



Title:

A Criteria-Based CAD Pre-Modeling Decision Method (CBPMDM) For Early-Stage Industrial Product Design

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Introduction:

The transition from early design concepts to robust and fully parametric CAD models remains a demanding task for designers across different levels of expertise. This difficulty is not only related to the technical complexity of contemporary CAD systems, but also to the numerous decisions that must be made early in the process, including geometry definition, command selection, and the explicit embedding of design intent. Despite the availability of advanced CAD tools and extensive educational materials, such as books and tutorials, designers often struggle to establish an effective design strategy, particularly when dealing with complex or organic geometries [1,2,3].

Design intent is often embedded at the start or after modeling begins, which forces product designers to retrofit constraints and parameters. This phenomenon is largely due to the lack of systematic guidance that helps designers in planning the CAD modeling workflow, selecting appropriate operations, and defining a logical command sequence before modeling starts [3]. As a result, CAD modeling frequently relies on trial-and-error approaches, leading to models that are difficult to modify, while also resulting in significant time losses during this modeling process [4,2].

The proposed method enables early placement of design intent in CAD models by systematically aligning product criteria with appropriate modeling routines and structural design strategies. To address this challenge, this paper proposes the Criteria-Based Pre-Modeling Decision Method (CBPMDM), a criteria-driven decision procedure that assigns an industrial product to an explicit modeling strategy before CAD execution begins by mapping product characteristics to modeling context, routine, and commands. The aim is to support the structured transformation of conceptual ideas into high-quality parametric CAD models. The CBPMDM introduces a predefined set of criteria that guides product designers in selecting the appropriate modeling platforms, defining modeling routines, and identifying suitable CAD commands according to the product's geometric and functional characteristics in respect to design intent. These criteria consider factors such as single part versus an assembly model, modeling routine complexity, recognizable geometric features, and the presence of organic surface geometry [4]. By applying these criteria prior to CAD execution, product designers can establish a clear and informed strategy that reduces unnecessary iteration and supports the early embedding of design intent in the CAD sense, [7]. The Criteria-Based Pre-Modeling Decision Method builds on established CAD principles, including feature recognition in B-Rep-based representations [8,9] and the effective management of part and assembly contexts [5,6,8]. An integrated example-based case study demonstrates the applicability of the proposed method and indicates potential benefits for CAD education and professional modelling practice. Collectively, these benefits can reduce modeling time and improved model robustness under

change, and enhanced consistency between the conceptual phase of product design intent and the resulting parametric CAD representation.

Traditional Modeling Workflows compared to Criteria-Based Pre-Modeling Decision Method (CBPMDM): In the traditional CAD modeling workflow, with and without initial design intent Fig.1, industrial designers often initiate CAD modeling immediately after forming an initial perception of the product's shape and their systematic translation into CAD modeling strategies is often not explicitly addressed before geometry creation begins, [4]. As a result, the CAD model may not fully reflect the intended behavior of the product when modifications are required. Although the objective at each design phase is to represent the solid in a way that best reflects the intended product behavior, function, and form, the modeling process is typically geometry driven, rather than intent driven. Designers tend to create an initial geometry first and only afterward consider how the model should be constructed, modified, or extended in subsequent steps, [9]. As a result, modeling decisions and CAD command selection are made in a reactive manner, rather than being guided by a clear hierarchy of features and constraints that embody design intent, leading to workflows that rely heavily on trial-and-error [3]. These methods produce solid models that do not accurately represent the original product and are not properly parametrized to support fast and efficient design modifications, particularly when substantial changes must be implemented after the initial feature structure has been established.

In contrast, the Criteria-Based Pre-Modeling Decision Method (CBPMDM) restructures this workflow by introducing an explicit pre-modeling decision step, Fig.2. Before CAD execution begins, the method uses predefined criteria to assign the product to an explicit modeling strategy, specifying the appropriate modeling context, modeling routine, and command strategy. By making these decisions upfront, CBPMDM supports systematic planning, and well-defined modeling sequences result in more robust and reliable parametric models.

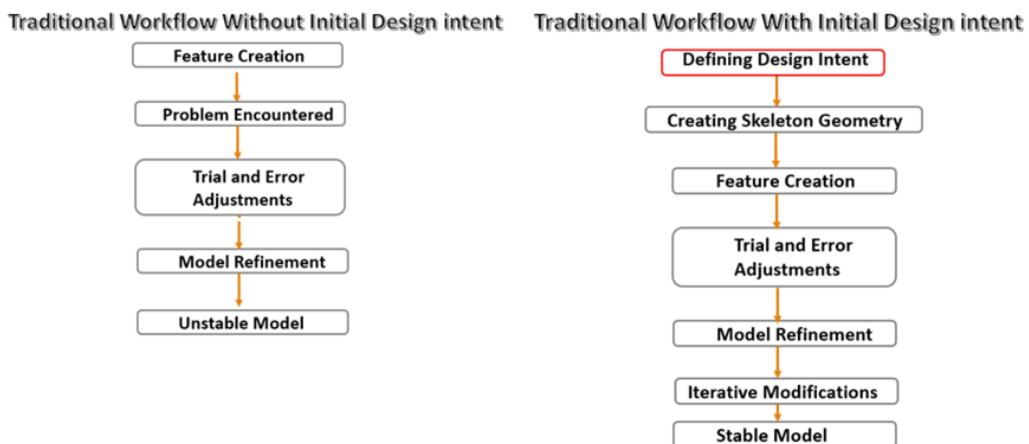


Fig. 1: A CAD modeling workflow with & without predefined criteria

Unlike existing approaches that focus on constraint optimization or feature reuse, CBPMDM introduces a pre-modeling decision stage in which the designer evaluates the product using predefined criteria and explicitly embeds design intent prior to CAD execution. Design intent refers to the explicit definition of parametric relationships, constraints, and feature dependencies that ensure predictable and efficient model modification.

Methodological Framework of the Criteria-Based Pre-Modeling Decision Method (CBPMDM):

The process begins with the detailed observation of the sketches, reference images, conceptual descriptions, or partially defined geometry, followed by the application of predefined criteria that classify the product according to its geometric structure and modeling requirements. The Criteria-Based

Pre-Modeling Decision Method (CBPMDM) is a structured decision-making method that supports designers in defining a complete CAD modeling strategy prior to geometry creation, Fig. 2. The method is based on the principle that effective parametric models are not the result of isolated command execution, but of a predefined sequence of decisions that align product characteristics with appropriate modeling contexts, tools, and feature routines, while explicitly supporting the embedding of design intent in the CAD model. The method is organized into three sequential stages, each addressing a critical aspect of the modeling process, such as geometric feature identification, CAD platform and tool selection and the definition of modeling strategy and feature routines, including the explicit embedding of design intent. These stages collectively form a systematic workflow that transforms the modeling process from a reactive activity into a proactive, controlled, and strategy-driven procedure.

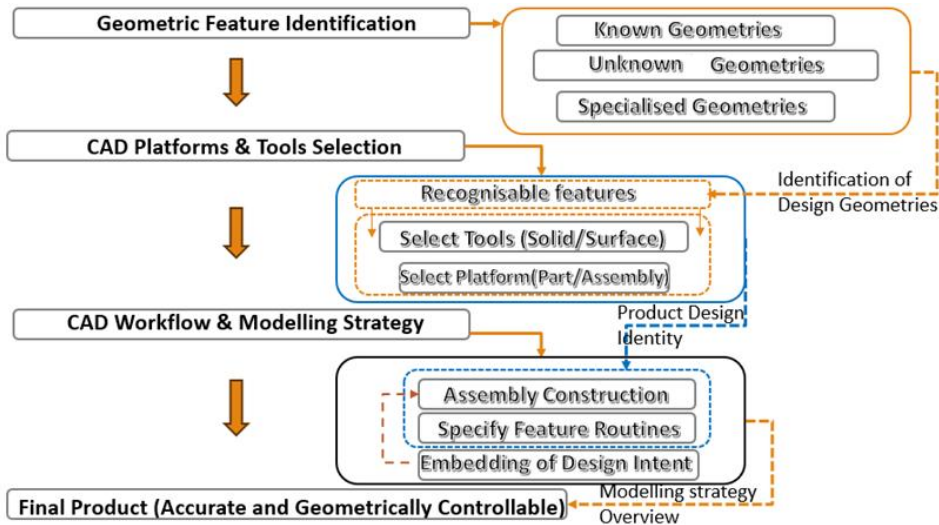


Fig. 2: Three-stage workflow of the Criteria-Based CAD Pre-Modeling Decision Method (CBPMDM).

The first stage of the CBPMDM involves systematic observation and classification of the target product geometry. The objective is to decompose the object into identifiable geometric categories that can be associated with known or unknown modeling geometries. Based on predefined criteria, geometric features are classified into distinct categories, including:

- Known geometries, such as primitives and standard feature-based elements that can be directly associated with established CAD commands and repeated geometric patterns.
- Unknown geometries, which cannot be immediately mapped to predefined modeling feature routines and require isolated analysis, such as organic or free form geometries, typically requiring surface-based modeling tools.
- Specialized geometries, such as sheet metal structures, generative forms.

Following geometric classification, the second stage of CBPMDM focuses on selecting the appropriate CAD environment/platforms and modeling tools, Fig. 2. These decisions are guided by new criteria related to product structure, feature distribution, and modeling complexity as shown below. The identification of design geometries has already been exported from the first stage of the method. With all this information inserted from the previous stage a new primary distinction is made between Part and Assembly modeling environment, and the appropriate modeling approach as new criteria:

- Number of Part modeling environments, suitable for single geometries and
- Number of Assembly and Sub-Assemblies are required where needed.
- Selection of modeling tools based on geometry type, such as solid modeling for volumetric forms, surface modeling for complex or free form geometries, and hybrid approaches as a combination of both solid and surface modeling.

The Criteria-Based Pre-Modeling Decision Method (CBPMDM) structures the final stage of the modeling process into a sequence of clearly defined sub-stages, each addressing a critical aspect of model development. The objective is to establish a comprehensive modeling strategy that transforms conceptual design into a fully parameterized product, enabling controlled and predictable geometric modifications. The main sub-stages are as follows:

- Assembly Construction (if needed),
- Feature Routine Definition, while firstly solve all the unknown geometry.
- Design Intent Embedding, horizontal applied to all the previous steps.

Design intent is embedded not only at the level of individual features but also across the entire modeling structure. This includes the definition of relationships between different parts, the control of feature hierarchies, and the alignment of modeling routines with expected product behavior. By introducing design intent after the modeling strategy has been fully defined but before or during controlled feature execution CBPMDM ensures that all parameters and constraints are aligned with the intended functionality of the product. This results in CAD models that can be more robust, predictable, and capable of supporting rapid and reliable design modifications.

Integrated Example-Based Case Study:

The primary objective of the selected case study was not only to evaluate geometric similarity between modeling outcomes, but to examine how design intent is embedded and preserved throughout the CAD modeling process. For the selected paradigm, design intent was explicitly defined prior to modelling and consisted of three core controllable aspects:

- *The parametric definition of two parallel elliptical profiles*, including their major axes.
- *The controlled distance between the two ellipses*, defining the overall height and proportional relationship of the form.
- *The organic grip geometry*, defined by spline-based curvature whose shape should be directly and intuitively adjustable through control points.

These elements were considered critical to the identity and functional adaptability of the product. Any valid CAD model was therefore expected not only to resemble the target form visually, but also to allow fast, reliable, and predictable modifications of these parameters without requiring geometry reconstruction and time spending. The modeling task was performed by an undergraduate industrial design student with intermediate CAD skills. The same object, Fig. 3 a), was modelled twice under identical technical conditions. Firstly, using a conventional, unguided workflow Fig. 3. b) and secondly using the Criteria-Based Pre-Modelling Decision Method (CBPMDM), Fig. 3. c).

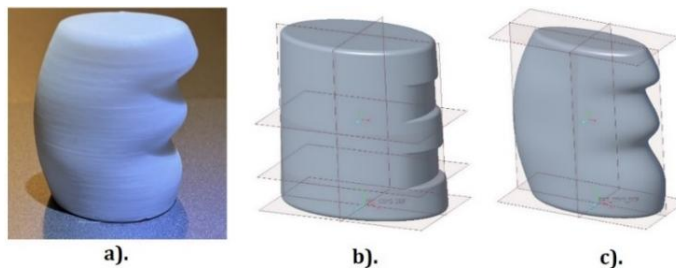


Fig. 3: Illustrative model to be designed(a), before(b), and after(c) (CBPMDM).

In the first attempt, the student-initiated CAD modelling without explicitly defining design intent or a structured modelling strategy. Modelling routines and commands were selected incrementally, as the student attempted to achieve individual geometric features through successive trial-and-error steps. Although the final model visually approximated the desired form, Fig. 3. b) the design intent was weak and inconsistently embedded. Specifically, the two elliptical profiles were not defined as independent,

parametric entities connected through an explicit design relationship. Instead, the upper ellipse was generated indirectly by applying a tapered extrusion to the lower ellipse. While this approach allowed partial control over the upper ellipse dimensions, it introduced an unintended dependency on the extrusion taper angle, a parameter that was not part of the original design intent. As a result, modifying the ellipses independently or adjusting their distance led to unpredictable geometric outcomes. Similarly, the organic grip geometry was produced through a sequence of material removal operations and rounding commands, rather than through spline-based surface definition. This modelling decision caused the grip form to be implicitly defined by Boolean and filleting operations, making its shape highly sensitive to parameter changes. When attempting to modify the grip geometry, local changes frequently resulted in feature failures or required complete re-modelling of affected regions. Due to these modelling choices, design modifications were neither fast nor reliable. Changes to ellipse proportions or grip form often propagated unintended effects across the model, significantly increasing correction time. Consequently, the time required to implement design changes became unpredictable, and in some cases, indeterminate, as modifications necessitated feature deletion and reconstruction rather than direct parameter adjustment.

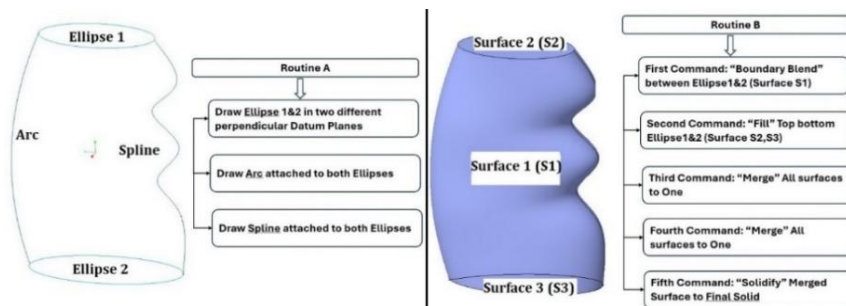


Fig. 4: CAD Routines A & B as part of the Design Strategy.

In the second modelling attempt, the student applied the CBPMDM framework. The modelling process began with explicit observation of the target object and formal definition of design intent parameters. Using the predefined criteria, the object was classified as a *single-part* industrial component with *complex organic* geometry, requiring a *surface-driven* modelling strategy. Based on this classification, a part platform on the parametric cad system was required once and two main modelling routines were defined in advance rather than emerging during design execution, Fig. 4. The main modeling routine (Routine A) consists of two elliptical sketches that were constructed as independent, fully parameterized reference geometries, with their dimensions and mutual distance explicitly controlled through specific values of parameters. This ensured that changes to either ellipse or to their spatial relationship could be performed directly, without introducing unintended geometric dependencies. The organic grip geometry was defined using spline-based curve and an arc, connecting the two elliptical sketches that were incorporated into a surface modelling routine that preserved curvature continuity and allowed instantaneous modification of the grip shape by adjusting spline control points alone. By embedding design intent at the earliest stages of the modelling process, all subsequent geometry generation followed a clear and predictable logic aligned with the intended behavior of the product. Following the predefined routines, Fig. 4, the student executed the modelling process with minimal trial-and-error. Surface construction, merging, and solidification were performed in a controlled sequence, as defined during the pre-modeling phase (Routine B) belongs to step 3 of CBPMDM. The resulting CAD model was not only visually closer to the intended final form, but also structurally aligned with the original design intent. Modifications to the elliptical sketches, their distance, and the grip geometry could be executed instantly and independently, without causing feature failures or requiring geometry reconstruction. Compared to the conventional workflow, the CBPMDM-guided model demonstrated stronger and more explicit design intent embedding, higher robustness under parametric changes, significantly reduced modification time, and improved confidence during modelling execution.

The final model remained stable and predictable under design changes, fulfilling both aesthetic and functional requirements of the intended product.

Conclusions:

This paper introduced the Criteria-Based Pre-Modelling Decision Method (CBPMDM), a structured approach that supports early-stage industrial product design by enabling explicit insertion of design intent prior to CAD execution. By applying predefined criteria related to geometric structure, modelling complexity, and recognizable features, CBPMDM assists designers in selecting appropriate modelling contexts, routines, and command strategies before geometry creation begins. The integrated example-based case study demonstrated that, compared to conventional unguided workflows, CBPMDM leads to clearer design intent embedding, improved parametric robustness, and more predictable model behavior under change. The results indicate that early, criteria-driven modelling decisions reduce trial-and-errors, support reliable modification of critical design parameters, and improve alignment between conceptual intent and parametric CAD structure, even for complex organic geometries. CBPMDM reframes CAD modeling as a strategy driven engineering process rather than a reactive sequence of commands. While further studies are required to evaluate the method across a broader range of products and user profiles, the presented findings suggest that CBPMDM offers practical value for both CAD education and professional design practice.

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