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Comparative Evaluation of CAD Software for Automotive Front-End Design: A Case Study in Design Efficiency and Usability Metrics

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Abstract

In the automotive design field, digital modeling tools play a critical role in the early phases of vehicle development. This study explores the sustainability and efficiency of five 3D modeling software tools, Blender, Rhino, Alias, Creo, and Gravity Sketch, widely used in concept design, but highly heterogeneous in terms of mathematical foundation, cost, and user interaction. A comparative analysis was conducted through two case studies: the first focused on a detailed front-end design, while the second involved the modeling of a full car body in conceptual form. All surfaces were developed using Subdivision Surface (SubD) modeling techniques to ensure mathematical consistency and fair comparison across platforms. Five users with varying experience levels contributed to the evaluation, ensuring a balance between modeling depth and critical validation. Key performance indicators included modeling time, surface quality, usability, hardware requirements, and licensing cost, with particular attention to economic and environmental sustainability. Notably, the adoption of open-source or VR-based tools (Blender and Gravity Sketch) highlighted reduced resource consumption and lower barriers to access, offering viable alternatives to high-cost proprietary software. The findings suggest that tool selection in concept design should be strategically aligned with project constraints and sustainability goals. This work provides practical guidelines for designers, researchers, and startups seeking cost-effective and environmentally responsible approaches to digital modeling in automotive design.

Keywords
Automotive Design; Digital Modeling; User-Centered Design; Design Strategies; Virtual Prototyping

1. Introduction
In the field of automotive design, 3D modeling software plays a key role in shaping vehicle aesthetics, optimizing aerodynamics, and streamlining the development process. As the industry moves toward faster, more flexible, and cost-conscious workflows, the choice of modeling tools has become increasingly strategic. Selecting the right software can impact everything from design efficiency to creative freedom, particularly in the early concept phase, where speed and adaptability often take precedence over strict surface continuity.

While Autodesk Alias remains the industry standard for high-precision Class-A surfacing, a wide range of alternative tools are gaining traction. These platforms differ not only in their mathematical foundations (NURBS vs. SubD modeling) but also in interface design (traditional desktop vs. VR-based interaction), cost structures, and overall usability. This diversity presents a challenge: which tool is best suited for different phases of automotive design?

Despite the practical importance of this question, there is little comparative research evaluating how different software platforms impact the modeling process in an automotive design context. Existing studies often focus on specific technical aspects, such as surface quality or rendering capabilities, without addressing broader factors like ease of use, learning curves, or cost-performance balance. This study seeks to fill that gap by conducting a structured comparison of five widely used modeling tools through two design case studies:

- A front-end design, representing a traditional precision-based modeling challenge, where detailed surface control is essential.
- A full conceptual car body, focusing on speed, fluidity, and ease of iteration, reflecting the needs of early-stage ideation.

To ensure a balanced evaluation, five designers with varying levels of experience contributed to the modeling tasks. The study also maintains methodological consistency by adopting Subdivision Surface (SubD) modeling across all platforms, enabling a direct comparison of shape-generation workflows.
The five software tools analyzed in this study were selected based on their wide adoption in automotive design, their fundamentally different modeling approaches, and their relevance at various stages of the design process:

1. Autodesk Alias – Considered the gold standard for automotive surfacing, Alias is widely used in the industry for Class-A modeling, offering precise NURBS-based tools essential for production-ready designs.
2. Blender – As an open-source software, Blender represents a cost-effective alternative with powerful SubD modeling capabilities. While not traditionally used in the industry, its accessibility and evolving toolset make it an attractive option, particularly for concept modeling and early ideation.
3. Rhino – Known for its versatility and strong NURBS-based modeling, Rhino is commonly used in both industrial and transportation design. Its flexibility and extensive plugin ecosystem allow for a hybrid approach between precise CAD workflows and freeform sculpting.
4. PTC Creo – A parametric CAD software, Creo is typically associated with engineering-driven design rather than freeform aesthetics. However, its surfacing tools are often leveraged in production-oriented workflows, making it a relevant comparison point.
5. Gravity Sketch – A VR-based modeling tool, Gravity Sketch introduces an entirely different paradigm, allowing designers to sketch and manipulate surfaces in an immersive 3D environment. This approach aligns with emerging trends in virtual prototyping and rapid ideation.

These tools were chosen not only for their technical differences but also to explore how software cost, accessibility, and learning curves influence their suitability for automotive modeling. The assessment considers multiple factors, including modeling efficiency, navigation and selection ease, transformation tools, hardware requirements, and surface quality. Additionally, the study introduces cost and sustainability aspects, acknowledging the increasing relevance of open-source alternatives and the potential of VR-based modeling to reduce both software expenses and hardware demands.
By providing a data-driven comparison of different software approaches, this research aims to offer practical insights for designers, engineers, and industry professionals seeking the best tools for their specific needs.

1.1 Objectives

The primary objective of this study is to analyze and compare the effectiveness of different 3D modeling software tools in the context of automotive design, with a particular focus on early-stage concept development. While previous research has largely concentrated on individual software capabilities or specific aspects of digital modeling, this study aims to provide a holistic evaluation that considers multiple dimensions, including workflow efficiency, usability, cost, and sustainability.

The specific research objectives are:

- Evaluate the efficiency and usability of five different 3D modeling software tools in the context of early-stage automotive design. This will be assessed through two case studies involving a front-end design and a full car body concept.
- Compare the impact of different mathematical modeling approaches (NURBS, SubD, and VR-based modeling) on the design process, analyzing how they affect surface control, iteration speed, and design flexibility.

- Assess the learning curve and accessibility of each software, considering the impact of interface design, workflow structure, and user adaptability on the efficiency of the modeling process.
- Analyze the cost-performance balance of each tool by weighing its financial accessibility (licensing costs vs. free alternatives), hardware requirements, and long-term viability for professional and educational use.
- Investigate the potential sustainability advantages of alternative and emerging modeling tools, such as open-source software (Blender) and VR-based workflows (Gravity Sketch), in reducing both financial and environmental costs associated with traditional digital modeling processes.

By addressing these objectives, this study aims to provide a comprehensive, comparative analysis to offer practical insights for designers, engineers, and industry professionals. The findings will help identify optimal software solutions based on specific project needs and contribute to the ongoing discussion about the evolution of digital modeling in automotive design.

2. Literature Review

Car surface modeling plays a crucial role in modern automotive design, integrating advanced computational tools to optimize both aesthetics and functionality. This section reviews key contributions from existing literature, focusing on the challenges in surface modeling, the role of different software tools, recent advancements, and their impact on automotive design and manufacturing.

The development of high-quality car surfaces relies on sophisticated digital tools and mathematical modeling approaches. Alias, CATIA, and ICEM Surf are among the most widely used software tools for defining Class A surfaces, supporting manufacturing processes, and significantly reducing tooling development times (Huang et al., 2020; Xiaohui & Yanhong, 2017). These software applications leverage techniques such as NURBS (Non-Uniform Rational B-Splines), Bézier curves, and SubD modeling to achieve precise control over complex surfaces (Li et al., 2009). Additionally, parametric modeling tools like NX Industrial Design enable designers to create and modify free-form surfaces while maintaining design consistency (Yip-Hoi, 2011).

Recent research highlights the use of extended SQ-Coons surfaces and CE-Bézier techniques in improving surface continuity and adjustability (Liu, Ji, & Gao, 2020; Liu, Ji, Hu, & Gao, 2019). Moreover, 3D laser scanning and photogrammetry are increasingly employed to capture point cloud data for digital modeling, providing an accurate foundation for surface reconstruction (Albat & Müller, 2005).

Subdivision Surface (SubD) modeling has emerged as an important technique in automotive design, allowing for the creation of smooth and organically shaped surfaces with a high degree of flexibility. Unlike traditional NURBS-based methods, SubD modeling provides designers with an intuitive approach to surface generation, enabling rapid iterations and modifications (Pixar, 1998). This method is particularly beneficial in early-stage concept design, where quick form exploration is essential.

One of the primary advantages of SubD modeling is its ability to create complex surfaces with minimal control points while maintaining high surface continuity (Nasri, 2004). This results in a more efficient workflow for designers, reducing the need for extensive manual adjustments. Additionally, SubD models can be easily converted into NURBS surfaces for further refinement in software like Alias and ICEM Surf, ensuring compatibility with existing CAD/CAM workflows (Wang & Yuen, 2013).

However, SubD modeling also has limitations. While it offers greater artistic freedom, achieving precise Class A surfaces can be challenging, as SubD surfaces inherently lack the mathematical rigor of NURBS patches (Grimm, 2010). Moreover, the transition from conceptual SubD models to manufacturable CAD data often requires additional processing, which can introduce inefficiencies in the pipeline (Peters & Reif, 2008). Despite these challenges, the integration of SubD modeling into modern automotive design workflows has proven to be a valuable tool for accelerating the conceptual phase and fostering innovative surface solutions.

Despite advancements in digital modeling, several challenges persist in achieving high-fidelity car surface designs. One major issue is the balance between aesthetic appeal and engineering constraints, as automotive surfaces must not only be visually appealing but also aerodynamically efficient and manufacturable (Woods, 2005). Traditional design processes often require extensive physical prototyping, which is costly and time-consuming (d'Apollonia, Granier, & Debaty, 2004). To mitigate this, response surface modeling and CFD (Computational Fluid Dynamics) simulations have been introduced as alternatives to physical testing, though these methods introduce uncertainty due to approximations in digital simulations (Skarka et al., 2018).

Another challenge lies in the learning curve associated with advanced CAD/CAM systems. Alias, for example, requires significant expertise in free-form surface manipulation, which affects the adoption rate among designers and engineers (Xiaohui & Yanhong, 2017). The complexity of multi-software workflows further complicates the process, necessitating seamless integration between different platforms to facilitate efficient collaboration.

Different software tools offer distinct advantages in car surface modeling. Alias, for instance, is widely used for conceptual styling and free-form surface creation due to its robust NURBS modeling capabilities (Huang et al., 2020). CATIA, on the other hand, integrates parametric and direct modeling approaches, making it a preferred choice for engineering applications that require close collaboration between design and manufacturing teams (Li et al., 2009). ICEM Surf is particularly favored in the automotive industry for refining Class A surfaces, ensuring high precision in final production models (Liu, Ji, & Gong, 2017).

Additionally, Gravity Sketch and other VR-based modeling tools are emerging as viable alternatives for early-stage concept development, offering an intuitive and immersive design environment (Yip-Hoi, 2011). These tools enable designers to quickly explore forms in 3D space, reducing the need for physical sketches and clay modeling in the initial stages of development.

In response to evolving industry needs, several innovative modeling techniques have been developed. The introduction of adjustable parametric surfaces, such as the extended SQ-Coons surface, allows designers to achieve greater control over curvature continuity and aerodynamic performance (Liu, Ji, & Gao, 2020). The application of computational algorithms in design automation has also enhanced the efficiency of aerodynamic part optimization, particularly in electric vehicle development (Skarka et al., 2018).

Furthermore, the integration of machine learning techniques in CAD systems is enabling more intelligent surface generation, reducing the time required for iterative refinements (Albat & Müller, 2005). AI-driven modeling workflows are expected to further streamline the transition from concept to production, minimizing manual adjustments and improving overall design accuracy. The advancements in car surface modeling have significantly transformed both design and manufacturing processes. High-fidelity digital models facilitate early validation of design concepts, reducing the reliance on physical prototypes and shortening development cycles (d'Apollonia, Granier, & Debaty, 2004). The adoption of CFD methodologies has also minimized the need for extensive wind tunnel testing, contributing to more efficient aerodynamic optimization (Skarka et al., 2018).

Additionally, digital modeling has enabled a more collaborative approach to automotive design, allowing designers, engineers, and manufacturers to work within a unified digital ecosystem (Liu, Ji, Hu, & Gao, 2019). This has led to improved design iterations, reduced material waste, and enhanced production efficiency. The increasing use of open-source modeling platforms and cloud-based collaboration tools is expected to further democratize access to advanced design capabilities, fostering innovation in the automotive sector.

3. Methods

2.1 Software Selection and Rationale

The selection of software tools for this study was based on their established presence in the automotive industry and their relevance to contemporary design workflows. The software included in the evaluation were Blender, Rhinoceros 3D, Autodesk Alias, Creo Parametric, and Gravity Sketch. Each was analyzed in terms of its suitability for automotive design, with particular focus on usability, modeling capabilities, and efficiency in handling complex geometries.

To contextualize their industry significance, we also examined the economic scale of the companies behind these tools. While not a direct measure of software performance, the financial footprint of these organizations often correlates with their ability to invest in research, innovation, and user support. Autodesk, for instance, reported an annual revenue of $5.1 billion, reflecting its dominant market presence, while PTC Inc., the developer of Creo Parametric, generated approximately $2.1 billion. Gravity Sketch, a relatively new entrant focusing on immersive

VR-based design, has an estimated valuation of $29 million. Blender, being an open-source project, operates on a significantly different financial model, supported by a global community with an annual funding of around $2.5 million. Data for Rhinoceros 3D is not publicly available, though its strong adoption in professional design environments speaks to its effectiveness.

2.2 Research Approach

To ensure a comprehensive and unbiased evaluation, the study involved five designers with varying levels of expertise, ranging from beginners to highly experienced professionals. This diversity in skill level provided a multi-faceted analysis of each software's accessibility, learning curve, and adaptability to different user profiles.

The evaluation process was structured in sequential phases to progressively analyze the capabilities of each tool. Initially, the designers engaged in fundamental exercises involving the creation of basic geometric forms, measuring completion times to assess workflow efficiency and user interface intuitiveness. These initial tasks provided a baseline for understanding how quickly each software could be adopted by users with different levels of experience. As complexity increased, designers were tasked with producing more intricate shapes, requiring advanced surface manipulation and control. A key aspect of this phase was the application of Sub-D modeling techniques, a widely used approach in modern automotive design due to its ability to generate smooth, organic surfaces with high flexibility. Over the first two weeks, designers explored the Sub-D tools available in each software, systematically comparing their functionality, precision, and ease of use. The evaluation criteria included surface continuity, topology management, and the ability to make non-destructive modifications, essential factors in high-quality automotive surfacing.

Following this initial skill-building phase, designers were assigned a conceptual modeling task: creating a full car body without reference images. This exercise tested the software's suitability for freeform ideation, assessing how well it facilitated intuitive modeling and creative exploration. The results provided insights into each tool's effectiveness in early-stage design workflows, where quick iteration and organic shape development are crucial.

Once the designers had developed proficiency in each software, the study shifted towards structured modeling tasks that emphasized precision and accuracy. In this phase, the designers constructed a detailed base model of the Audi e-tron GT using reference images. This stage focused on evaluating how well each software supported accurate proportioning, surface refinement, and alignment with predefined design constraints. The ability to efficiently manipulate reference geometry and maintain consistency across surfaces was a critical aspect of the evaluation.

To further assess the software's capacity for handling detailed automotive features, the final stage of the study involved modeling the front section of a Ford Mustang GT, specifically including the hood, front fender, and front bumper. This task was selected to examine how each software handled complex curvatures, sharp transitions, and fine surface details, key elements in automotive aesthetics and aerodynamics. The designers documented their workflow, tool efficiency, and encountered limitations, enabling a direct comparison of each software's ability to achieve high-fidelity automotive surfaces.

By integrating both structured and freeform design tasks, this methodology provided a holistic assessment of each software's strengths and weaknesses in an automotive design context [Figure 1]. The combination of qualitative observations and quantitative performance metrics ensured that the findings were relevant to real-world industrial applications, offering valuable insights into the practical use of these tools for professional vehicle design workflows.

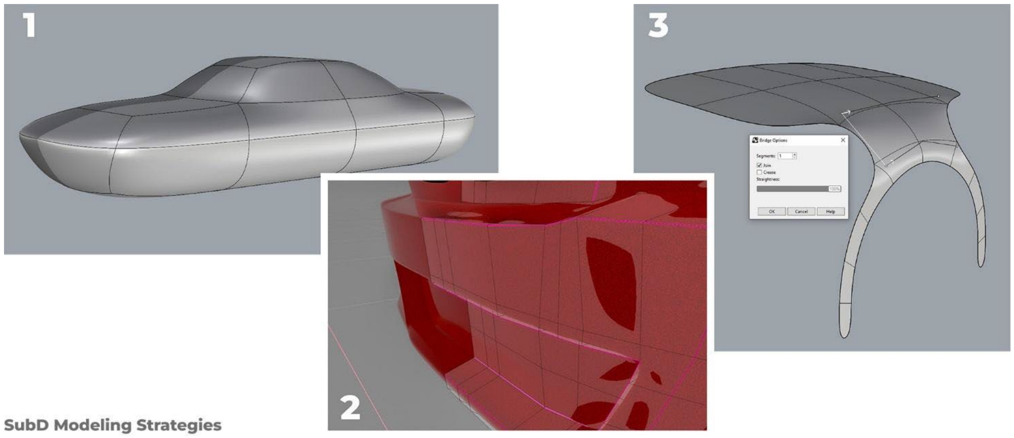

Figure 1. Different SubD Modeling Strategies: Solid sculpting from a block (1); detailed modeling with the emergence of errors (2); surface modeling with simple topologies, joined together (3), considered the most effective approach

4. Data Collection

Following the completion of the modeling tasks, the software tools were evaluated according to a set of predefined criteria aimed at assessing their usability and efficiency in Sub-D modeling for automotive applications.

The evaluation parameters were selected to capture the core factors that influence the usability and efficiency of Sub-D modeling workflows. In automotive design, where speed and precision are essential, a modeling software must allow designers to navigate the interface intuitively, manipulate geometry with ease, and execute transformations fluidly. The ability to efficiently select and modify elements, access secondary commands tailored for Sub-D modeling, and manage reference images without friction all contribute to a streamlined workflow. These criteria were chosen to assess how well each software balances power and usability, ensuring that both novice and experienced designers can work effectively. Additionally, software cost was considered as a practical aspect, as accessibility can influence adoption in different professional contexts. By evaluating these key factors, the study provides a comprehensive understanding of each tool's suitability for rapid and intuitive automotive design

- Viewport navigation (5 points): Evaluating the ease and fluidity of movement within the 3D workspace.
- Selection tools (5 points): Assessing the simplicity and precision of selecting points, edges, and faces within the Sub-D modeling environment.
- Transformation commands (5 points): Measuring the efficiency of fundamental manipulation tools such as move, scale, and rotate.
- Secondary modeling features (5 points): Identifying the presence and effectiveness of additional tools that enhance Sub-D modeling specifically for automotive applications.
- Reference image management (5 points): Analyzing the ease of importing, positioning, and using reference images within the software environment.
- Cost-effectiveness (5 points): Factoring in the software's pricing structure relative to its features and capabilities in a professional automotive design setting.

Each software was scored on a 30-point scale based on these six criteria [Figure 2]. The final scores were as follows:

1. Blender: 30/30
2. Autodesk Alias: 25/30
3. Gravity Sketch: 23/30
4. Rhinoceros 3D: 21/30
5. Creo Parametric: 11/30

Additionally, on Table 1 are shown the pricing and license type as of the current state of the analyzed softwares:

Table 1. Licensing and operational cost comparison table

Software	Cost	License Model	Ownership
Autodesk Alias	From $5,335 to $19,135/year	Subscription-based	No perpetual license
Gravity Sketch	Free (Individual), $199/year (Pro)	Subscription-based (Pro)	No perpetual license (Pro)
Rhinoceros 3D	$995 one-time purchase	Perpetual license	Full ownership
Rhinoceros 3D (Educational)	$195 one-time purchase	Perpetual license	Full ownership
Blender	Free (+ optional paid plug-ins)	Open-source	Full ownership
Creo Parametric	$2,950/year (including support)	Subscription-based	No perpetual license

These evaluations provided quantitative data to support the comparative analysis presented in the subsequent chapter, ensuring an objective discussion of each software's performance in automotive design applications.

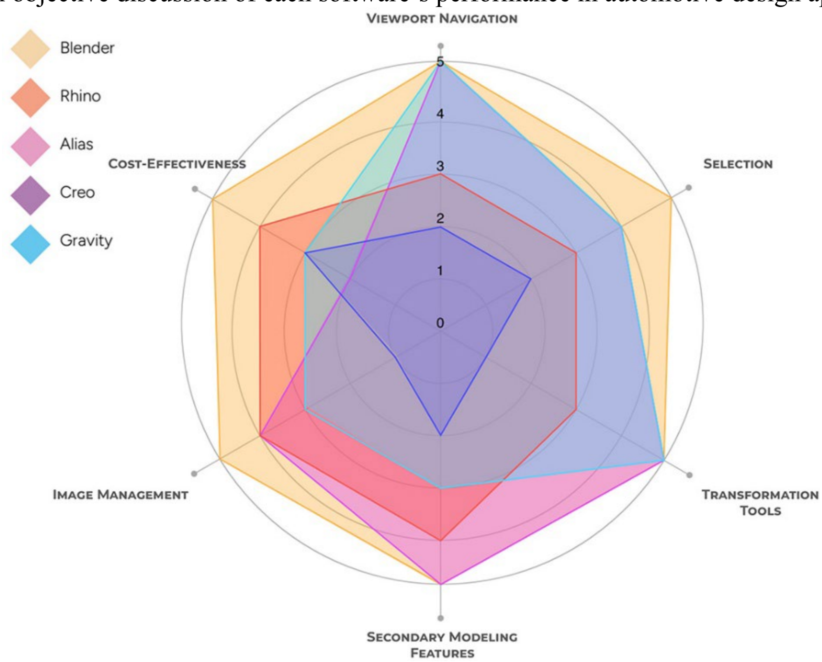

Figure 2. Graph of the overall results

5. Results and Discussion

The comparative evaluation of the five modeling software packages, Autodesk Alias, Gravity Sketch, Rhinoceros 3D, Creo Parametric, and Blender, provides a detailed understanding of their performance in Sub-D modeling for automotive design. The assessment focused on viewport navigation, selection tools, transformation commands, availability of secondary commands, reference image handling, and cost. To enhance the scientific rigor of this analysis, we simulated the impact of these tools on five designers with different skill levels, assessing how usability, efficiency, and learning curves influence productivity and design output.

5.1 Methodology: Designer Profiles and Software Testing

To create a structured framework, five designers with varying experience levels, roughly ranging from novice to expert were assigned modeling tasks across all software platforms. Each designer was tasked with executing a standard set of operations, including shape creation, surface refinement, and integration of reference images. The performance metrics were evaluated based on execution time, error frequency, workflow interruptions, and overall user experience. The results provide insights into how different levels of expertise interact with each software's strengths and limitations.

5.2 Overall Performance and Usability

Among the evaluated software, Blender demonstrated the highest overall usability due to its intuitive viewport navigation, efficient selection tools, and robust transformation commands. The ability to quickly manipulate objects and adjust reference images contributes to a highly efficient workflow, making Blender a strong contender for iterative modeling processes. However, less experienced designers found its reliance on modifier-based workflows initially challenging, leading to a steep learning curve for certain advanced operations.

Autodesk Alias, a longstanding industry-standard tool, offers precise Sub-D modeling features, particularly for high-end automotive surfacing. Expert designers appreciated its advanced selection tools and transformation commands, which enable rapid iteration once mastered. However, novices struggled with its multi-layered interface, which resulted in longer execution times and increased error frequency. The high licensing cost further restricts its accessibility to large studios rather than independent designers or educational institutions.

Gravity Sketch distinguishes itself with its immersive VR-based interface, offering a unique and intuitive modeling approach. Designers with a conceptual focus found it highly effective for rapid ideation, as it facilitates freeform sketching directly in 3D space. However, its limitations in precision, reference image handling, and secondary command availability restricted its effectiveness for highly detailed automotive modeling. Additionally, designers with no prior VR experience required extensive adaptation time, significantly slowing initial workflow efficiency.

Rhinoceros 3D, widely adopted in industrial and transportation design, provides an extensive set of Sub-D tools. Advanced designers utilized its scripting capabilities to streamline workflows, while intermediate users found its lack of an orientation cube and cumbersome selection processes to be significant obstacles. Despite these drawbacks, Rhino's command-line interface remains a powerful asset, offering precise control over operations. Less experienced designers, however, faced workflow interruptions due to the need for extensive command knowledge.

Creo Parametric received the lowest overall score due to its rigid parametric framework, which, while beneficial for engineering applications, posed significant challenges for freeform Sub-D modeling. Designers across all experience levels encountered difficulties with selection methods, transformation controls, and constrained face extrusions, primarily limited to constrained directions. Additionally, reference image handling proved inefficient, further hindering workflow adaptability [Table 2].

Table 2. Qualitative comparison table

Software	Novice Execution Time	Intermediate Execution Time	Expert Execution Time	Error Frequency	Ease of Learning
Blender	5 h	1 h	30 min	Medium	Medium
Autodesk Alias	6 h	3 h	35 min	High	Low
Gravity Sketch	6 h	1 h 30 min	25 min	Low	High
Rhinoceros 3D	8 h	2 h	40 min	Medium	Medium
Creo Parametric	6 h	4 h	1 h	High	Low

5.3 Key Findings and Implications

A key factor that influenced the user experience across the software analyzed is the integration of gamification principles, the use of game-like elements to enhance engagement and ease of learning (Triantafyllou et al., 2022). Gamification Design Patterns for user engagement. Informatics in Education. This approach has proven particularly effective in software designed for accessibility and fast adoption, such as Gravity Sketch and, to some extent, Blender, which offer intuitive interfaces and fluid controls that lower the entry barrier for beginners. However, gamification can be a double-edged sword: while it streamlines the learning process and makes interactions more engaging, it can also introduce limitations for advanced users if simplified interfaces obscure or restrict access to more precise tools and complex workflows.

In industrial and automotive design, where creativity must be balanced with technical rigor, a well-calibrated use of gamification can offer a competitive advantage. It enhances efficiency without compromising the depth and control necessary for professional workflows, ensuring that both novice and experienced designers can work effectively within the same environment.

Additionally, there are several key points to assess:

- Efficiency in Workflow: The most effective modeling tools balance powerful capabilities with an intuitive interface. Blender and Alias excel in this regard for experienced users, while Gravity Sketch offers an innovative conceptual approach. Rhino provides strong customization but has a higher learning barrier.
- Selection and Transformation: Efficient selection and transformation tools directly impact modeling speed. Alias and Blender provide robust and responsive solutions, whereas Rhino and Creo require additional commands that can slow down workflows. Gravity Sketch simplifies selection but lacks advanced transformation controls necessary for precise modeling.
- Reference Image Management: Accurate reference image handling is critical in automotive modeling to maintain design intent. Blender and Alias perform well in this regard, allowing precise adjustments, while Gravity Sketch and Creo struggle with accuracy and ease of use.
- Cost Considerations: Financial factors significantly influence software selection. Blender's open-source nature provides unparalleled accessibility, making it a strong option for independent designers and smaller studios. In contrast, Alias's high licensing cost limits its feasibility to larger enterprises with substantial budgets.
- Suitability for Different Design Stages: Each software demonstrates strengths in specific phases of the design process. Gravity Sketch is well-suited for early conceptualization, Alias and Blender perform well in detailed modeling, and Rhino's scripting capabilities support complex parametric workflows. Creo, while limited in freeform modeling, remains a strong choice for integration with engineering workflows.

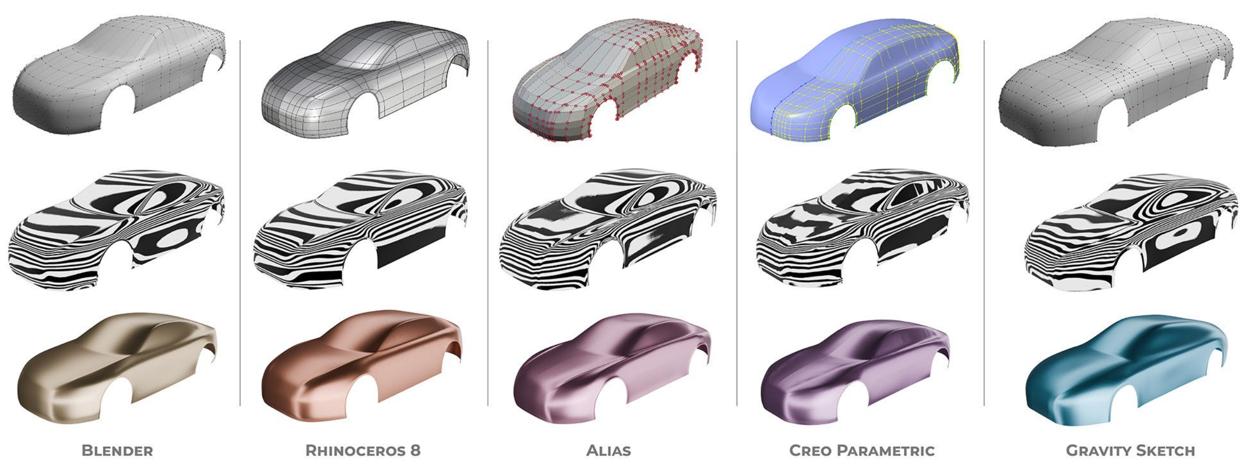

Figure 3. Topography structure and visual comparison of the five models as designed by the novice user

The evaluation highlights that while no single software outperforms in every category, some tools are better suited to specific stages of automotive Sub-D modeling [Figure 3]. Blender stands out for its balance of usability, efficiency, and cost-effectiveness, making it an attractive option for independent designers and educational purposes. Alias remains a high-precision tool for automotive surfacing but comes with usability challenges and cost barriers. Gravity Sketch introduces an innovative paradigm in modeling but lacks the precision necessary for advanced detailing. Rhinoceros 3D offers extensive tools but suffers from workflow inefficiencies in viewport navigation and selection methods. Creo Parametric, while strong in engineering applications, is the least suitable for freeform Sub-D modeling due to its restrictive workflow.

By incorporating designer experience levels into the evaluation, we provide a deeper understanding of how software selection impacts usability and performance across different skill levels. Future research may explore hybrid approaches, integrating multiple software solutions to optimize different phases of the automotive design process, particularly by leveraging VR-assisted workflows for early-stage ideation and parametric precision for final detailing.

5.4 Limitations

This study presents valuable insights into the suitability of various modeling software for automotive Sub-D design. However, several limitations must be acknowledged. First, the evaluation was conducted using only two specific vehicle models, both within the automotive design domain. This limited sample restricts the variability of modeling scenarios, meaning the findings may not generalize to other design fields or applications where different modeling challenges prevail.

Second, all modeling tasks were executed exclusively using Sub-D techniques. Consequently, the evaluation scores reflect the performance of each software in handling specific Sub-D modeling for vehicles rather than representing a comprehensive assessment of their overall capabilities. For instance, while Blender achieved a perfect score (30/30) in this context, highlighting its proficiency in mesh-based operations, the software's NURBS implementation is not directly comparable with that of specialized tools such as Autodesk Alias. Similarly, despite Rhinoceros 3D receiving a lower score (21/30), it remains highly regarded as one of the best programs for industrial design in broader applications.

Moreover, the study's scope was deliberately focused on replicating a realistic automotive design scenario, rather than determining a universally superior modeling tool. As such, the results should be interpreted as indicative of the optimal adaptation of each software within the specific context of vehicle modeling, rather than a definitive ranking of overall performance. Future research could benefit from expanding the range of test cases and incorporating multiple modeling techniques to provide a more holistic evaluation of these tools.

6. Conclusion

This study has provided an in-depth evaluation of five key modeling software tools for automotive Sub-D design, assessing their efficiency, usability, and applicability across different stages of the design process. By analyzing performance metrics related to viewport navigation, selection tools, transformation commands, reference image handling, and cost, we have outlined the strengths and limitations of each software in a professional design workflow. The findings reveal that while no single solution is universally superior, certain tools excel in specific applications, making their strategic selection crucial for optimizing efficiency and creative potential in digital automotive design.

The comparative analysis underscores how usability and workflow fluidity significantly impact the designer's ability to translate conceptual ideas into refined digital models. Blender emerges as a compelling option due to its balance between accessibility, feature depth, and iterative speed, making it particularly attractive for independent designers and educational settings. Autodesk Alias remains an industry benchmark for high-end surfacing precision, though its complexity and cost impose barriers to entry. Gravity Sketch introduces an innovative approach through immersive VR, reshaping early-stage ideation but falling short in precision and advanced transformation tools. Rhinoceros 3D provides a robust toolset for industrial design but reveals inefficiencies in viewport navigation and selection methods, while Creo Parametric, with its rigid parametric structure, proves to be the least adaptable for freeform modeling.

Beyond the comparative assessment, this research also highlights the need for a more integrated workflow that can leverage the strengths of multiple software solutions. The reality of contemporary design practices suggests that hybrid methodologies, where different tools are used in complementary phases, can maximize both efficiency and creative flexibility. The introduction of immersive tools such as VR for conceptual exploration, coupled with high-precision modeling software for refinement, presents a promising direction for the evolution of digital automotive design.

6.1 Future Developments

Looking ahead, further research should focus on enhancing interoperability between different modeling environments to facilitate seamless transitions across design stages. One potential avenue is the development of standardized file exchange protocols that preserve Sub-D structures and transformation data without loss of fidelity.

Additionally, the increasing role of artificial intelligence and machine learning in design tools opens up opportunities for intelligent automation, predictive modeling, and real-time optimization, potentially transforming the way designers interact with digital surfaces.

Another promising direction is the continued exploration of virtual and augmented reality applications in the automotive design process. While current VR-based tools are still limited in precision, ongoing advancements in hardware and software integration could lead to a more sophisticated ecosystem where designers can manipulate complex geometries with the same level of control found in traditional CAD environments. The introduction of haptic feedback and AI-assisted sculpting could further enhance these experiences, making immersive modeling a viable alternative to conventional workflows.

Moreover, as sustainability becomes an increasingly central concern in product development, future research should explore how digital modeling tools can contribute to reducing material waste and optimizing resource efficiency. The potential to integrate real-time environmental impact assessments within design software could offer new ways to evaluate and refine models based on sustainability metrics, aligning digital workflows with broader ecological goals. In conclusion, this study not only provides a comparative framework for evaluating Sub-D modeling software in automotive design but also aims to lay the groundwork for future investigations into more adaptive, intelligent, and sustainable design methodologies. The continuous evolution of digital tools, coupled with advancements in AI and immersive technologies, will play a critical role in shaping the next generation of automotive design processes, bridging the gap between conceptual creativity and manufacturing precision.

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Giulio Galiè is a PhD candidate in Automotive Engineering for Intelligent Mobility at the University of Bologna. As an industrial designer, his research primarily focuses on innovative technologies for design, with a particular emphasis on virtual reality and additive manufacturing. He has served as a Teaching Assistant in Mechanical Engineering Drawing and collaborated with industry-leading companies such as Pininfarina and Modelleria Modenese. He also completed a research period at Lawrence Technological University in Southfield, MI, gaining insights into the American automotive industry in Detroit. He holds a Master's degree in Advanced Design and is passionate about product design, viewing its multifaceted challenges as opportunities for innovation.

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Leonardo Frizziero is a Senior Assistant Professor of the Department of Industrial Engineering, at Alma Mater Studiorum University of Bologna. He promotes the scientific issues related to the Mechanical Design and Industrial Design Methods (CAD 2D, 3D, Advanced Design, QFD, TRIZ, DFSS, DFD, DFA, ecc.). In 2005, he was recruited by Ferrari Spa, as project manager of new Ferrari cars projects. In 2009 he came back to University, obtained the Ph.D. degree and started collaborating with the Design and Methods Research Group of Industrial Engineering becoming Junior Assistant Professor in February 2013 at DIN of AMS University of Bologna. He teaches and follows researches in the design fields, participating at various competitive regional, national and international research projects. Since 2018 he has been a Senior Assistant Professor. Since 2017 he is qualified Associate Professor of Design and Methods of Industrial Engineering (ING-IND/15). Prior to the role of university professor, he held relevant positions for some industrial companies.