult to manipulate easily in a parametric environment [13]. In these cases, the efficiency of the operations will be related solely to the geometry.

4. Methodology

Triumph Motorcycles Ltd have provided access to a database containing ≈600 of their production-level industrial parametric CAD part models, produced using PTC Creo. The proposed methodology utilises a number of techniques, both within and external to the Creo CAD software, to create text file documents. Parsing information from these documents will populate a database detailing quantities of a broad sample of entities related to the parametric construction and geometry of each part. In addition, various operations related to the aforementioned design development processes (Design Intent and Data Exchange) will be completed for each part and the time taken to perform these tasks measured.

By comparing the measurable model characteristics against the time it takes to perform design process tasks, it is the goal of the study to detect patterns that can be used to identify inefficiencies within these parts.

Once initial observations are made a selection of the models identified as being inefficient will be remodelled, to test any observations and quantify potential efficiency levels, and associated improvements/savings, across the complete database.

5. Future Opportunities for Study

The field of CAD is a wide and varied one and the difference between industries, companies and products, coupled with the idiosyncrasies of the various CAD platforms means broadly applying any observations gathered from this study would be premature. While the results should be generally applicable, it is only by expanding the study to additional platforms, industries and companies that wider application can be posited.

It is generally assumed that the creation of a poor quality CAD model is directly related to the experience level of the designer responsible. If this study shows that inefficient models are, as predicted, being produced by experienced users in industry, this assumption needs to be challenged and investigated.

The value of this research could be further increased through examination of CAD model development during different stages of the design process. By understanding the type and quantity of operations performed on a typical CAD file at each stage of the design process it should be possible to determine an optimal strategy for using these parts. For example, it might be more time efficient to produce poor quality, disposable models (CAD prototyes) during the earlier stages of the project to facilitate faster development. Replacing these models with new, higher quality versions will facilitate faster modification at the time in the development process when cost to change is significantly more.

6. Concluding Remarks

This is a position paper for consideration, detailing the initial work completed during the first year of a three-year study. The next step is to further refine the operations that will extract and collate the required information identifying patterns in inefficient models. This will be followed by remodelling of some of those identified as being suboptimal.

This work should be of particular value to anyone wanting to improve the overall efficiency of the design process, and will also assist with providing targeted training to those users that require it. Beneficiaries will include all those involved with the design, development or management of these file types.

Acknowledgements

This work would not be possible without the invaluable support of Triumph Motorcycles Ltd. Additional thanks must be given to PTC for the loan of the software required for these studies and Concurrent Engineering Ltd for their continued technical support.

References

[1] X. Chen, "Representation, evaluation and editing of feature-based and constraint-based design," Purdue University, 1995.

[2] S. Danjou and P. Koehler, "Challenges for Design Management," *Comput. Aided. Des. Appl.*, vol. 4, no. 1–4, pp. 109–116, 2007.

[3] W. F. Bronsvoort and F. W. Jansen, "Feature modelling and conversion-Key concepts to concurrent engineering," *Comput. Ind.*, vol. 21, no. 1, pp. 61–86, 1993.

[4] B. Bettig and C. M. Hoffmann, "Geometric Constraint Solving in Parametric Computer-Aided Design," *J. Comput. Inf. Sci. Eng.*, vol. 11, no. 2, p. 021001, 2011.

[5] C. Jackson and M. Buxton, "The design reuse benchmark report: seizing the opportunity to shorten product development," *Aberdeen Group, Bost.*, no. February, 2007.

[6] C. González-Lluch, P. Company, M. Contero, J. D. Camba, and R. Plumed, "A survey on 3D CAD model quality assurance and testing tools," *Comput. Des.*, vol. 83, pp. 64–79, 2017.

[7] M. Contero, P. Company, C. Vila, and N. Aleixos, "Product data quality and collaborative engineering," *IEEE Comput. Graph. Appl.*, vol. 22, no. 3, pp. 32–42, 2002.

[8] J. D. Camba, M. Contero, and P. Company, "Parametric CAD modeling: An analysis of strategies for design reusability," *CAD Comput. Aided Des.*, vol. 74, pp. 18–31, 2016.

[9] M. R. Henderson, "Representing functionality and design intent in product models," in *ACM Symposium on Solid and Physical Modeling*, 1993, pp. 387–396.

[10] F. Mandorli, H. E. Otto, and R. Raffaeli, "Explicit 3D functional dimensioning to support design intent representation and robust model alteration," *Comput. Aided. Des. Appl.*, vol. 13, no. 1, pp. 108–123, 2016.

[11] V. Salehi and C. McMahon, "Action research into the use of parametric associative cad systems in an industrial context," *17th Int. Conf. Eng. Des. ICED 09*, vol. 5, pp. 133–144, 2009.

[12] I. S. O. 10303-224, "BS ISO 10303-1: 1994 Industrial automation systems and integration - product data representation and exchange," *part 224 Appl. Protoc. Mech. Prod. Defin. Process plans using Mach. Featur.*, 2000.

[13] Y. Bodein, B. Rose, and E. Caillaud, "Explicit reference modeling methodology in parametric CAD system," *Comput. Ind.*, vol. 65, no. 1, pp. 136–147, 2014.