Title:
Investigating and characterising variability in CAD modelling: An overview

Authors:
Peter Rosso, Peter.Rosso@bristol.ac.uk, University of Bristol
James Gopsill, J.A.Gopsill@bath.ac.uk, University of Bath
Ben Hicks, Ben.Hicks@bristol.ac.uk, University of Bristol
Stuart Burgess, S.C.Burgess@bristol.ac.uk, University of Bristol

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Introduction:

Today almost without exception design processes use some form of computer-based models, where digital models enable designers to easily introduce, exchange and collaborate on models as part of the design workflow. Modern CAD tools enable the reuse of existing parts [9]: Reusing the design and manufacturing process from an existing design improves product development efficiency [11]. Despite a number of drawing standards, such as BSi [8] and STEP [2, 5], the vast number of commands within CAD software presents the opportunity for variability in CAD models and the CAD modelling process. [7] investigate variability in design, but variability in CAD modelling per se does not appear in the literature. Variability in modelling and models becomes particularly important when cost and efficiency of reuse are considered. Such requirements are common in industries such as aerospace and automotive where groups of engineers collaborate and exchange both new and existing CAD models in order to maximise efficiency [1, 10]. This paper presents a set of measures that can be used to examine variability of CAD models and CAD modelling process. Through application of these measures to practical study the paper reveals, for the first time, evidence in variability.

Variability in CAD modelling and models:

This study considers users to be any individual who would use CAD tools in order to view, create or modify a CAD model. The paper also adopts the perspective of the 'CAD model' as a product that is used and reused by users. Product and creation-process variability for a CAD model are then considered:

- CAD model variability.
- CAD modelling variability.

CAD model variability can be assessed by inspecting completed files at checkpoints. Possible measures that may vary are file size, modelling time, complexity of the object, number, choice and order of features and the completeness of the model. Variability in the CAD modelling process can be attributed to the actions which led to the definition of the CAD file. CAD modelling variability ca be inferred by variability in modelling time, number of total actions, number of actions per minute, complexity of the object, and any pattern and repetition in the actions chosen.Industry standards and guidelines have been introduced attempting to control sources variability [4], however, different users may still not necessarily create models which are identical even when given the same instruction.

Methodology:

Users where provided with detailed drawings for six parts (Fig. 1) and asked to model and create an assembly. Users were given an incentive to complete the task in the shortest time possible. The data collected included both the final CAD models and the log files which includes every action performed within the Autodesk Inventor environment. The latter were collected using a data logger designed by [3]. Fig. 2 presents the study method. The Data was processed using Pandas [6] in which commands were classified.

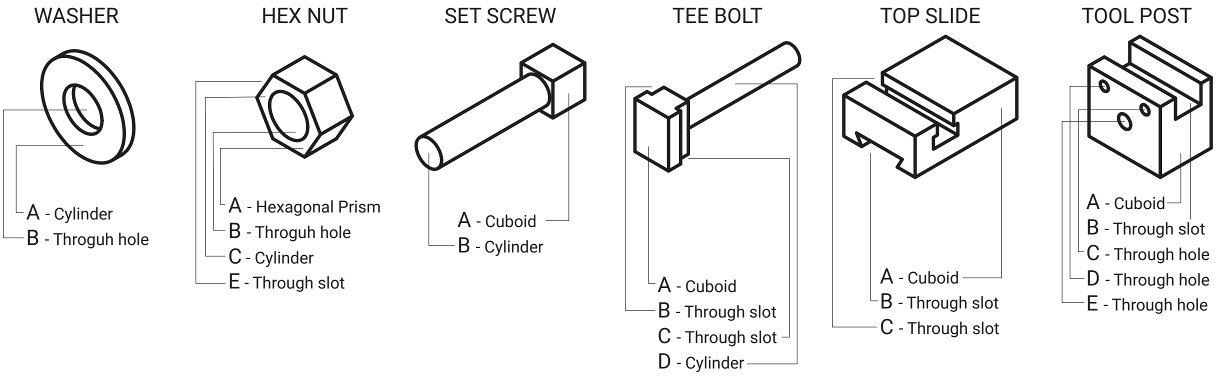

Fig. 1: Features in Object Assigned to users.

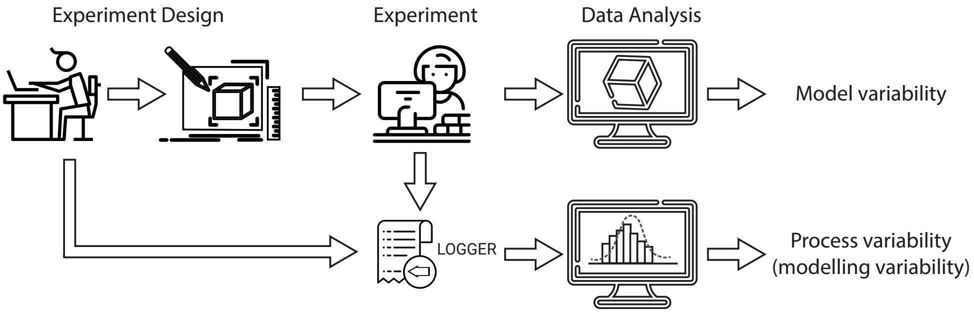

Fig. 2: Experiment

CAD Study results

The final models were inspected and both file size and detail regarding construction were recorded. Fig. 3 shows CAD models variability across the same parts modelled by different users. File size is determined by information carried by the file, thus the next inspection was carried on the structure of the models. Table 1 uses capital letters to describe the use of a profile in a additive manner, while lower case letters refer to a subtractive use. Commas are used to delimit features as perceived within Autodesk Inventor

Table 1: Construction trees

	washer	**hex_nut**	**set_screw**	**top_slide**	**tee_bolt**	**tool_post**
user01	Ab	Ab	B,A	Ab,c	Abc,D	Ab,fg,cd,e
user02	Ab	D,e6	A,B	A,b,c	A,bc,D	A,b,cde
user03	Ab	Ab	A,B	A,B,c	Abc,D	A,b,cd,tc,td,e
user04	Ab	Ab	A,B	Ac,b	Abc,D	Ab,c,d,2d
user05	Ab	Ab	A,B	Ac,b	Abc,D	Ab,e,cd
user06	Ab	A,b	A,B	Ac,b	Abc,D	Ab,he,hcd
user07	Ab	A,b	B,A	Ac,b	Abc,D	A,b,cde,e
user08	Ab	A,b	A,B	Ac,b	A,bc,D	A,b,cde
user09	Ab	A,b	A,B	Ab,c	Abc,D	Ab,cd,e
user10	Ab	Ab	A,B	Ac,b	Abc,D	A,b,cd,e
user11	Ab	Ab	A,B	Ac,b	Abc,D	Ab,e,cd
user12	Ab	Ab	A,B,B'	Ac,b	Abc,D	Ab,cd,e

construction tree. The prefix t indicates the use of a thread, while the numbers refer to repetitions. The correspondence between letter and feature is shown in Fig. 1. After analysing the data in the logger it was possible to investigate the variability in CAD modelling across users. Fig. 4 shows the cumulative events recorded by logger by user (organised in order of finishing time which is indicated by a black dot), these events have been classified into eight contextual categories: Viewing, Creating(2D and 3D), Editing(2D and 3D), Constraining, Deleting, Reversing, Transitioning and Assembly. As shown in [3] it was possible to calculate transition matrices from the logged files Fig. 5.

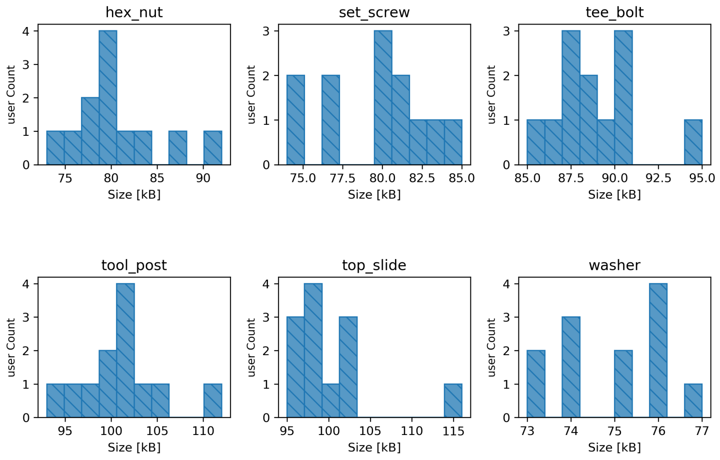

Fig. 3: Variability in file size for part files

Discussion

Comparing files, their size is the first comparable measurement that can be observed without opening the models (Fig. 3 highlights this variability). Table 1 allows comparison of the construction trees of the different part files. According to combinatorics the larger the number of features in a part the greater the number of possible combinations of features to achieve the same part. Despite the constraints imposed by using the same software, task and education it is possible to observe some small variance in the way users have produced the parts. While the simplest part (*washer*) has been created in the same way by all users, the part with most features (*tool_post*) has a higher spread in terms of variability. A construction

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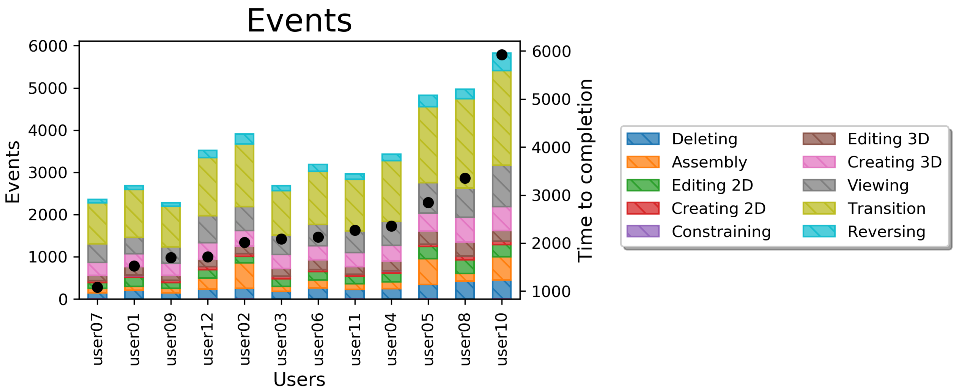

Fig. 4: Cumulative events count compared across users

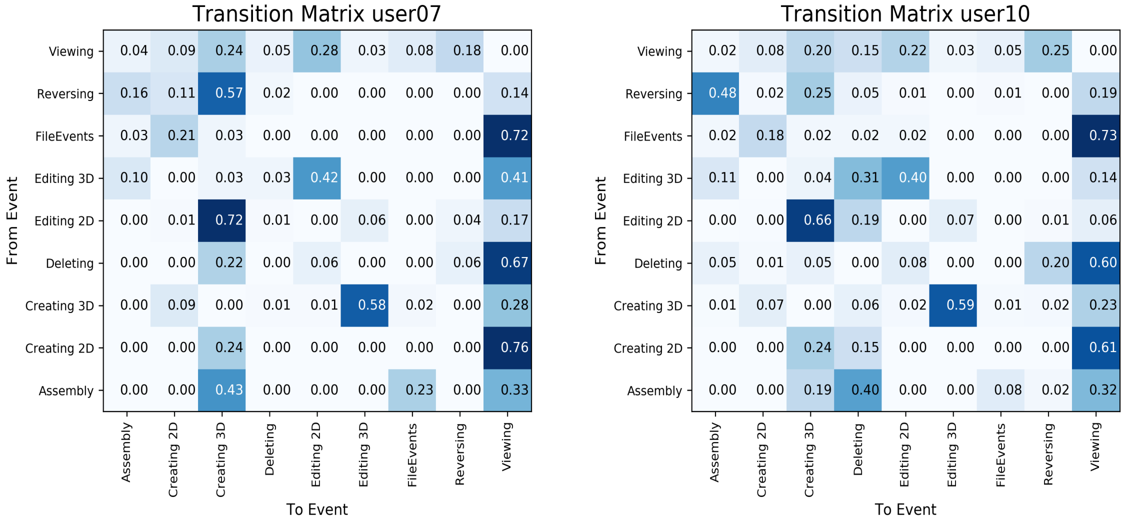

Fig. 5: Comparison of transition matrices for the fastest (user07) and slowest (user10) users.

tree describes most of the relationships between features, thus it informs us about the extent to which a user is capable to efficiently reuse an already existing model.

Variability in the CAD modelling process was observable looking at the length of the logs and the distribution of events different users invoked - see Fig. 4. Users have been displayed in the order in which they completed the task. It is possible to infer that users worked at different rates, and invoked different number of event types. A more detailed inspection of the choices of the users can be carried out on the transition matrices representing how likely a user was to transition to a specific event type after invoking another one. From the transition matrices it is possible to infer the different approaches the users had to the task. Comparing the two transition matrices it can be observed that user07 (faster user) has much more concentrated values, which are characteristic of a more methodical approach. On the other side user10 has a higher level of spread in the transition from one event type to another which might be more characteristic of indecision, or repeated errors.

Conclusions:

This paper gives an overview of an assessment of variability in CAD models and CAD modelling processes. Through the analysis of CAD models and logged data from a CAD study it was possible to investigate and observe some measures of variability in both CAD models and the CAD modelling processes. The authors focused on file size and features as evidence of CAD model variability. The number and type of events invoked during the experiment, coupled with the transition between type of events highlight the existence of variability in CAD modelling processes. Future work aims to investigate and fully characterise variability in both CAD models and CAD modelling with partcilaur attention to the reusability of CAD models.

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