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Exploring the Usability and Future Development of AI-Generated 3D Models in CAD Workflows and the Metaverse Based on 3D Model Standards

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Abstract. This study explores the usability of AI-generated 3D models in metaverse applications, focusing on topology structure, UV layout, and compatibility with CAD models. Through evaluations based on 3D model standards and expert interviews, the study identified key deficiencies, including inconsistencies in edge loops, UV layout design, and texture mapping issues. These challenges hinder the performance of AI-generated models in real-time rendering, animation production, and CAD workflows. To address these issues, the study proposes a multi-step validation framework encompassing topology inspection, UV layout validation, and geometric quality checks aimed at improving the compatibility and practicality of AI-generated 3D models. The findings provide recommendations for advancing AI 3D modeling technology and propose a usability framework for evaluating the compatibility of CAD models.

Keywords: Artificial Intelligence; AI 3D modeling; 3D model topology; UV layout; metaverse; CAD models
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1 INTRODUCTION

In recent years, the concept of the "metaverse" has evolved from science fiction to reality, driven by technological advancements and becoming a key enabler of virtual and physical integration. The application of 3D models in CAD workflows extends beyond precise design, prototyping, and engineering validation, offering the potential for bridging virtual and real environments. As noted by Lo and Tsai [18], 3D models not only facilitate the creation of realistic simulations but also enable greater possibilities in virtual spaces, supporting user immersion, interaction, and exploration. Specifically, in the metaverse, CAD models contribute to enhancing the connection between virtual and real-world environments, enabling benefits such as asset reusability, cross-platform compatibility, and flexibility for diverse applications. However, CAD models differ from the real-time rendering models typically required in the metaverse, which are focused on visual performance. The compatibility and adaptability of these two approaches for different scenarios require further exploration.

While CAD models offer certain advantages, current manual modeling processes often involve a series of time-intensive steps. According to Labschütz et al. [14], a team of 26 students spent approximately 1,550 person-hours completing the game *Dynamite Pete*. The time allocation for 3D modeling was as follows: 500 person-hours for low-poly modeling, 50 person-hours for high-poly modeling, 150 person-hours for UV unwrapping, 190 person-hours for texture painting, and 20 person-hours for rigging. These figures indicate that low-poly modeling demands higher time investment as it involves building initial structures from scratch and balancing visual quality and performance. High-poly modeling, on the other hand, builds upon low-poly models and often employs tools like subdivision and sculpting, which reduces the time required. However, these time allocations might vary depending on project requirements and tool usage, which warrants further clarification of the data's context and methodology.

The high costs associated with manual modeling not only limit the creation of large-scale metaverse environments but also restrict non-professionals from participating in 3D modeling. Nonetheless, advances in artificial intelligence (AI) have opened new opportunities to address these challenges. For example, NVIDIA's NeRF (Neural Radiance Fields) technology, demonstrated in March 2022, can quickly generate fully rendered 3D scenes from a small number of static photos, significantly reducing production time. While this innovation holds great potential for industries such as gaming, film editing, and architectural design, its application in CAD modeling, which demands higher structural accuracy, remains to be validated.

From a technical perspective, AI modeling primarily relies on deep learning frameworks such as TensorFlow or PyTorch. These algorithms learn data features to generate new models or optimize existing ones. Huynh-The et al. [11] highlighted that AI technology can enhance the visual effects and realism of virtual worlds. However, whether AI-generated models can meet the geometric precision, topological integrity, and UV layout standards required by CAD workflows remains uncertain. Ratican, Hutson, and Wright [25] noted that AI technology enables non-professionals to create high-quality 3D models, reducing barriers and costs for content creation. However, in scenarios demanding high engineering accuracy and structural requirements, AI still requires human intervention to ensure reliability.

Manual modeling continues to dominate professional fields, particularly in CAD workflows. CAD models, often used for product design, engineering simulations, and manufacturing, impose strict requirements on parameter control, mesh quality, and UV layout. These demands make them difficult to achieve solely through AI-generated models. Unlike optimized real-time rendering models used in game development, CAD models prioritize structural integrity and geometric precision, further limiting AI's immediate applicability in such contexts.

Even so, AI modeling has the potential to complement manual modeling. By combining AI-generated preliminary models with human refinements, it can improve efficiency and lower technical barriers for non-professionals. Future efforts should focus on validating AI-generated models in CAD workflows, particularly in areas such as topology verification, UV unwrapping, and geometric consistency, to ensure seamless integration into CAD processes.

As Mystakidis [22] noted, the scope of 3D model applications in this study is closely tied to extended reality (XR) technologies, including multiplayer online games, open-world games, and interactive 3D environments. Integrating CAD models into these technologies requires emphasis not only on visual fidelity but also on structural integrity, geometric precision, and cross-platform compatibility. These features are crucial in fields such as engineering, architecture, and industrial design. Particularly in VR, AR, and MR, CAD models must maintain accurate dimensions, compatibility with simulation tools, and support for interactive modifications to meet the demands of immersive design reviews, prototyping, and collaborative design sessions.

In conclusion, this study aims to explore the potential applications of AI-generated 3D models in CAD workflows and the metaverse, focusing on the following topics:

1. Evaluating the usability of AI-generated 3D models in CAD workflows and metaverse environments, particularly in terms of topology structure, UV unwrapping, and geometric quality.
2. Investigating how AI modeling can complement or partially replace manual modeling in CAD-based design and engineering workflows.
3. Providing recommendations for the future development of AI modeling, specifically in improving compatibility with CAD workflows and supporting structural validation.

2 RELATED WORK

2.1 The Application and Relationship of 3D Models and CAD Technology in the Metaverse

Lee et al. [24] pointed out that the metaverse is characterized by a high degree of interactivity and immersion. Users can interact with virtual objects in the metaverse as if they were physically present in the virtual environment. Similarly, Li et al. [16] mentioned that the realistic nature of the metaverse enhances user immersion, making them feel as though they exist within the virtual world. Additionally, Li et al. emphasized the interoperability and scalability of the metaverse, which can support a large number of users simultaneously, providing a seamless and uninterrupted experience. Bojic [3] argued that the metaverse emphasizes users' sense of presence, enhancing interaction through avatars' facial expressions, gestures, and realistic visual experiences. Based on these characteristics, the metaverse can be categorized into three main dimensions: immersion, interactivity, and complexity of scale.

These characteristics of the metaverse are closely related to the application of 3D models. Dionisio, Burns III, and Gilbert [7] stated that 3D models create high-quality virtual environments and avatars, allowing users to experience psychological and emotional immersion, thereby increasing the appeal of the metaverse. Therefore, 3D models are indispensable for both the metaverse and its users. Moreover, 3D models are closely linked to computer-aided design (CAD). CAD, as a core tool for 3D modeling, not only supports precise geometric modeling but also facilitates the creation of designs that meet structural and functional requirements, which is critical for virtual environments and interactive scenarios in the metaverse.

In terms of specific relationships, the metaverse aims to provide a highly immersive virtual experience. To achieve this goal, 3D models must possess high visual quality to meet users' visual demands. Additionally, the scenes in the metaverse typically exhibit a high degree of interactivity, requiring 3D models to have good deformation capabilities. Whether it is character animation, physical collision, or object manipulation, 3D models need to move smoothly to ensure that users' interactions are fluid and natural. At this point, the finely crafted topology and optimized mesh design generated through CAD can significantly enhance the deformation performance of 3D models. Furthermore, the metaverse often involves large and complex virtual environments, necessitating the efficient handling of a vast amount of 3D model data. In large-scale virtual scenes, the polygon mesh count and texture size of models need to be balanced to avoid performance issues in rendering and to maintain a good user experience. The parametric design functionality provided by CAD can also support large-scale environments in the metaverse, reducing resource burdens through automated design processes.

Finally, according to Kochetov [13], 3D models can be visually categorized into two major types: hard surface models and organic models. Hard surface models refer to objects with a rigid visual feel, such as metals and inorganic materials. These surfaces are typically flat, sharp, and have distinct edges. Examples include mechanical parts, metal armor, and architectural structures, which rely heavily on the precision modeling capabilities of CAD systems. On the other hand, organic models refer to objects with a soft visual feel, such as biological and organic materials. These surfaces usually have undulations, curves, and natural transitions. Examples of organic models include animal skins, plants, and human facial expressions. These distinctions are illustrated in Figure 1.

(a) Hard surface (b) Organic models

Figure 1: Examples of 3D modeling types.

2.2 The Workflow of AI-Generated 3D Models

This section outlines several major AI modeling techniques that not only represent the latest advancements in the field of 3D modeling but also demonstrate the principles of current AI modeling workflows.

Firstly, Neural Radiance Fields (NeRF) is an innovative modeling technique that converts 2D photos into 3D scenes. According to Mildenhall et al. [21], NeRF employs a fully connected neural network, specifically a multi-layer perceptron (MLP), which directly learns the 3D representation from 2D images. This technique breaks through traditional modeling methods, efficiently producing realistic and natural 3D rendering results.

Subsequently, Poole et al. [24] proposed the DreamFusion technique, a method that combines AI-generated images from text with NeRF technology. DreamFusion transforms textual descriptions into 3D models, enhancing the efficiency and intuitiveness of 3D modeling. For example, a 3D model can be generated from a natural language description such as "a peacock standing on a surfboard."

Further advancing this field, Lin et al. [17] introduced Magic3D, a technique built on the foundation of DreamFusion. Magic3D employs a two-stage generation strategy, transitioning from coarse to fine detail to optimize 3D models. Additionally, Magic3D allows for modifications through prompting, enabling users to fine-tune models to generate 3D representations with specific styles or features.

Lastly, to ensure the consistency of 3D models generated from textual descriptions from any viewpoint, Shi et al. [26] developed the MVDream technique. This technique uses a multi-view diffusion model, ensuring that 3D models created by MVDream maintain high visual consistency across different perspectives, avoiding discrepancies due to varying viewpoints. Beyond text-to-3D model generation, Long et al. [19] proposed Wonder3D, which can convert single-view images into highly accurate and textured 3D models. This automated and efficient process not only lowers the knowledge threshold for creating 3D models but also saves operational time.

Based on these foundational technologies, current AI modeling techniques allow users to generate 3D models from simple text descriptions or images quickly. This significantly improves modeling efficiency, reduces technical barriers, and broadens the range of people who can produce 3D models. The advantages of AI modeling techniques are mainly reflected in the following aspects: (1) Efficiency: significantly reduces the time required for 3D modeling, enabling one-click generation of 3D models; (2) Usability: users only need to provide simple inputs without needing professional modeling skills; (3) Consistency: ensures that 3D models maintain high consistency across different viewpoints, avoiding issues of visual discordance; (4) Flexibility: allows model fine-tuning through prompts to generate 3D models with specific styles or features; (5) Innovation: breaks the framework of traditional modeling methods, enabling automated conversion from text or images to 3D models.

2.3 Usability Standards for 3D Models and application to CAD models

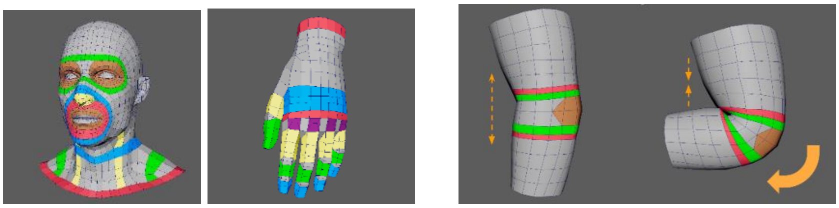
Based on the analysis of the relationship between the metaverse and 3D models, the visual quality of 3D models directly impacts user immersion. In 3D models, visual appearance is imparted by texture information. Textures, which are images applied to the surface of 3D models, represent material and details. Their accuracy and clarity are critical factors determining visual quality. The ability of textures to accurately and clearly represent details depends on the UV layout of the 3D model.

Overall, UV layout, UV mapping, and UV unwrapping are critical processes in 3D modeling, ensuring that textures are correctly applied to the surface of 3D models. (1) UV layout refers to unfolding the surface of the model into a 2D plane and generating UV coordinate maps; (2) UV mapping is the process of applying the 2D texture to the surface of the 3D model, which involves correctly aligning each part of the 2D texture with the corresponding part of the 3D model to ensure the texture appears correctly; (3) UV unwrapping is the specific operation of UV layout, i.e., unfolding the surface of the 3D model into a plane. According to Heikkilä [9] guide, several key points should be considered during UV unwrapping: (1) The rationality of scale and seams: During UV unwrapping, the model's proportions and the placement of seams should be carefully considered. Seams should ideally be placed away from prominent areas to ensure there are no visible seam marks in the final rendering; (2) Maintaining consistent proportions in the unwrapped UV parts: Each part should be scaled proportionately to prevent texture distortion. This means that in the unwrapped UV layout, all parts should be proportionately scaled to ensure the texture aligns correctly. An example of UV layout is shown in Figure 2.

(a) UV layout (b) UV with corresponding texture

Figure 2: UV examples.

In the metaverse, high interactivity is closely related to the deformability of 3D models. This means that 3D models need to have flexible and precise deformability to allow users to interact naturally and smoothly in the virtual environment. Additionally, to ensure the smooth operation of large virtual environments, the data volume of 3D models must be effectively controlled, requiring a balance between model complexity and rendering performance. In essence, this implies that 3D models should have a reasonable polygon count limit and a simple yet structurally appropriate topology. An example of topology is shown in Figure 3.



(a) Topology layout (b) UV motion and topology deformation

Figure 3: Topology examples.

These requirements are crucial for AI-generated CAD models, especially for interactive or simulation-based applications. Gao et al. [8] and Bahirat et al. [2] observed that increased polygon counts significantly reduce frame rates. For instance, Cheng et al. [6] demonstrated that reducing a model's polygon count from 21 million to 2.5 million achieved a smooth VR experience at 82 frames per second. Similarly, Chang and Shao [5] noted that optimized topology can reduce polygon counts while maintaining structural integrity and detail, which is particularly relevant for games and animation.

For CAD models, adhering to these standards enhances compatibility with simulation platforms and reduces computational demands. By limiting polygon counts and applying efficient topology optimization, CAD models maintain high visual fidelity while supporting real-time interaction in AR/VR environments. This ensures smooth navigation and interaction, making them suitable for immersive design reviews, virtual prototyping, and interactive product demonstrations.

In summary, usability standards for 3D models—particularly UV layout, polygon count, and topology—are equally applicable to CAD models. Effective UV layout and accurate texture mapping improve visual quality, while controlling polygon counts and optimizing topology ensures smoother interactions and better performance in virtual environments. These standards establish a robust framework for validating AI-generated CAD models, ensuring their suitability for immersive and interactive applications.

3 MEHODS FOR VALIDATING THE APPLICABILITY OF AI-GENERATED 3D MODELS

This experiment involved experts in the field of 3D modeling, who utilized AI tools to generate 3D models. The usability of these AI-generated 3D models in the metaverse was evaluated based on the standards of 3D model topology and UV layout, as well as feedback obtained from expert interviews. This section will detail the subjects and procedures of the experiment, the classification of AI-generated 3D models, and the usability evaluation standards for these models.

3.1 Experiment and Interview Subjects

The expert team participating in this experiment consisted of eight "3D domain experts" from Reallusion Technology in Taiwan, including four 3D technical artists and four 3D animators. The 3D technical artists have a comprehensive understanding of the production process and structure of 3D models, enabling them to thoroughly evaluate AI-generated 3D models to ensure their fundamental structure, mesh quality, and UV layout meet industry standards. The 3D animators further examine the topology of these models to ensure their suitability for animation production. The researchers conducted semi-structured interviews with the experts, based on the criteria listed in Tables 1 and 2, to gather their assessments of the topology, mesh quality, and UV layout of the AI-generated 3D models.

Criterion	*Description*
Polygon Count and Basic Topology	Examine the fundamental structure of AI-generated 3D models to ensure that the polygon count, topology, and mesh quality meet industry standards.
UV Layout	Evaluate the UV layout of AI-generated 3D models to ensure there is no stretching or overlapping of textures, which could affect the rendering results.
Model Editability	Assess the editability of AI-generated 3D models to ensure they are compatible and flexible for subsequent modifications and refinements.

Table 1: Evaluation criteria for "3D technical artists" interviews.

Criterion	*Description*

Animation Topology	Examine the topology structure of AI-generated 3D models to ensure their suitability for rigging and deformation. This includes checking the mesh quality and distribution at critical joints to prevent unnatural deformations during animation.

Table 2: Evaluation criteria for "3D animators" interviews.

3.2 Experiment Procedure and Classification of AI-Generated 3D Models

The experiment begins with a detailed explanation of the AI modeling process for generating 3D models from text or single images. Each expert is provided with technical guidance to ensure a clear understanding of the process. Afterward, the experts use the AI modeling tool "Meshy" to generate 3D models. The total experiment duration is approximately 30 minutes for each expert. Meshy was chosen as the primary AI modeling tool due to its versatility and user-friendly interface. It allows for 3D model generation using either text descriptions or single images, accommodating experts with varying levels of technical expertise. Meshy's key features include automatic UV texture mapping, quad-based topology generation, and face count control, all of which are essential for ensuring precise mesh and topology quality. Additionally, Meshy provides clear copyright guidelines, enabling users to utilize the generated models without legal concerns.

To evaluate the application performance of AI-generated 3D models, the models are categorized into "hard surface" and "organic modeling" themes. This classification aligns with the concept presented by Boulos [4] in "Abstract and Stylized Design in 3D Animated Films," where objects in 3D modeling are generally divided into two main categories: (1) Characters; and (2) Props. The visual styles for the models are further divided into the following categories: (1) Realistic; (2) Cartoon; (3) Low-Poly; (4) Sci-Fi; and (5) Fantasy.

This study's classification framework is based on two primary perspectives: visual categories ("hard surface" and "organic modeling") and subject types ("characters" and "props"). For the hard surface category, which focuses on objects with rigid visual characteristics like metal and inorganic materials, relevant styles include Low-Poly and Sci-Fi, which often incorporate mechanical elements. For the organic modeling category, which focuses on objects with softer, biological features, relevant styles include Realistic, Cartoon, and Fantasy. As the Realistic style aims to replicate real-world objects with high accuracy, it is treated as a distinct test target from the Cartoon and Fantasy styles. Each visual category (hard surface and organic modeling) includes both characters and props as subject types. The classification of AI-generated 3D models is shown in Table 3 below.

Hard Surface		*Organic Modeling*	
ID	**Character**	**ID**	**Character**
A	Low-Poly Style	A	Realistic Style
B	Si-Fi Style	B	Cartoon/Fantasy Style
ID	**Props**	**ID**	**Props**
E	Low-Poly Style	G	Realistic Style
F	Si-Fi Style	H	Cartoon/Fantasy Style

Table 3: Classification of AI-generated 3D models.

To ensure a systematic and consistent generation process, the researchers assigned 3D model themes from Table 3 to eight experts, with each expert tasked to generate a specific type of model. For example, one expert created a low-poly style character to test AI modeling performance on hard surface characters, while another generated a realistic-style prop to evaluate AI modeling's effectiveness for organic props. Other experts worked on various combinations, such as cartoon-style characters and sci-fi-style props, to explore AI modeling's application across different styles and subjects.

The generation process required experts to input text descriptions and relevant keywords specific to the tested model type. To maintain consistency, unified prompts were designed for characters, props, hard surface models, and organic models. Generic terms like "character," "prop," "hard surface," and "organic model" served as primary guidance keywords.

For hard surface models, experts used descriptive keywords such as "mechanical," "metallic," and "sci-fi" to emphasize mechanical and futuristic characteristics. For organic modeling, keywords like "skin," "muscle," and "natural texture" highlighted organic and biological features.

To align with the classification categories in Table 3, structured keyword prompts were provided for each model type. For instance:

- **Type C** (Character, Organic, Realistic Style): Keywords include "an elf girl with long blonde hair, pointy ears, symmetrical, medieval style, high quality, beautiful, glowing jewelry, character, organic modeling, realistic style."
- **Type G** (Prop, Organic, Realistic Style): Keywords include "a valuable ruby and jade necklace, golden framing, ancient, mythical, prop, organic modeling, realistic style."

The fixed keywords "character, organic modeling, realistic style" or "prop, organic modeling, realistic style" ensured alignment with the classification categories. Experts could further refine the model descriptions by adding details such as "a long-haired elf girl with golden hair" or "medieval style" to highlight specific features. This prompt design not only distinguished the eight styles but also standardized the generation criteria while offering experts flexibility to enhance model characteristics.

3.3 Usability Evaluation Criteria for AI-Generated 3D Models

For usability evaluation of AI-generated 3D models, the primary criteria are based on the mesh count, topology structure, and quality of the UV layout, as discussed in the literature review. In addition to quantitative data, this study also collects expert insights through interviews, providing a comprehensive evaluation of AI-generated 3D models from different perspectives to enhance the completeness and accuracy of the assessment.

3.3.1 Basic usability testing standards

Based on the industry's fundamental testing standards for 3D models, this study first uses Blender's 3D Print Toolbox plugin to conduct basic tests on AI-generated 3D models to identify any common structural errors. These specific testing items are listed in Table 4. While these testing standards have been widely applied in fields such as 3D modeling, animation production, game design, and 3D printing to ensure geometric and topological integrity and accuracy, they are also directly relevant for validating AI-generated CAD models, which often require stringent topological and geometric consistency to be effectively utilized in downstream CAD processes.

When integrated into a CAD-oriented workflow, these basic checks help ensure that the AI-generated models meet the rigorous requirements of CAD kernels and parametric modeling systems. For example, detecting and correcting non-manifold edges or bad contiguous edges at an early stage allows the model to be more easily processed by CAD software for subsequent feature operations, such as Boolean operations, surface extensions, and parametric modifications. Similarly, identifying intersecting faces, zero-area faces, and zero-length edges ensures that the model will not fail during key CAD functions, such as solid feature generation or surface refinement. Moreover, non-flat faces, if left uncorrected, can cause issues with CAD-based shading, surface quality, and visualization, ultimately affecting design decision-making and analysis.

Basic 3D Model Check	*Reason for Testing and Additional Benefit for CAD Models*
Non-Manifold Edges	Can cause topological issues, preventing the model from properly closing.
	Ensures the model meets the stringent topology requirements of CAD kernels, making parametric editing and downstream operations (e.g., Booleans) more reliable.
Bad Contiguous Edges	Disrupts the continuity of the model, affecting deformation and animation.
	Improves the model's continuity and consistency, enabling smoother CAD feature generation, such as surface extensions and parameter-driven modifications.
Intersecting Faces	Causes errors in rendering and physics engines, leading to visual and physical issues.
	Prevents geometry conflicts that could halt CAD feature operations, ensuring that the model is suitable for engineering tasks like drafting, assembly, and tolerancing.
Zero Area Faces	Invalid faces affect rendering and performance.
	Eliminates degenerate geometry, ensuring successful CAD-based surface operations and stable downstream steps like CAM toolpath generation and CAE mesh creation.
Zero Length Edges	Invalid edges affect rendering and performance.
	Removes problematic edges that complicate CAD workflows, improving model integrity for parameter updates, associative features, and data exchange between CAD systems.
Non-Flat Faces	Uneven surfaces can cause shading issues in rendering
	Ensures surface accuracy and quality, allowing CAD tools to properly generate fillets, chamfers, and other precision features, as well as support accurate simulations and analyses.

Table 4: Basic usability testing standards for AI-generated 3D models.

In addition to the basic checks mentioned above, McCallum [20] in a feature article in Reallusion Magazine outlines several indicators for evaluating good topology, including (1) Clean and efficient mesh quality; (2) Evenly distributed mesh quality; (3) Quad-based topology; (4) Edge flow; and (5) Animation-ready topology. Among these indicators, "Quad-based topology," "evenly distributed mesh quality," and "edge flow" are evaluated in this study by counting the number of quads and closed edge loops, as well as analyzing the size distribution of edge loops. The evaluation items are listed in Table 5.

Mesh Count Check	*Reason and Standards for Testing*
Number of Quads	A higher number of quads indicates a greater amount of data. It is recommended to construct meshes using quads rather than triangles or polygons, as quads better preserve the mesh flow and optimize deformation quality, resulting in smoother and more natural animations and deformations. For AI-generated CAD models, this metric can evaluate the standardization of the geometric foundation, ensuring the generated results align more closely with the expected topology structure

	of traditional CAD design workflows.
Edge Structure Check	
Number of Closed Edge Loops	A higher number of closed edge loops indicates better geometric flow and smoother, more natural surfaces, especially in key deformation areas such as joints and facial features. If the number of closed edge loops is too low, it may suggest the presence of excessive triangles or pentagons, which can negatively affect deformation and animation quality. This metric evaluates the topology quality of AI-generated CAD models in critical areas to ensure they meet the requirements for subsequent design modifications and dynamic simulations.
Size Distribution of Edge Loops	The average size of edge loops reflects the overall distribution of edge loop sizes within the model, with a higher average value indicating a more complex structure. The standard deviation shows the variability in the size distribution of edge loops: a larger standard deviation suggests a more uneven size distribution, while a smaller standard deviation indicates a more uniform distribution. For AI-generated CAD models, this evaluation can detect uneven structural distributions caused by the automatic generation process and verify whether the topology facilitates manual adjustments, feature extraction, and functional design, thereby improving usability and reliability.

Table 5: Topology usability evaluation criteria for AI-generated 3D models.

Firstly, the number of closed edge loops refers to the count of edge loops in a 3D model that can be connected in a circular manner, as illustrated in Figure 4. Calculating the number of these closed-edge loops allows for the assessment of whether the edge flow and topology of the model are uniform and consistent. This evaluation helps determine if the model can maintain high-quality geometric distribution and usability in processes such as CAD design, parametric modifications, functional testing, and animation deformation. For AI-generated CAD models, this metric serves as a key indicator of whether the topology quality of the generated results meets the standards required for professional CAD applications.

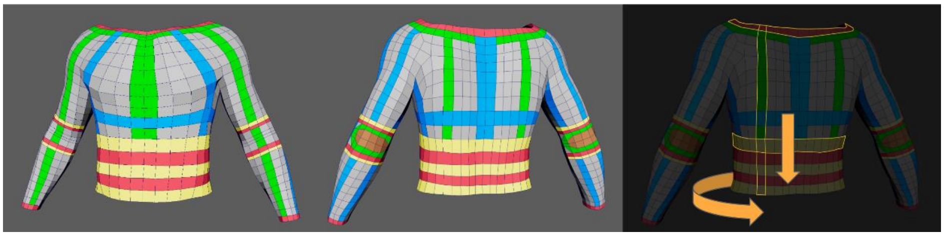


Figure 4: Illustration of closed-edge loops.

The size of edge loops is described by calculating the number of edges each loop contains. Assuming there are n loops in the model, the size of each loop s_i is given by:

$$s_i = \sum_{j=1}^{k_i} e_j \tag{1}$$

where k_i is the number of edges in the $\boldsymbol{i}$-th loop, and e_j is the j-th edge. Additionally, the distribution of loop sizes can be examined by calculating the average loop size $\bar{s}$ and the standard deviation σ_s:

Average Loop Size:

$$\bar{s} = \frac{1}{n}\sum_{i=1}^{n} s_i \tag{2}$$

Standard Deviation:

$$\sigma_s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(s_i - \bar{s})^2} \tag{3}$$

For AI-generated CAD models, the previously mentioned mean and standard deviation can be utilized to evaluate the uniformity and stability of the topology. These metrics also help identify whether the automated generation process has resulted in excessively uneven areas, which could pose challenges in subsequent CAD operations, such as CNC toolpath optimization, meshing for finite element analysis (FEA) preprocessing, or adjustments to parametric design intent. Furthermore, such irregularities may lead to instability during deformation processes in animation workflows.

Other topological indicators, such as a "clean and efficient geometric structure" and "animation-ready topology," fall within the realm of professional judgment and qualitative evaluation. To more accurately assess the practical impact of these indicators on AI-generated CAD models, this study invited experienced 3D animators to participate in the evaluation process. Through semi-structured interviews, the animators were asked to rate the topology of AI-generated 3D models and provide improvement suggestions. This approach not only ensures that the topology quality of the models meets practical requirements but also provides valuable insights into the functionality of CAD models, future design adjustments, and animation production workflows.

A 'clean and efficient mesh quality' refers to a model that avoids unnecessary vertices, edges, or faces and eliminates redundant overlaps and excessive complexity. This ensures efficiency and precision in CAD-related operations, such as computational graphics, feature modifications, and parametric design adjustments. On the other hand, an "animation-ready topology" emphasizes that the mesh structure should be suitable for animation production workflows. This includes well-structured edge loop distribution, proper face layout, and convenient skeleton binding. A well-designed topology allows for natural deformations during animation, preventing stretching or tearing, thereby enhancing animation quality and improving workflow efficiency.

By combining quantitative methods (such as counting the number of closed edge loops and calculating the mean and standard deviation of loop sizes) with qualitative methods (evaluation through professional animator interviews), a comprehensive usability assessment of the topology of AI-generated CAD models can be conducted.

3.3.2 UV layout testing items and procedures

In terms of UV layout quality, McCallum underscores the importance of "avoiding seams in highly visible areas" and ensuring "detailed handling of critical areas." Building on these principles, this study adopts guidelines from NVIDIA Omniverse [23] and testing methods by James [12], as outlined in Table 6. To refine these assessments, researchers engaged with 3D technical artists who possess extensive professional experience and contextual awareness. Unlike automated tools that rely on standardized parameters, these experts can swiftly identify subtle UV layout issues—such as overly visible seam placements, imbalanced UV space allocations, or texture distortion—and then fine-tune evaluation criteria to suit different model types.

This nuanced, expert-driven judgment is especially valuable in addressing complex visual requirements and aesthetic considerations commonly encountered in game and animation pipelines. While the current focus remains on entertainment-oriented 3D models, the insights gained through professional scrutiny can also inform future adaptations of the evaluation framework. For instance, as certain CAD workflows and advanced 3D printing processes begin to incorporate texture mapping or visual feedback loops, the same principles used to ensure clean and coherent UV layouts may help maintain surface integrity, enhance detail clarity, and support efficient downstream modifications. Thus, while this study is primarily situated within the game and animation domain, the evaluative strategies it develops are well-positioned to influence broader production ecosystems, including those that converge with CAD-based modeling and digital fabrication contexts.

UV Layout Testing Item	*Reason for Testing*
Distortion Test	In UV mapping, checker maps are used to visualize stretching, compression, and distortion in meshes. This concept can be extended to the surface parameterization stage of CAD models. For AI-generated CAD models, the surface can be unfolded into an isoparametric grid using methods such as NURBS or B-splines. A standard calibration pattern is projected onto this parametric domain to assess surface quality. Distortions in the pattern indicate issues such as uneven parameterization, abnormal local curvature, or deficiencies in surface discretization. This method evaluates surface smoothness, curvature continuity, and parameter distribution rationality.
Seam Placement	UV mapping principles recommend placing seams in non-critical visual regions. Similarly, for CAD models, surface joins or feature boundaries should be carefully positioned. In AI-generated CAD models, composed of multiple surface patches (common in reverse engineering or automated generation), seams should align with natural topology divisions, such as contour lines or functional boundaries, avoiding visible or critical areas. Proper seam placement enhances texture mapping quality and downstream applications, including machining, 3D printing, and finite element analysis (FEA).
Texture Space Utilization	UV unwrapping emphasizes efficient use of UV space to maximize texture resolution. In CAD parameterization, this corresponds to a rational allocation of the parametric domain. Uneven parameter distribution, such as regions with "high parameter density" adjacent to "low parameter density," can result in uneven detail distribution during texturing or machining. Effective parametric space distribution ensures optimal resolution for processes like rendering, texturing, and numerical analysis (e.g., CFD or FEM).
Texel Density	In UV mapping, texel density ensures uniform texture clarity. In CAD models, this translates to uniformity in mesh density during surface discretization. For AI-generated CAD models utilizing multi-parameterization techniques, mesh divisions or sampling point distributions should be consistent to prevent sparse details or missing features in processes like rendering, texture mapping, or engineering simulations.
Overlap Test	UV overlap can cause texture mapping errors. Similarly, CAD models with overlapping surface segments, boundaries, or improperly merged features can introduce errors in texture mapping, machining, or numerical analysis. An overlap check ensures clarity in the parametric domain and topology, preventing data conflicts in downstream applications.

Table 6: UV layout usability testing standards for AI-generated 3D models.

3.4 Application of Usability Evaluation Methods to AI-Generated CAD Models

To ensure that AI-generated 3D models can be effectively used in computer-aided design (CAD), this study applies usability evaluation methods for topology, UV layout, and mesh inspection specifically to AI-generated CAD models. These methods are used to detect and validate the usability of the models in practical application scenarios.

In the CAD workflow, the rationality of the topology structure plays a critical role in subsequent parametric editing, Boolean operations, and surface extension tasks. Specifically, the number of closed edge loops and the coefficient of variation of edge loop sizes are key indicators of whether the topology is sufficiently uniform. For example, closed edge loops serve as crucial structural support for functional interfaces such as joints, sockets, and mounting points in CAD models. If the number of closed edge loops is insufficient, the model's deformability will be compromised, particularly during local modifications such as surface trimming or stretching functional features, leading to unexpected anomalies. When designing mechanical components like sockets and connectors, it is essential for these areas to have a sufficient number of closed edge loops to prevent unwanted model damage or geometric distortion. For instance, when designing the mating area of a gear bearing, it is necessary to check whether the number of closed edge loops meets the required standards. This ensures that the model can be smoothly modified parametrically within CAD software.

Although UV layout is not as commonly utilized in CAD models as it is in 3D animation and game assets, it has become increasingly important with the integration of CAD with visualization and rendering technologies, such as Digital Twins and Augmented Reality (AR) applications. The quality of the UV layout affects the model's performance in visualization rendering, material application, and the automated generation of labels, such as part labels or production sequence labels. In digital twin systems, companies often use CAD models for virtual product demonstrations. UV layout must ensure not only seamless texture display but also clear and logical texture space allocation. This is especially critical when CAD models are imported into AR environments or 3D visualization platforms. Any gaps, overlaps, or stretching in the UV layout could result in display anomalies when users view the model in 3D. Therefore, ensuring the UV layout is free from such issues enhances the model's visual quality and usability.

In CAD modeling, the core goal of mesh inspection is to eliminate issues such as zero-area faces, overlapping faces, non-planar faces, and non-manifold edges. These issues can cause errors during Boolean operations and feature generation in CAD software. For example, when two parts are combined using a Boolean union, overlapping faces or zero-area faces may prevent the generation of a solid body or cause Boolean operations to fail. Checking for zero-area faces and overlapping faces is essential in the design of mechanical components, especially for manufacturing processes like injection mold design. Overlapping faces can lead to incorrect CNC machining paths, which could disrupt the manufacturing process. Furthermore, inspecting for zero-length edges, non-planar faces, and overlapping faces helps improve the overall mesh quality, reducing the risk of CAD calculation errors that could result in production failures for physical parts.

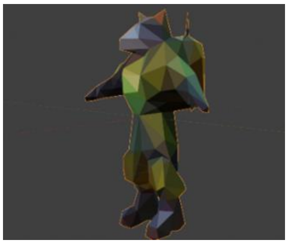
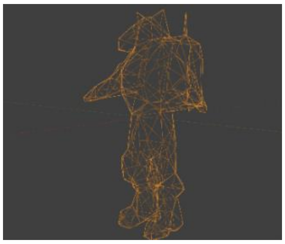
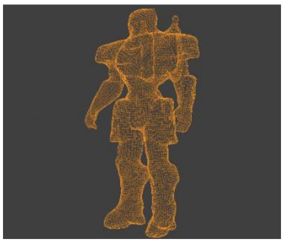
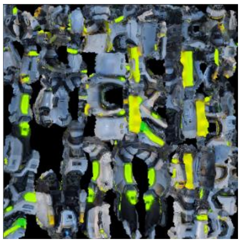
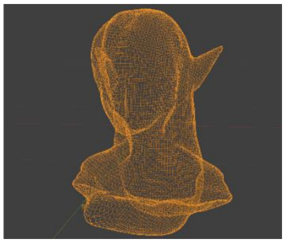
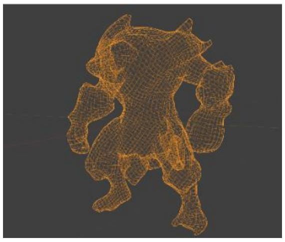
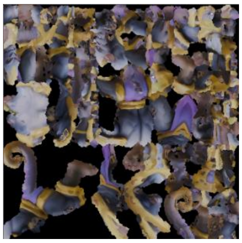
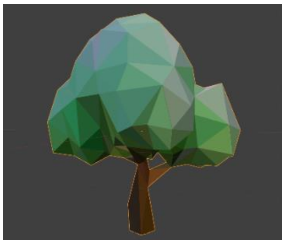
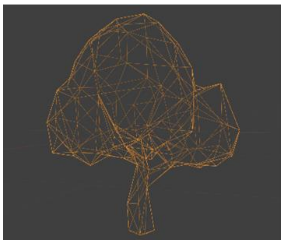
This evaluation framework for topology, UV layout, and mesh inspection ensures that AI-generated CAD models can be smoothly integrated into practical CAD workflows, enhancing their usability for real-world applications like parametric editing, digital twin visualization, and manufacturing.

4 RESULTS AND DISCUSSION

4.1 AI-Generated 3D Model Outputs

Experts used AI modeling tools to generate 3D models according to the categories listed in Table 3. The resulting 3D models, including perspective views, topology diagrams, and UV layouts, are shown in Table 7:

ID	*prompt*	*3D Model View*	*Topology*	*UV Layout*

A	Game Assets, Border Collie, Upright, Wearing Sci-Fi Military Armor, Dead Space, Detailed, Character. Hard Surface. Low-Poly			
B	future, standing in A-pose, robot, Human male high-tech angular plate armor exosuit game ready, future armor, Character, Hard Surface, Sci-Fi			
C	an elf girl with long blonde hair, pointy ears, symmetrical, medieval style, high quality, beautiful, glowing jewelry, Character, Organic Modeling, Realistic			
D	dota2 night stalker A-pose monster, monkey king, Character, Organic Modeling, Cartoon			
E	cotton wood, fantasy, Soft, cute, Prop, Hard Surface, Low-Poly			

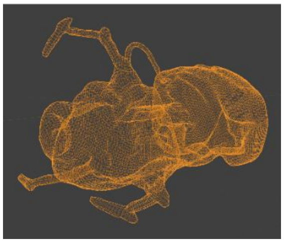
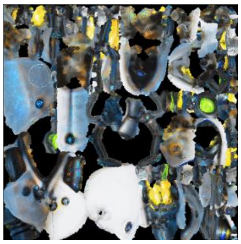
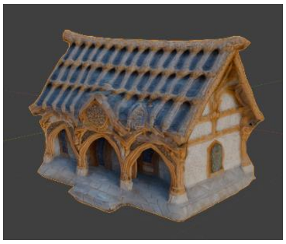
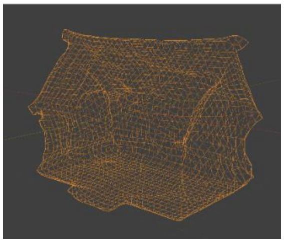
F	portal gun, tech, light, Prop, Hard Surface, Sci-Fi			
G	Valuable ruby and jade necklace, golden framing, ancient, mythical, Prop, Organic Modeling, Realistic			
H	house, Medieval, Fantasy, ultra-realistic, highly detailed, best quality, oriental style, Prop. Organic Modeling. Cartoon			

Table 7: Generated 3D models with corresponding views, topology, and UV layouts.

4.2 Results and Discussion of Basic Inspection Items

The basic inspection results obtained using Blender's 3D Print Toolbox plugin are shown in Table 8:

Basic 3D Item	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Non-Manifold Edges	0	0	0	6	0	0	0	0
Bad Contiguous Edges	0	0	0	0	0	0	0	0
Intersecting Faces	0	0	67	2	0	2	21	0
Zero Area Faces	4	91	142	0	0	3370	83	0
Zero Length Edges	0	0	0	1	0	0	0	0
Non-Flat Faces	0	25	43	25	0	56	100	16

Table 8: Basic inspection results.

Overall, in the basic inspection items, the AI-generated 3D models exhibited varying levels of quality, with many still having defects. Firstly, most samples had issues with non-flat faces, indicating significant problems with the surface smoothness of these 3D models, which could lead to anomalies in rendering and physical simulations. Additionally, more than half of the 3D models had numerous zero-area faces, with model F having as many as 3,370, indicating a high degree of precision or data errors in the mesh generation process. These invalid faces could cause issues during rendering.

Furthermore, some 3D models had intersecting faces, suggesting potential overlaps or intersections in the geometric structure that need correction to prevent rendering errors or anomalies in physical simulations. Lastly, while non-manifold edges were only detected in model D, it indicates that this model has edges shared by more than two faces, which should not be present in a well-structured, closed 3D model.

The artifacts identified during basic inspections, such as zero-area faces, intersecting faces, and non-flat surfaces, primarily stem from the limitations of AI modeling tools and the automated generation process. For instance, UV layout algorithms may not account for the geometric complexity of certain models, resulting in overlapping or distorted layouts. Similarly, the occurrence of zero-area faces often reflects either precision issues in mesh calculations or insufficient input parameters, such as generic keywords or low-resolution text prompts. These challenges highlight the need for enhanced algorithms and input workflows to address structural inconsistencies and improve the overall mesh quality.

4.3 Results and Discussion of Topology Usability

The topology usability inspection results obtained using Blender scripts and loop size formulas are shown in Table 9.

Topology Usability Check Item	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Number of Quads	386 (Triangle)	8,752	11,396	5,176	260 (Triangle)	14,562	3,686	2,617
Number of Closed Edge Loops	42	267	101	334	27	356	493	82
Average Loop Size	2.375	3.132	4.118	4.672	3	4.009	5.055	2.857
Standard Deviation	0.695	2.187	5.743	6.459	1.603	4.696	8.505	2.474
Coefficient of Variation (CV)	0.293	0.698	1.394	1.382	0.534	1.171	1.682	0.866

Table 9: Basic Inspection Results.

For low-poly models like Model A (Character. Hard Surface. Low-Poly) and Model E (Prop. Hard Surface. Low-Poly), Gregory [9] and Watt [27] point out that triangular meshes are preferred because triangles ensure planar surfaces, reduce computational complexity, and are directly compatible with real-time rendering engines, which automatically convert quads into triangles.

4.3.1 Results and discussion of quad count

Generally, the face count standards for 3D models vary depending on their intended use and performance requirements. According to information provided by the professional 3D art outsourcing studio 3D-Ace [1], the recommended quad counts for VR and AR platforms related to the metaverse are as follows: low-detail characters should have between 2,000 and 10,000 faces; high-detail characters should have between 10,000 and 20,000 faces; simple props should have between 500 and 1,500 faces; and complex props should have between 1,500 and 5,000 faces. According to these standards, AI-generated 3D character models generally have higher face counts, except for low-poly style characters and props. For example, model C, which is only a face, exceeds 10,000 faces. While these models' quad counts may maintain their appearance and meet the operational standards of metaverse environments in some cases, the prop models generally have excessively high quad counts. Moreover, these prop models mostly feature monolithic structures, lacking mechanical or architectural layers and details, failing to meet the visual standards for complex props, resulting in unnecessary face count waste compared to character models.

In metaverse environments, performance optimization is crucial, especially for real-time rendering in VR and AR applications. Excessive face counts increase the rendering load, affecting performance and user experience. Therefore, it is necessary to reasonably control and optimize the mesh count. Measures to improve the mesh count issue in AI-generated 3D models include simplifying the mesh while retaining necessary details and deleting excess faces, using level of detail (LOD) techniques to automatically adjust mesh details based on the model's distance in the scene, and splitting detailed prop models into multiple parts to reduce unnecessary mesh count waste.

4.3.2 Results and discussion of closed edge loops

In comparing the number of closed edge loops, this study uses a standard human model with 4,942 faces as a benchmark, which has 715 closed edge loops. In comparison, all AI-generated 3D models with a face count higher than this standard have fewer than 715 closed edge loops, indicating lower geometric flow and less smooth surfaces than the standard human model. These results show that, despite potentially higher face counts, AI-generated models still have room for improvement in structure and surface quality.

4.3.3 Results and discussion of average loop size

Regarding the uniformity of mesh distribution in AI-generated 3D models, this study uses the coefficient of variation (CV) as a statistical indicator to measure the data set's dispersion relative to the mean. A smaller CV (typically less than 10\%) indicates low data variability, while a larger CV (typically greater than 50\%) indicates high data variability. The CV is calculated as the ratio of the standard deviation σ to the mean $\bar{s}$:

$$CV = {}^{\sigma}/_{\bar{s}} \times 100\% \tag{4}$$

Firstly, Model A has a CV of 0.293, indicating that its standard deviation is about 29.3% of the mean. This relatively low CV suggests that the edge loop sizes in its topology are consistent and evenly distributed, which enhances performance and stability in rendering and physical simulations. In contrast, Models B, C, D, F, G, and H have CVs of 0.698, 1.394, 1.382, 1.171, 1.682, and 0.866, respectively, indicating high variability and uneven edge loop distribution. Such uneven topology may negatively impact the models' rendering performance and stability in physical simulations. Model E has a CV of 0.534, reflecting moderate variability, where edge loop sizes show some differences but maintain overall consistency.

The occurrence of uneven topology distribution, particularly in models with high CV values, is often caused by artifacts generated during the modeling process. These artifacts, such as zero-area faces, intersecting faces, and non-flat surfaces, result from limitations in AI algorithms or insufficient input details affecting mesh quality. For instance, automated simplifications made during mesh generation can disrupt edge flow, while incomplete UV layouts or overly generic prompts may fail to guide the algorithm in producing consistent geometric structures. Understanding and addressing these causes is essential to improving the reliability of AI-generated models.

Overall, the topology distribution of AI-generated 3D models, whether for hard-surface or organic models, tends to be uneven. Only low-poly style characters and props exhibit relatively uniform distribution due to their simpler structure and lower polygon count. This observation highlights the need for improvement in AI-generated 3D model topology, particularly in achieving consistent edge loop distribution. Addressing this issue would enhance the models' usability and performance in rendering and animation.

In CAD models, mesh quality issues, such as intersecting faces and zero-area faces, can severely affect downstream processes by introducing errors in geometric precision or modifiability. These problems often stem from algorithmic oversights during automatic generation, where complex features are simplified at the expense of structural accuracy. For example, zero-area faces may cause instability in numerical simulations, while intersecting geometry can compromise manufacturing workflows.

Uneven topology in a CAD model may further affect the accuracy and stability of numerical analyses, such as fluid dynamics or stress analysis. Additionally, excessively dense topology increases computational load and machining complexity during CAD/CAM processes.

To address these challenges, designers and engineers can evaluate AI-generated CAD models against industry-standard reference models. This allows for a quantitative assessment of model usability and quality. If necessary, mesh simplification, edge loop redistribution, or Level of Detail (LOD) techniques can be applied to enhance model efficiency and support production workflows. These measures ensure that AI-generated CAD models meet industry standards, enabling seamless integration into engineering, visualization, and manufacturing processes.

4.3.4 Summary of 3D animators' feedback

The evaluation of the topological structure of AI-generated 3D models and CAD models is crucial for understanding their practical usability. To determine whether AI-generated 3D models meet the criteria for "clean and efficient geometry" and "animation-ready topology," researchers collected feedback from 3D animators based on animation topology evaluation standards. The key insights are as follows.

First, the mesh density and edge flow do not meet the standards. While the surface of AI-generated 3D models appears uniformly distributed, the mesh density and edge flow fail to follow the direction of muscle movement, especially in key areas like the face and joints. This misalignment hinders natural deformations, affecting their animation usability.

Second, there is insufficient awareness of animation needs. In organic modeling, critical animation areas like the face and fingers require higher mesh density, while areas like the arms and body can have lower density. However, AI-generated models fail to recognize this distinction, leading to unnecessary face count waste and inadequate detail in key areas required for animation deformations.

Third, the correction cost is high. AI-generated 3D models often contain structural defects that require extensive corrections to meet animation standards. For instance, the eyes and mouth lack independent structures, making it impossible to achieve eye movement or mouth opening without significant modifications. These structural issues increase production time and costs.

Lastly, AI-generated 3D models struggle to accurately represent hard surfaces. They fail to distinguish mechanical structures and lack the precise mesh features needed to depict the hardness of metal or mechanical components. Although surface details may appear rich, they often rely on textures, and without them, the meshes lack structural clarity essential for animation or mechanical modeling.

This evaluation framework can also be applied to CAD models, where precise geometric shapes and logical topological structures are essential for efficient editing, analysis, and manufacturing. By adopting a similar assessment approach, engineers and designers can evaluate the rationality of AI-generated CAD models. The key evaluation criteria are as follows.

First, local density configuration. Critical design areas, such as joint interfaces, functional holes, and stress-concentrated regions, require higher mesh density to support downstream processes like manufacturing and structural analysis. Non-critical areas can use lower density to reduce computational costs and improve model efficiency.

Second, edge flow and structural distribution. The edge flow of CAD models should align with the functional logic of mechanical components. For example, shafts, gears, arch structures, and support beams require a topology that supports CAD/CAM (Computer-Aided Manufacturing) tools for simulation and analysis. Proper edge flow facilitates accurate simulations and downstream processes like machining and assembly.

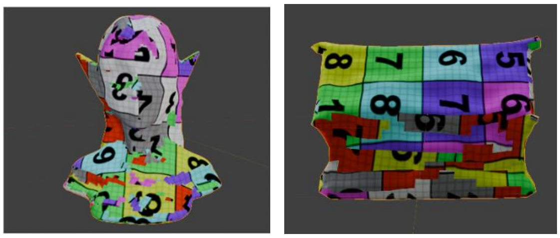
Third, structural logic and precision. CAD model topology must reflect the geometric characteristics of the object to minimize errors in CAE (Computer-Aided Engineering) analysis, process planning, and manufacturing. Mechanical components require symmetrical, regular topologies to support assembly simulations and numerical analysis. Imprecise topology can result in errors during analysis or manufacturing, increasing production costs and development time.

By adopting these criteria, engineers and designers can evaluate and improve the topological quality of AI-generated CAD models at an early stage. This inspection framework is not only useful for assessing AI-generated models in animation and entertainment but also extends to CAD design, manufacturing, and engineering analysis. It facilitates the seamless integration of AI-generated CAD models into existing CAD/CAM/CAE workflows, ensuring precision, efficiency, and feasibility in the final product.

4.4 Results and Discussion of UV Layout Usability

4.4.1 UV layout testing results and discussion

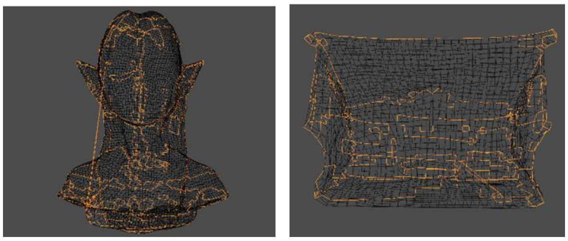
First, for the distortion test and texel density, this study used a UV map checker to conduct the inspection. The UV map checker uses a grid of regular numbered squares to check the configuration and size of textures on 3D models. Ideally, these numbered squares should appear regular in size and evenly distributed on the 3D model. However, in AI-generated 3D models, variations in the configuration and size of the numbered squares can be observed, indicating stretching or compression. Examples from models C and H are shown in Figure 5.



(a) Model C (b) Model H

Figure 5: Distortion and texel density results of UV layout.

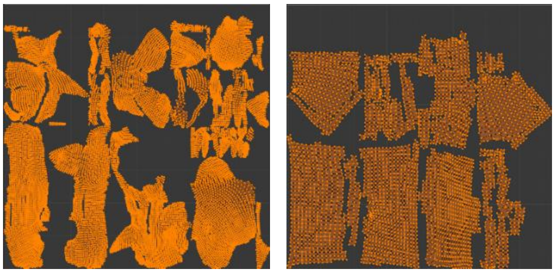
In the seam placement inspection, it was observed that AI-generated 3D models did not handle seams properly. Notably, model C had seams positioned in the center of the face, which directly impacts the visual effect after rendering and violates the principle of hiding seams. This is illustrated in Figure 6.



(a) Model C (b) Model H

Figure 6: Seam placement inspection results of UV layout.

Finally, in the texture space utilization and overlap test, the UV layouts of AI-generated 3D models still had many unused spaces, and overlaps between UV grids were observed. Most importantly, the layout structure was rather chaotic, not following the inherent structure and split logic of the 3D model, which led to inefficient use of texture resources. This is illustrated in Figure 7.



(a) Model C (b) Model H

Figure 7: Texture space utilization and overlap test results of UV layout.

For CAD models, although UV layout is not traditionally a primary inspection item in CAD tools, its importance is growing with the increasing integration of CAD workflows with visualization rendering, material recognition, and downstream processes such as Computer-Aided Engineering (CAE). High-quality UV layout is particularly valuable for modern CAD applications, especially in areas like digital twins and AR/VR-based engineering training. A well-structured UV layout ensures consistent visual appearance during product visualization, facilitates material allocation, and supports the integration of automated post-processing tools.

To assess the UV layout of AI-generated CAD models, key indicators such as UV distortion, seam placement, texture space utilization, and symmetry should be evaluated. These factors directly impact the convertibility of CAD models from pure geometric structures to comprehensive digital workflows with editable material configurations. For instance, reducing UV distortion and optimizing seam placement ensures smooth material transitions, while logical texture space utilization enables efficient integration with rendering and manufacturing processes.

This evaluation framework for UV layout provides CAD practitioners with a robust tool to assess the usability of AI-generated CAD models, particularly in terms of texture and material management. It also allows designers to identify and address potential issues that could hinder integration with engineering analysis, numerical simulation, and production process optimization. For applications requiring high precision, such as digital twins or AR/VR, ensuring high-quality UV layout contributes significantly to visual fidelity and interaction quality.

In addition, while UV layout plays a critical role in visualization and material management, practitioners should also consider mesh optimization and polygon count, especially for real-time rendering or AR/VR environments. Combining UV layout inspection with topology refinement ensures that AI-generated CAD models meet the standards of precision, efficiency, and usability required in modern CAD workflows.

4.4.2 Summary of 3D technical artists' feedback

Similar to the interviews with 3D animators, this study conducted interviews with 3D technical artists to gather practical insights. To evaluate whether AI-generated 3D models meet the requirements for "avoiding visible seams in high-visibility areas" and "detailed handling of critical areas" in UV layouts, researchers collected and summarized the opinions of 3D technical artists using criteria related to UV layout design and model editability. The key findings are as follows.

First, the configuration of UV layouts did not meet industry standards. In standard practice, UV grids are allocated according to the importance of model areas. For instance, the UV grid for a character's face typically occupies a significant portion of the entire UV layout, such as onequarter, to ensure sufficient texture detail. However, AI-generated 3D models exhibited irregular UV splitting and configurations, lacking logical coherence and consistency.

Second, there were issues with seam placement. To maintain visual integrity, seams should be avoided in prominent areas such as the face or the front of limbs. However, AI-generated 3D models often used random UV unwrapping, leading to highly visible seam placements in high-visibility areas. This flaw significantly affects the visual quality of the model, especially in close-up renders.

Lastly, the editability of UV layouts was poor. Ideally, UV grids are divided into distinct blocks corresponding to different areas of the 3D model. For example, UV grids for the character's face, shirt, pants, and limbs should each be assigned to separate blocks. This structured division allows for efficient identification and quick, unified modifications. However, the UV layouts of AI-generated models were scattered and irregular, making it difficult to identify corresponding 3D model parts, thereby hindering subsequent modifications and processing.

These UV layout issues are equally significant for CAD models. If the design's appearance is intended for use in engineering visualizations, marketing displays, or digital manufacturing, a well-structured UV layout becomes essential. It facilitates the precise alignment of materials, textures, and label graphics (such as maintenance guides or quality control markings) onto the model's surface. Additionally, it supports automation processes, such as the automatic generation of part labels or instructional guides.

When UV layouts lack logical structure and clarity, CAD engineers and technical personnel may face difficulties during subsequent modifications, annotations, and simulation testing. Disorganized UV layouts can hinder processes like retexturing, visualization updates, and the application of standardized markings. Therefore, the aforementioned UV inspection criteria can also serve as quality assessment standards for AI-generated CAD models. By addressing UV layout issues early, designers can ensure better texture alignment and facilitate seamless integration of CAD models into workflows for visualization, engineering analysis, and manufacturing. This approach enhances the practical value and applicability of AI-generated CAD models.

5 CONCLUSIONS

Based on the research findings, although AI-generated 3D models have shown significant improvements in visual appearance, there are still numerous issues regarding topology structure and UV layout. While these 3D models can operate within metaverse environments, their effectiveness is not optimal. Therefore, the current AI modeling cannot replace manual modeling for character and prop 3D models that require rich details and smooth animations. However, for non-critical and static characters or props, if mesh count can be effectively controlled, AI modeling might partially replace manual modeling.

To ensure the usability of AI-generated CAD models, it is essential to establish a comprehensive validation framework. This study proposes a multi-step evaluation process that incorporates topology structure inspection, UV layout validation, and geometric quality checks. Adopting this validation framework enables AI-generated CAD models to achieve greater compatibility with CAD/CAM/CAE workflows, facilitating smoother integration into engineering applications. This approach enhances the relevance of AI-generated models in industrial processes and promotes the development of standardized production pipelines.

With these evaluation methods, the usability of CAD models can be significantly enhanced. The combined approach of topology, UV layout, and geometric checks ensures the compatibility of AI-generated CAD models with design, analysis, and manufacturing standards. As AI modeling continues to evolve, its role in CAD processes is expected to grow, supporting faster prototyping, more adaptable design iterations, and greater flexibility in production workflows.

Moreover, the future impact of AI-generated 3D models on the industry is profound. By accelerating the design process, AI technology empowers designers to rapidly iterate on concepts, reducing the overall time required for product development. This agility is particularly advantageous in industries like automotive, aerospace, and consumer electronics, where time-tomarket is critical. As AI-generated CAD models become more refined, they are expected to support end-to-end workflows, from concept development to manufacturing, with minimal human intervention. This transformation not only increases design efficiency but also facilitates the mass customization of products. Industries can leverage AI-driven automation to produce personalized designs tailored to individual customer preferences, thereby expanding product offerings and enhancing customer satisfaction. The shift toward automated CAD modeling processes also aligns with the growing trend of digital transformation and smart manufacturing, where AI-driven automation plays a central role in Industry 4.0. The convergence of AI, CAD, and manufacturing technologies will lead to new business models, reduce production costs, and improve design flexibility, further advancing the industry's competitive edge.

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