Title:
Parametric Surface-Based Modelling: A Review of Modelling Strategies and Identification of Future Research

Authors:
Aritz Aranburu, aaranburug@mondragon.edu, Mondragon Unibertsitatea
Daniel Justel, djustel@mondragon.edu, Mondragon Unibertsitatea
Ivan Angulo, ivan.angulo@alumni.mondragon.edu, Mondragon Unibertsitatea

Keywords:
CAD, modelling methodology, surface modelling, reusability

DOI: 10.14733/cadconfP.2020.199-203

Introduction:
Recent years have witnessed growing demands on product specifications as a result of increasing competition in worldwide markets. This puts pressure on companies to develop higher quality products with greater speed. Consequently, the work volume and the number of elements affecting the design process increases, alongside decreased working time.

Existing CAD systems, which are based on parametric associative technology, have become indispensable tools to face this challenge. Today, these platforms are frequently used in design projects [17], because they help in the creation of parametric 3D models, collaboration between employees and work-teams, management of the entire product life-cycle, thus reducing time to launch.

During part design, there are many possible modelling procedures in the solution space to generate any one part. Although the desired geometry is generated, not all models are reusable because the degree of reusability of the model depends on the procedure determined by the original designer [2]. Therefore, not all 3D models meet the designer's original expectations. In view of this, as reviewed by Cheng and Ma [5], the robustness and reusability of 3D models is key during downstream engineering activities, such as manufacturing, engineering analysis, and optimisation. To obtain fully parametrised and adaptive products during the product design phases, the overall strategy, modelling methods, established procedures and approaches are key considerations. For this reason, companies often create internal design guides [3] for the effective representation and communication of design intent between designers [4]. Part of this process involves collecting good modelling practices and reducing/simplifying the possible number of procedures for their implementation. Thus, the need for a modelling methodology becomes clear.

Bodein *et al.* [1] analysed CAD systems in the automotive sector and defined five principal aspects for an efficient CAD strategy: to reduce design time in all design phases (conceptual, preliminary or detailed), to reuse existing CAD models and geometry, automatisation of routine design tasks based on knowledge-based engineering (KBE) applications, to enhance collaboration between designers, and to improve the general quality of CAD models. In addition, Bodein *et al.* [1] propose a road-map with five phases – namely, standardisation, methodology, generic modelling, expert rules and automation – to improve CAD efficiency.

During a review of the literature, we identified that reusability in modelling methodologies is a neglected topic. Only one study was identified, that of Camba *et al.* [3], in which modelling methodologies were analysed and compared. Specifically, Camba *et al.* [3] analyse the three solid modelling methods. This study concludes why certain methods are easier to edit and contain fewer errors in 3D model regeneration.

Nevertheless, the basis of CAD systems is classical solid-state or surface modelling [3],[4]. On the contrary, we have not identified any studies on surface modelling that provide a similar comparison to that of Camba *et al.* [3]. Such a comparison would help CAD designers identify which modelling methodology provides the greatest flexibility and reusability with regards to surface-based models.

Our purpose in this research is to identify the principle aspects in CAD development workflows which influence the flexibility and reusability of surface-based models in order to develop a parametric surface-based modelling methodology. We will establish a framework for these aspects for future research aimed at developing surface-based CAD modelling methodologies in order to tackle reduction of design time and the reusability of CAD models and geometries. To this end, in the following sections we have analysed the surface-based modelling methodology, solid modelling methods, identified product modelling strategies, surface modelling case studies are reviewed and to conclude, we have presented aspects for future research.

Review of Modelling Strategies and Future Research

Firstly, we carried out a literature review on parametric surface-based modelling, which justifies the need to study surface modelling methodologies in order to achieve flexible and reusable models. Thus, in addition to the industry benchmark standard surface modelling procedure of Vukašinović and Duhovnik's [15], we identified the following articles as important contributions to this field of literature: Camba *et al.*'s [3] comparative study of solid modelling methodologies, VDI2209 [14] 3D modelling standard, Forrai *et al.*'s [7] case study , Xiang *et al.*'s [16] case study, Gabrielides *et al.* [8] work on branching geometries, Ryenne and Gaughran's [12] study on cognitive modelling strategies, and Otto and Mandorli's [10] investigations on surface modelling in education.

As a result of its ubiquitous application in surface modelling, Vukašinović and Duhovnik's [15] modelling methodology is the starting point in this study. Vukašinović and Duhovnik assert that products for the mass-market require the designer to possess a great deal of previously-acquired experience and product specific knowledge. Taking as reference the development of a surface model of a hand blender, Vukašinović and Duhovnik describe a procedure of ten steps: (i) import the concept image, (ii) create boundary curves, (iii) generate the surface with boundary curves, (iv) free-form the generated surfaces, (v) create and delete sections onto the surface, (vi) fill gaps by repeating steps ii-iv, (vii) join the surfaces, (viii) mirroring and joining the two surfaces, (ix) convert surface to solid, and (x) add details such as fillets or chambers. Moreover, Vukašinović and Duhovnik remarked that working with curves and surfaces optimally requires understanding their mathematical properties. To maintain desired aesthetic it is necessary to maintain the continuity of curves and surfaces during the digitalisation of sketched forms [15]. However, this procedure guides the designer in the construction of the geometry, but this approach does not consider the reusability and flexibility of surface-based geometries.

To date, reusability and flexibility have been subject to a considerable lack of attention [3]. Camba *et al.*'s [3] comparative research helps us to understand the key factors of associative parametric technology for the reusability and flexibility of 3D models. This study determines that Resilient Modelling Strategy (RMS) is the optimal methodology for model reusability. This is mostly due to the way it names and organises the elements of the GSD tree, which helps with ease of operation identification. Therefore, during the organisation process, the operations that are most susceptible to change or are most volatile are placed as far down the tree as possible. Along with these important criteria, it should be noted that the approach also contains a collection of good modelling habits, an interesting idea that should be applied in all scenarios. In surface modelling, there are more elements in the tree, so the criteria for organisation and nomenclature should be determined. We believe that the strategy of identifying functional parts so that they are not interdependent (as proposed by Bodein *et al.* [2]) may be an interesting consideration in the categorization of the curves and surfaces in the tree. In general, as the technology is identical, the basic principles that will govern surfaces will be the same. Therefore, the aim will be to reduce to the greatest possible extent the parent-child dependencies in these new elements in order to generate robust and stable models, which are both flexible and reusable.

In addition, it is important to include not only part-oriented modelling methodologies but also product development strategies or product development workflows, since these two factors are inherently interrelated. In order to outline possible case studies, we have used the VDI 2209 standard [15]. The standard states that surface modelling is used mainly when volume-oriented modelling is not appropriate (sheet metal parts, automotive bodies etc.). Therefore, individual areas need to be modelled separately from the volume on account of their geometrical complexity (*e.g.* in the case of castings and forgings), and production-related aspects are paramount (*e.g.* separate modelling of milled surfaces in mould and die-making). According to the VDI 2209 standard [14], a *top-down* strategy can take two different approaches: on one hand, "from the outside in" approach (focused on complex overall products, *e.g.* a complete car) and, on the other hand, "from the inside out" (oriented to components with special requirements relating to design or production, *e.g.* trim parts, housing and sheet metal parts).

To gain more insight into surface modelling, we have collected two industrial case studies that are based on a *top-down* strategy: Xiang *et al.* [16] whose work focuses on the streamlined head of high speed trains, and secondly Forrai *et al.* [7] whose study focuses on automotive bodies. It is important to mention that these two approaches are not modelling methodologies, but practical methods focused on the product and the development of process workflow. We have evaluated them as interesting case studies to optimise future approaches.

Perhaps, the most interesting contribution from these studies is that Xiang defines a "package" to describe the typical minimum spatial parameters and the main form constraints for automobile design, which have been previously regarded as specification hard points. Xiang and Forrai [7, 16] both found, however, that many constraints and hard points still exist. These simplified sketches recall Cheng *et al.*'s [5] functional approach which defines future parametrisable characteristics embodied in CAD sketches as future modelling sources. It is also seen that presenting a surface modelling method in the decision-making process would help the overall process to be more agile. It follows that, with appropriate application of this approach, Xiang would be able to perform the tasks of aerodynamic analysis, aesthetic validation with renders and ergonomic analysis more quickly due to the ease of modelling versions.

In case of Forrai's automotive body case study [7], the surface with the highest quality and aesthetic value, which defines the product, is contained in a separate file. The pieces that are generated from the first surface by means of derived surfaces must be made in such a way that if the mother surface is restyled, the derived pieces are updated. The specific approach here is not clearly defined; however, this approach proposes the creation of intermediate pieces between the skin and the definitive pieces, to use them in calculations or as cutting elements of pieces derived from the mother skin.

Notwithstanding, having the foundations to model on surfaces and two product design processes, such as a train head or a car, does not provide a sufficiently generalised approach for the application to other design geometries. Not all geometries are volume-centred geometries as in the discussed case studies. In certain cases, we can find complex geometries that branch out (Fig.1-a and b) and, in these cases, achieving a surface with acceptable continuities is therefore challenging. For this reason, Gabrielides and others [8] have studied how to achieve the desired continuities in various cases. This has resulted in the development of a process in which the desired continuities are obtained up to G_1 (Fig. 1-c and d). Nonetheless, this does not apply to the case in which the finish of the product requires greater continuity than G_1.

However, surface modelling has its own specifications that differentiate it from solid modelling, *e.g.* curve/surface continuities and the aesthetic quality of the surface. It is seen that it is interesting to collect both good and inefficient practices to analyse different surface modelling approaches. Although the following practices are not performed in parametric software, Otto and Mandorli's [10] study of the errors in NURBS-based modelling has great future potential as this enables analyses of both favourable and unfavourable approaches in model creation. This novel approach makes us reflect on the need for modelling methodologies to integrate guidelines which aid in strategic knowledge acquisition. But what do we mean with all this? As we have initially highlighted, the most important part of the design workflow in the generation of reusable models is designer's input [2] and not all CAD users have the same modelling capacity. It is important therefore to differentiate between the two necessary components of CAD systems training: procedural knowledge (knowledge of software) and strategic knowledge (knowledge needed to apply a modelling strategy) [6],[9]. As specified, Bodein *et al.* [1] and

Camba *et al.* [3], training methods are not adapted to parametric-associative CAD. Standard courses offered by CAD vendors are based solely on software functionality and its inherent limits. These courses are known as "Computer Based Training" (CBT) and currently do not include aspects of strategic knowledge application. In this sense, Ryenne and Gaughran [12] identify that spatial visualisation ability, sketching ability and model deconstruction ability are crucial for developing efficient part modelling strategies. However, there is a notable lack of methodologies or resources to assist CAD users in the deconstruction of the geometry and model. In light if this, the work of Gabrielides *et al.* [8] may help to create a procedure for geometry deconstruction and, additionally, Otto and Mandorli's [10] work may inspire procedures that help designers develop strategic knowledge.

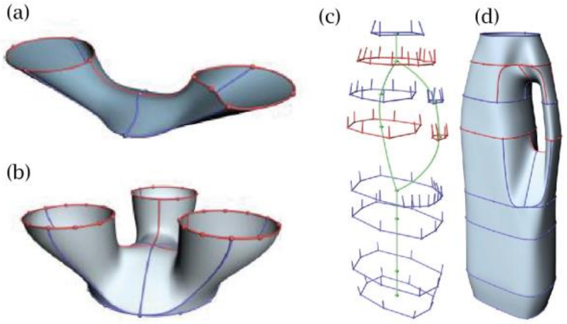

Fig. 1: Branching as tackled by Gabrielides et al. [8]: (a) The final "one-to-two" surface, (b) The final "one-to-three" branching surface. (c) Contour point sets, tangent-vector estimates and the correspondence graph of the container example, and (d) the final container surface.

<u>Conclusions</u>
To conclude, this review highlights the need for research into parametric surface modelling in order to develop modelling methods that will enable industrial optimisation of the flexibility and reusability of CAD models. In our opinion, the applied product modelling strategy should always be a top-down approach, but depending on the needs of each product there will be two possible design approaches when modelling: from *outside to inside* (*e.g.* cars, trains, etc.) or from *inside to outside* (*e.g.* parts that require a mould for manufacture). Our research team has identified the opportunity to investigate a modelling procedure that allows these two approaches (i.e. *outside to inside* and *inside to outside*) to the addressed. This procedure is therefore based on:

- RMS method. As seen in the RMS method [11], tree structures which categorise features according to their impact on the tree and their proper naming are the most important factors for reusability and flexibility of 3D models. Therefore, it would be interesting to adapt this method to surfaces. It will be necessary to incorporate good modelling practices based on continuities of curves and surfaces. Reducing tree dependencies is a key consideration when working on surface-based models in order to achieve robustness and flexibility. No cases have been found where this issue has been explicitly studied. Therefore, this remains a significant area of interest.
- Deconstruction of geometries. Another area that has been comparatively neglected is the deconstruction of geometries [12] as the geometries of surfaces are more complex to visualise. Therefore, it would be interesting if a methodology were to be developed to assist in the deconstruction of shapes by means of clear guidelines. This, in turn, would help to further develop the modelling strategy and a better organization of the tree.
- VDI2209 Standard. According to VDI2209 [14] the usual products that are modelled on surfaces are mainly volume-oriented, sheet metal parts, casting and forging parts, or parts requiring separate modelling of milled surfaces for mould or die making. Therefore, it is possible that future surface-based modelling methodologies should take into consideration different approaches in order to adapt to the differing requirements of these types of parts (*i.e.* variations in manufacturing specifications).

References:

[1] Bodein, Y.; Rose, B.; Caillaud, E.: A roadmap for parametric CAD efficiency in the automotive industry, Computer Aided Design, 45(1), 2013, 198–214. https://doi.org/10.1016/j.cad.2013.05.006

[2] Bodein, Y.; Rose, B.; Caillaud, E.: Explicit reference modeling methodology in parametric CAD system, Computers in Industry, 65, 2014, 146–47. https://doi.org/10.1016/j.compind.2013.08.004

[3] Camba, J. D.; Contero, M.; Company P.: Parametric CAD Modeling: An Analysis of Strategies for Design Reusability, Computer-Aided Design, 63, 2016, 18–31. https://doi.org/10.1016/j.cad.2016.01.003

[4] Cederfeldt, M.; Sunnersjö, S.: Solid modelling with dimensional and topological variability, International Conference on Engineering Design, Design ICED'03, Stockholm, SWEEDEN, 2003, 1–10.

[5] Cheng, Z.; Ma, Y.: A functional feature modeling method, Advanced Engineering Informatics, 33, 2017, 1–15. https://doi.org/10.1016/j.aei.2017.04.003

[6] Chester, I.; Teaching for CAD expertise, International Journal of Technology and Design Education, 17, 2007, 23–35. https://doi.org/10.1007/s10798-006-9015-z

[7] Forrai, M.; Gavačová, J.; Gulan, L.: A Practical Methodology for Creating Robust Parametric Surface-based Models in Automotive Engineering, Procedia CIRP, 50, 2016, 484–9. https://doi.org/10.1016/j.procir.2016.04.145

[8] Gabrielides, N. C.; Ginnis, A. I.; Kaklis, P. D.; Karavelas, M. I.: G1-smooth branching surface construction from cross sections, CAD Computer Aided Design, 39(6), 2007, 39–51. https://doi.org/10.1016/j.cad.2007.05.004

[9] Lang, G. T.; Eberts, R. E.; Barash, M. M.; Gabel, M. G.: Extracting and Using Procedural Knowledge in a CAD Task, IEEE Transactions on Engineering Management, 38(2), 1991, 57–68. https://doi.org/10.1109/17.83758

[10] Otto, H. E.; Mandorli, F.: Surface Model Deficiency Identification to Support Learning Outcomes Assessment in CAD Education Harald, Computer-Aided Design and Applications, 16(4), 2019, 29–51. https://doi.org/10.14733/cadaps.2019.429-451

[11] RMS. Resilient Modeling Strategy: Solids Modeling Best Practices Manual. V9 2018. https://learnrms.com. Visited on 30/01/2020.

[12] Rynne, A.; Gaughran, W. F.: AC 2007-2132: Cognitive modeling strategies for optimum design intent in parametric modeling (PM), American Society for Engineering Education, 2007.

[13] Stroud, I.; Nagy, H.: Solid Modelling and CAD Systems: How to Survive a CAD System, Springer, 2011. https://doi.org/10.1007/978-0-85729-259-9

[14] Verein Deutscher Ingenieure (VDI). VDI 2209, 3D product modelling - Technical and organizational requirements Procedures, tools, and applications - Cost-effective practical use, 2009:165.

[15] Vukašinović, N.; Duhovnik, J.: Advanced CAD modeling. Explicit, Parametric, Free-Form CAD and Re-engineering, Gewerbestrasse, Springer, 2019, 81-109. https://doi.org/10.1007/978-3-030-02399-7

[16] Xiang, Z.; Zhi, J.; Huang J.; Kang H.; Li T.; Gao P.: A systematic approach for streamlined head form design and evaluation of Chinese high-speed train, International Journal of Rail Transportation, 2018, 1–23. https://doi.org/10.1080/23248378.2018.1501776

[17] Xu, X.: Integrating Advanced Computer-Aided Design, Manufacturing, and Numerical Control: Principles and Implementations, 2009, University of Auckland, New Zealand. https://doi.org/10.4018/978-1-59904-714-0