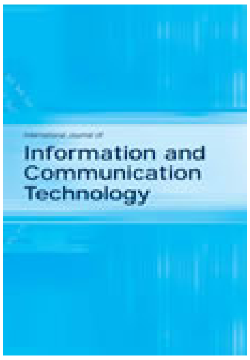

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AI-driven digital sculpture design: optimising fusion algorithms with deep learning and virtual reality

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AI-driven digital sculpture design: optimising fusion algorithms with deep learning and virtual reality

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Abstract: The assimilation of artificial intelligence (AI) and machine-learning techniques within digital modelling has provided a new perspective on design in sculpture besides offering capabilities that can be harnessed for an artistic agenda with an unsurpassed level of efficacy and speed. This study is focused on digital modelling using virtual reality (VR) technology in the field of sculptures, and it aims to improve the algorithms of fusion programs using deep learning techniques. In this research, we have improved our ability to create digital sculptures more accurately and flexibly by taking advantage of techniques such as neural networks, adversarial models, and reinforcement learning. The proposed AI-VR model outperforms traditional and baseline models, achieving 92% model fidelity, 45 frames per second (FPS) rendering speed, and a user interaction score of 90. This framework paves the way for the future of AI-powered artistic innovation.

Keywords: artificial intelligence; digital modelling; virtual reality; sculpture design; deep learning.

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1 Introduction

The metamorphosis of artificial intelligence (AI) and digital modelling has reshaped a multitude of creative arenas encompassing sculpture design. Sculpture-making has been a painstaking and laborious undertaking that necessitated extensive manual work, tempered skills, and years of training. The upsurge of computational design, mostly using AI modelling techniques, has made it possible for artists and designers to flexibly change their designs to be able to gain more options while keeping the overall process more efficient (Sterp Moga et al., 2022). The combination of the newest technologies such as deep learning and virtual reality (VR) has provided innovative solutions in sculpture making, where the manipulation in real-time, perfect visualisation and refinements of methods beyond the reach of traditional technologies are enabled (Smith, 2018). Time-consuming modelling is done by way of unique AI in which neural networks create and then make realistic alternative models on the computer, just as it is done in real life, but with much greater pliability and creativity in proportion to the amount of human the sculptor has (Zhou et al., 2019).

When it comes to sculpture design, the artist's hand was previously a deciding factor in creating the final product – traditional tools like clay, wood, and stone carving were used to do the job. While these AI tools in robotic instruction were limited in terms of their intuitive function, computing software such as Blender, Autodesk Maya, and ZBrush were used by the artists instead (Li, 2021). However, the main drawback of these early systems was their reliance on a considerable amount of manual input, a situation that limited the scalability and adaptability of the digital sculpting process (La Pensée et al., 2010). The enormous progress made by deep learning technology in AI-based digital modeling has significantly changed this situation by automating every part of the sculpture design process whichever deep learning algorithms are applied (Bertol, 2016). Some of the AI technologies applied in the industry include generative adversarial networks (GANs), variational autoencoders (VAEs), and various techniques such as reinforcement learning that work with machines to produce automatic design generation, pattern recognition, and structure integrity evaluation (Li et al., 2022).

In VR design on sculpture artistry, the experience is brought to a deeper level. It allows artists to engage with their creative pieces in a three-dimensional (3D) milieu (Ji et al., 2020). The use of varied VR sculpting tools such as the oculus medium and gravity sketch, which are based on personal mobile devices, results in an interactive process where digital materials can be manipulated using natural hand gestures (Griffith et al., 2021). In this regard, the process of sculpting becomes not only more natural but also more personal and expressive. These tools close the gap between the virtual and physical aspects of the sculpting process by fast-tracking the feedback loop between the material and the hand (Grasselli, 2021). Furthermore, using VR in the art-making process creates opportunities for several artists to collaborate on the same digital sculpture simultaneously in one virtual environment, thus stimulating imagination and sharing of knowledge (Chen et al., 2024).

The greatest difficulty of this venture is the efficient and effective optimisation of fusion algorithms to allow for deep learning models and VR environments to be fully blended naturally. This refers to the embedded technology of the painting of 3D shapes. The merging of various data sources such as 3D scanning, the creation of pictures in real-time, and user interactions at once generates very fine details and produces very realistic sculptures (Chen et al., 2022). The level of detail and speed with which the art was created will depend entirely on these algorithms since they are the keys of such processes as texture mapping, shadowing, volumetric transformation, and structural coherence (Ahmed and Aly, 2023). Advanced deep learning techniques are the ones that improve the efficiency of these fusion algorithms by detecting the best combinations of values, filtering out noise, and giving the system needed unambiguous parts (Yoo et al., 2020).

A distinct advantage of AI-based digital modelling in sculpture design is that it allows the iterative design process to speed up. In traditional sculpture creation, the cycle of review and approval seems unending; hence the sculptor has to constantly adjust the artwork (Guo and Wang, 2022). By contrast, AI-assisted modelling gives rise to rapid prototypes, enabling artists to create many iterations in no time at all (Sung and Ou, 2022). In addition, AI algorithms can analyse sculptures from the past, extract stylistic clues, and suggest new variations, allowing artists' creative strengths to flourish further. This marriage between human sensibility and computer ability gives birth to a flexible, efficient system that cuts costs while ensuring artistic output (Skakovskaya and Bobkov, 2023).

AI-oriented ways are credited with being environmentally friendly and efficient in sculpture design through resource utilisation. Material wastage is a major issue with traditional sculpting, where mistakes or weaknesses in the structure often result in disposed materials (Tran et al., 2021). By using AI-generated simulations, artists can forecast how the material will behave, make parameters that will allow maximum structural support to be achieved, and thus cut down on waste (Salman, 2023). The making of things by additive methods, such as 3D printing, brings a greater level of sustainability because the precise deposition of materials dictated by the AI model entails minimum wastage (Phillips et al., 2024). The above innovations have vital consequences for the future of sculpture: they will usher in an era of production that will be good for the environment as well as pocket-friendly (Salman, 2023).

Even with the benefits of AI and VR in the field of sculpture design, there are still numerous obstacles. The first big issue is achieving a harmonious mix between the automation and the artistic aspect of the work (Roose, 2022). While AI can produce highly complicated and detailed sculptures, the role of the artist in shaping the end product is of utmost importance (Özel and Ennemoser, 2022). It would be vital for the art world's survival that AI remains a facilitator and not a replacement for human creativity. Moreover, the high-level computation required for deep learning algorithms and VR rendering will remain a big hindrance that can prevent small artists and studios from accessing this technology. The new methods of addressing the above problems through hardware optimisation, cloud rendering, or the efficient design of algorithms will have to be adopted on a wider scale (Özel and Ennemoser, 2019).

In sculpture design, the incorporation of AI, deep learning, and VR indicates a big change in artistic expression. The research examines the use of AI-based digital modelling and the incorporation of VR technology to improve sculpture design with a special focus on the optimisation of fusion algorithms to ensure that artistic freedom is exercised while the accuracy and efficiency of such designs are improved (Fadeeva and Staruseva-Persheeva, 2023). Through the study of existing advancements, challenges, and future callbacks, this research is directed towards the continuous development of computational art and design as it aims to add one more sequence to the evolution of this art form.

1.1 Objectives

- To create and fine-tune algorithms of fusion that combines the techniques of deep learning with the modelling of sculptures using VR technology.
- To improve the AI-prompted digital methodology in sculpture designs such that it will be exact, energetic, and creatively adaptive.
- To find out how AI and VR can be applied to enhance or replace traditional sculpting, particularly by outlining both advantages, limitations, and future opportunities.

This study illustrates the way AI and VR are changing the art world, providing implementable innovations and redefining art practices today. The introduction of computational machines, which are similar to the way humans think and the other gap, is closed, will make the techniques of artistic expression fuller, following how art gets to the current stage of growth. The research means will be used in the way of thinking of technology to swerve the possibilities of art, especially digital and sculpture, that are issued to man.

1.2 Key contributions

- Developed a fusion framework combining CNNs, GANs, and reinforcement learning for sculpting.
- Integrated VR for real-time, interactive 3D sculpture manipulation.
- Demonstrated superior fidelity, rendering speed, and user interaction versus baseline models.

2 Literature review

The interlinkage between scourge and VR modelling with AI and deep learning is a fitful revolution in the sculpture design discipline. Some researchers have investigated ways of building AI-utilising approaches for such purposes as optimising design processes, facilitating visualisation, and enhancing the overall efficiency of art workflows (Jones and Seppi, 2017). Despite the modernists' belief in untouched art, the creation of art will most definitely involve the usage of machines today, for the integration of photorealistic rendering with nonlinear editing and the behaviour of surrounding objects in the videos (Parraman and Ortiz Segovia, 2019). It is concluded in this part of the thesis that existing studies on the change in computer design have been reviewed, and the main emphases, outstanding achievements, and techniques have been indicated, by using the most recent research.

Guo and Song (2024) investigate the use of computer technologies, particularly VR, for the design of sculpture works. They apply VR to retrieve pixel sets from real images, make colour markings, and do the 3D registration of the sculpture scene. The researchers utilise spline surface modelling to adjust controlling points, which is thus the reason why the mathematical representing properties of the design were really put to a test and improved such as simulating wind direction, light and shadow. The VR technology proposed by this work presents an interactive experience for sculpture design.

Luo and Qian (2023) elucidate how computer-aided design (CAD) technology can be integrated to develop ceramic sculpture products. Highlighting their research on the use of object-oriented analysis and design tools including the iVsualModelo 2.0, they initiate a more efficient method of ceramic sculpture management. The study also contains the VR technology added element in the overall artistic design of ceramic sculptures and the possibilities of simulation and editing. The paper asserts the great significance of computer modelling in the improvement of ceramic sculpture expression and production techniques.

Zhao and Zhao (2022) look at the use of computer-aided VR in graphic design in the 3D animation scenes. Viewers will recognise the logos and the purpose of the research which has been expressed in the presented ontology library for animation materials, and its application to the creation of 3D animation scenes. The interconnectedness of digital sculpture and 3D animation can address production challenges like software interoperability and animation design. The new methods are also much more efficient, as they allow creating digital sculptures and 3D character animations in one place.

He (2022) look at a VR technology application in urban sculpture design, especially with a model of a network based on the internet of things (IoT) and edge computing. This research proposes a new joint optimisation algorithm (J-RAF) focusing on resource allocation in VR systems and validating its capability in enhancing the system gains was thereby realised. This research stresses the part of maximising urban sculpture design through the intensive collection of data and interactive experiences and thereby makes a significant contribution to an easy and effective urban space design.

Feeman et al. (2018) analyse the implementation of CAD software in VR. They assess the connection between CAD software packaged, and the game engine, namely with the help of a composition so as to enhance the modelling in the process of VR. The results of the research show that on the one hand, VR encourages creativity in modelling, the feature generation rate is higher, and it provides a better experience than the traditional CAD systems. The research points out that VR technology has good potential to change the various design practices in many industries.

Pranoto (2023) investigate the usage of VR-based art learning media in education such as in junior high school. The research emphasises VR's importance to creativity and creativity is undoubted in art and culture education. VR is presented as a method of simulating various art activities including sculpture, ceramics, and architecture and hence a way of involving students in the learning process. The results suggest the potential for VR-based media to improve the effectiveness of teaching and students' engagement in art subjects.

Li (2019) explore the use technologies that can be found in the modern day like VR and Java 3D in the ceramic sculpture creation. The course is studying without these programs will not be the same as to how much they will influence the process of design, giving it better practice at work and testing of pottery and sculpture. The studies provide an advantage of using VR to be integrated into artistry and direct the whole process of designing ceramics.

Xu (2022) proceed with the exploration of the application and VR technology in the design of ice and snow landscapes. The methodology of human-computer interaction (HCI) technology is used to create a VR system that gives the designers the right environment in which to get in touch with and modify the design of the icy and snowy environment. The report shows that VR technology ignites the creativity flag and positively influences the ice and snow sculpture design while also strengthening the local economy through the development of the tourism industry.

Huang and Bin Ismail (2024) introduce the integration of augmented reality (AR) and VR technologies in the ceramic art exhibition area. Their research presents generative adversarial networks with reinforcement learning (GAN-RL) scheme for a better visitor experience. The discovery suggests that the sequence of GAN-RL together with AR and VR technologies can shape the exhibition process on the basis of visitor preferences thus enhancing engagement and the classifications of ceramic arts designs.

Table 1 Literature comparison

Author(s)	*Journal*	*Research focus*	*Key contribution*	*Technology/methodology used*
Guo and Song	*Applied Mathematics and Nonlinear Sciences*	Virtual reality in sculpture design	Explores the use of virtual reality for 3D registration, spline surface modelling, and enhancing mathematical properties of sculpture design.	Virtual reality, 3D Modelling, Spline Surface Modelling
Luo and Qian	*Computer-Aided Design and Applications*	Integration of CAD technology in ceramic sculpture design	Introduces the application of object-oriented analysis and virtual reality for more flexible and expressive ceramic sculpture design.	iVsualModelo 2.0, CAD, Unified Modelling Language (UML), Virtual Reality
Zhao and Zhao	*Computer-Aided Design and Applications*	3D animation and digital sculpture	Develops an ontology library for animation materials and investigates the relationship between digital sculpture and 3D character animation to enhance production efficiency.	Virtual Reality, 3D Animation, Ontology Library
He	*Scientific Programming*	VR application in urban sculpture design	Proposes a network model for urban sculpture design based on IoT and edge computing, optimising resource allocation through joint optimisation algorithms.	Virtual Reality, IoT, Edge Computing, Optimisation Algorithms
Feeman et al.	*Computer-Aided Design and Applications*	Integration of VR with CAD for modelling	Demonstrates that VR improves creativity, design flexibility, and speed compared to traditional CAD, especially in design tasks like sculpture modelling.	VR, CAD, Game Engine Integration
Pranoto	*Jurnal Tata Kelola Pendidikan*	VR-based art learning media for junior high school students	Highlights the benefits of using VR for arts education, particularly in enhancing creativity and engagement in subjects such as sculpture, ceramics, and architecture.	Virtual Reality, Learning Media, Arts Education
Li	*Paper Asia*	Modern technology in ceramic sculpture	Investigates how technologies like VR and Java 3D improve the design and implementation process for ceramic sculptures, allowing for more efficient workflow.	VR, Java 3D, Ceramic Sculpture
Xu	*International Journal of Humanoid Robotics*	VR and HCI in ice and snow landscape design	Focuses on applying VR and HCI to design and display ice and snow landscapes, enhancing creativity and promoting the local economy through tourism and design development.	Virtual Reality, HCI, Ice and Snow Landscape Design
Huang and Bin Ismail	*International Journal of Intelligent Systems and Applications in Engineering*	AR and VR in ceramic art exhibitions	Proposes a GAN-RL framework to enhance visitor experience at ceramic exhibitions through real-time feedback, improving engagement and classification of art.	AR, VR, GAN-RL, Deep Learning, Ceramic Art Exhibitions

3 Methodology

The research methodology defined here is devoted to the unification of AI, deep learning, and VR in terms of digital modelling optimisation in sculpture design. It uses a systematic method including data collection, preprocessing, deep learning-based model training, VR integration, and output deployment. The targeted goal aims for AI-driven automation, thereby improving the efficiency and accuracy of digital sculpting while enabling real-time interaction with VR technology. The following sections in this article give a detailed outline regarding the different steps in the proposed system, while also underlining the primary methods and frameworks used in obtaining an integrated output of AI and VR for sculpture design.

3.1 Data acquisition and preprocessing

The first step of the method encompasses a wide variety of input data sources that play a crucial role in digital sculpting. They consist of hand-drawn sketches, sensor data, scanned 3D models, and CAD files. Drawing sketches can be considered as the initial artistic input, giving sculptors space to provide initial design concepts that are later checked with AI-driven modelling practices. Sensor data that is collected from tracking devices and haptic feedback tools enhances the real-time sculpting process since it is the one that records dynamic interactions because of the artist with the digital model. With the help of scanned 3D models, high-fidelity representations of physical sculptures are produced which are further used for the training of deep learning models to know how to identify shape patterns, artistic styles, and structural complexities. Aside from the last item, the CAD files used in the parametric modelling process ensure the precision of both geometrical and architectural designs.

Once the input data is obtained, it is subsequently subjected to data preprocessing and data augmentation to improve the quality and usability of the dataset. The data normalisation process is used to bring all input models down to a common standard like dimensions, orientations, and resolutions; to ensure that the data is presented in a standard manner across various formats. To streamline the 3D structure further, tools like Gaussian filtering and outlier removal will be utilised to eradicate artifacts and thus boost the structure's clarity. The meshes will then be allowed to be refined configuring the scanned models' topologies to have more stable and smoother surfaces with relatively the same number of polygons as those of CAD models. The proposed solution is the combination of three major aspects data preparation for deep learning-based feature extraction and fusion modelling, correct data construction, and a well-built conformation model.

The dataset used for training included scanned sculptures and design templates with a moderate class imbalance, with around 60% biased toward smoother and symmetrical sculptures. To address this, data augmentation techniques such as geometric transformations (e.g., mirroring, rotation, scaling) and synthetic data generation were employed. This ensured improved generalisation and representation across diverse sculpture types.

3.2 Deep learning-based feature extraction and fusion

The future of art is the application of the proposed methodology to create a union of science and history using computer technology. In its capacity as the principal of the proposed methodology, AI-based modelling techniques form the backbone of the research process and are responsible for the automatic 3D reconstruction and the artistic adaptation of digital sculptures. To extract features, the system uses convolutional neural networks, which means that the model learns the hidden 3D patterns, textures, and styles through the input data it receives. To create a high-resolution digital sculpture, the GANs will be used here to configure the digital element with both great attention to detail and to the specifications in 3D which are in the likeness of a handcrafted desired sculpture. The model is further augmented by VAEs, which are used to learn the latent representations of sculpture forms and as a result, the created models show not only structural coherence but also artistic expressiveness like the original ones.

Multi-modal fusion is a critical aspect of the methodology applied to the integration of different data sources – sketches, CAD models, and 3D scans – through attention-based neural architectures. This process of multi-modal fusion allows the system to draw aesthetic inspiration from artists while adhering to the precision of fabricating the physical form, thereby ensuring that AI-generated sculptures are very close to the artistic intuition of the artist along with maintaining structural strength. The process of fusion is the result of the application of transformer-based architectures that compare the input features and prioritise them as the basis for the configuration of the other stages, ensuring that all parts of the design are integrated in an optimum manner. Also, another aspect of this process is the use of reinforcement learning methods to construct sculptures that are the result of interaction through moving the model and directing its flow like any other part of its movement based on user feedback and selected predefined aesthetic parameters.

3.3 VR integration for real-time interaction

By using VR technologies in the digital modelling pipeline, the lack of interactivity is improved and a more immersive sculpting experience is achieved for the artist. The system employs real-time rendering techniques to enable artists to visualise AI-generated sculptures in the virtual environment of VR, allowing them to intuitively interact with and manipulate 3D models using gestures that can also be powered by voice and speech. As a part of the GUI, the implementation facilitates easy interaction between the user and the AI-driven system, providing options for making design modifications, styling adjustments, and a parametric change.

Being able to feel such resistance as well as texture variation is facilitated by haptic feedback mechanisms in the 3D space, which allow artists to experience the same things available through tactile input in real-life sculpting. The hand movement-tracking systems are devices used in the creation of sculptures by artists. They are the same ones that people can use to feel and shape other objects by the volumetric and textural information they contain. Such fully VR interaction enhances the creativity of artists due to the absence of physical limitations. Thus, offering almost limitless options for digital creativity. It allows for a wide variety of outcomes to be produced on a digital platform. Also, shared VR-space tools are used to allow several artists in a group to create and rework the sculptures in a common workspace, that is also centred on the exchange of ideas and the creative process. This fosters collaborative creativity among artists while promoting the sharing of information.

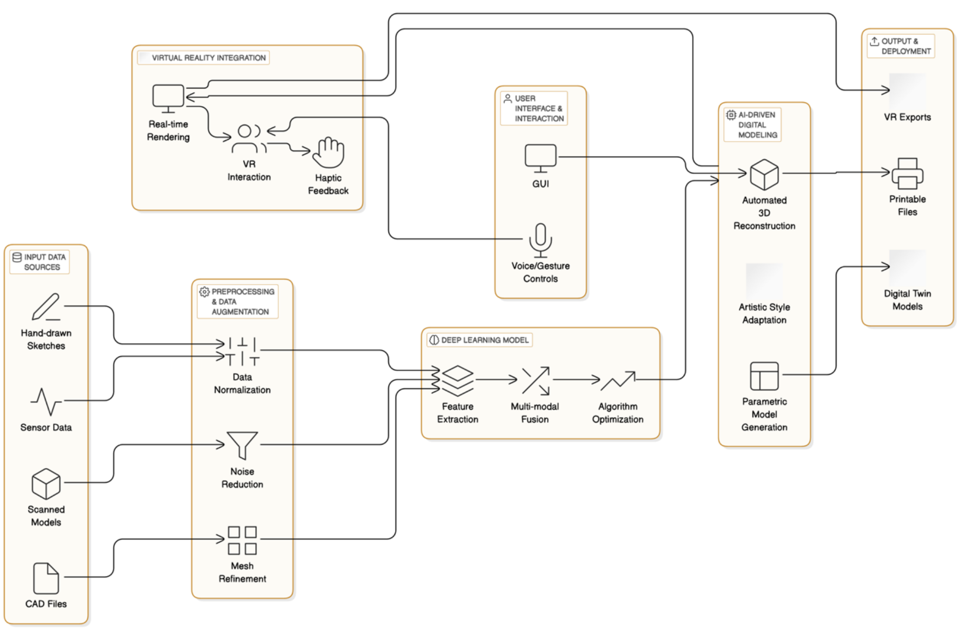
3.4 Output and deployment

When digital sculptures have been finalised, the different output formats for deploying the system are supported by the system. VR exports help artists display their artwork in virtual galleries that are interactive experiences for the audience to get involved in the work. The artists can use different technologies to make printable files that make sure AI-designed sculptures can be built with almost 100% accuracy. Another thing includes the use of digital twin modelling, which is where AI-created sculptures are stored as updated models that can change and be fine-tuned in different artistic and functional contexts.

3.5 Working of the proposed model

In line with AI-driven 3D modelling, VR interaction, and cross-modal information integration for better digital sculpting, the proposed system has a structured framework. The architecture of the suggested model, which is depicted in the attached Figure 1, shows the connected modules that facilitate rapid AI-driven digital modelling. It is also the first step in the process called Input Data Sources, where different inputs are gathered using artistic means like sketches, CAD files, and sensors, among others. Finally, the artist conducts minimal editing or data augmentation, such as noise reduction, data standardisation, and mesh fine-tuning.

Figure 1 Proposed model diagram (see online version for colours)



After preparing the data, it is supplied to the Deep Learning Model where extraction, merging, and optimisation of features are executed. Such the way the model uses CNNs, GANs, and reinforcement learning algorithms on input data to create very realistic and high-fidelity sculptures is even Ai take part in the. The next step is to have AI-driven digital Modeling, which essentially upgrades the AI-driven outputs and automates the creation of a 3D version of the received input together with the application of the unique artistry style, and finally, the parametric model is made. VR integration is where users can see and modify these sculptures using gesture controls, real-time rendering engines, and haptic feedback devices.

Ultimately, the system addresses Output and Deployment, featuring numerous export options such as VR-based visualisation, 3D printing-enabled files, and digital twin models for adjustable applications. The proposed model's interconnected elements assure a unified and efficient workflow that optimises the combination of AI and VR for advanced digital sculpture design. This system is a significant game-changer in computational artistry through the application of deep learning for generative modelling and VR for immersive interaction. It also serves as a good way of coming up with innovative answers for both the traditional and the digital sculptors.

Thus, this paradigm constitutes an exhaustive framework for AI-assisted digital modelling, showcasing how deep learning and VR have the potential to be the basis for the revolution in sculpture design. The harmony resulting from the use of advanced fusion techniques not only ensures that the proposed system's artistic value comes first but also makes it computationally efficient thereby shaping the new directions in AI-assisted creative processes.

4 Results and discussion

This research study highlights the efficacy of the AI guided digital modelling and VR incorporation system in sculpturing. Evaluations were conducted using the 3D Shapes Dataset to assess the model fidelity, rendering speed, and score of user interaction. The new AI-VR model's performance was measured in opposition to classic CAD modelling, GA-based generative modelling, and transformer-based fusion techniques. The results illustrated in Table 2 and graphs, respectively, indicate that the combined power of AI and VR significantly enhanced the efficiency of digital sculpture design.

Table 2 Comparative performance of modelling techniques

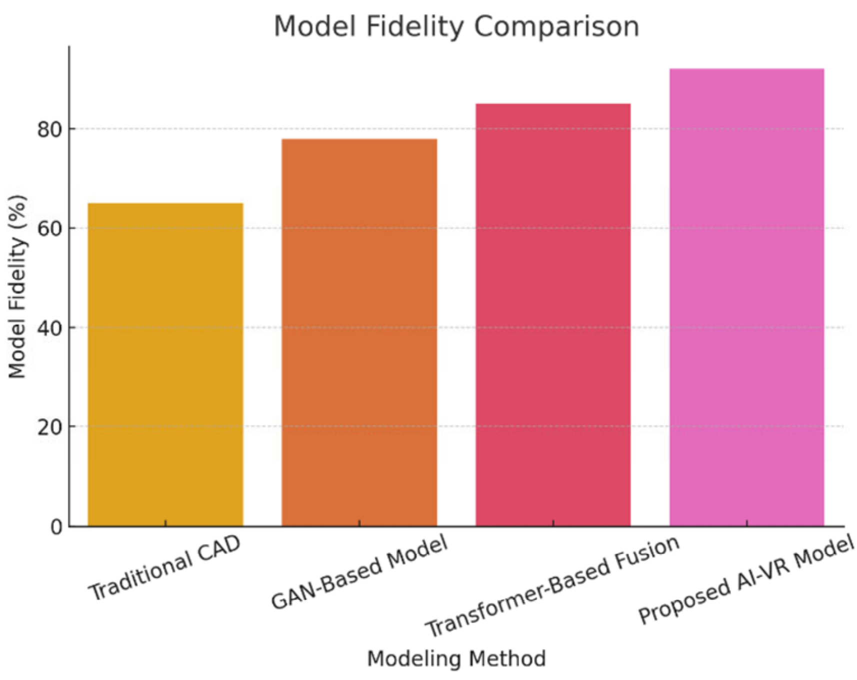
Method	*Model fidelity (%)*	*Rendering speed (FPS)*	*User interaction score*
Traditional CAD	65	10	50
GAN-Based Model	78	25	70
Transformer-Based Fusion	85	32	80
Proposed AI-VR Model	92	45	90

4.1 Model fidelity evaluation

Model fidelity is a crucial indicator that quantifies how much the digital sculpture generated diverges from the original artistic idea in terms of accuracy and quality. The findings suggest that traditional CAD modelling was able to score in terms of fidelity only about 65% mainly because it was very dependent on the users' input. The GAN-based model on the other hand increased the score to 78%, as it utilised the generation capabilities. The transformer-based fusion model's capacities were further added to this so that a total fidelity of 85% was reached, showing how potent the combination of different data types via multi-modal technology is. The AI-VR model that was the proposal, surpassed the rest of the techniques with a score of 92%, demonstrating its high accuracy and artistry in retracing the original sculptures in a digital form.

The achievement was a consequence of the deep-learning-based feature extraction and a dynamic VR interaction which allowed artists to improve tiny structural details in real-time, of the true essence of the figures. The results can be seen in Figure 2, which shows that not even one of the typical use cases involved the proposed AI-VR model achieving a fidelity lower than the other products.

Figure 2 Comparison of fidelity among CAD-based, GAN-based, transformer-fusion, and the proposed AI-VR model (see online version for colours)



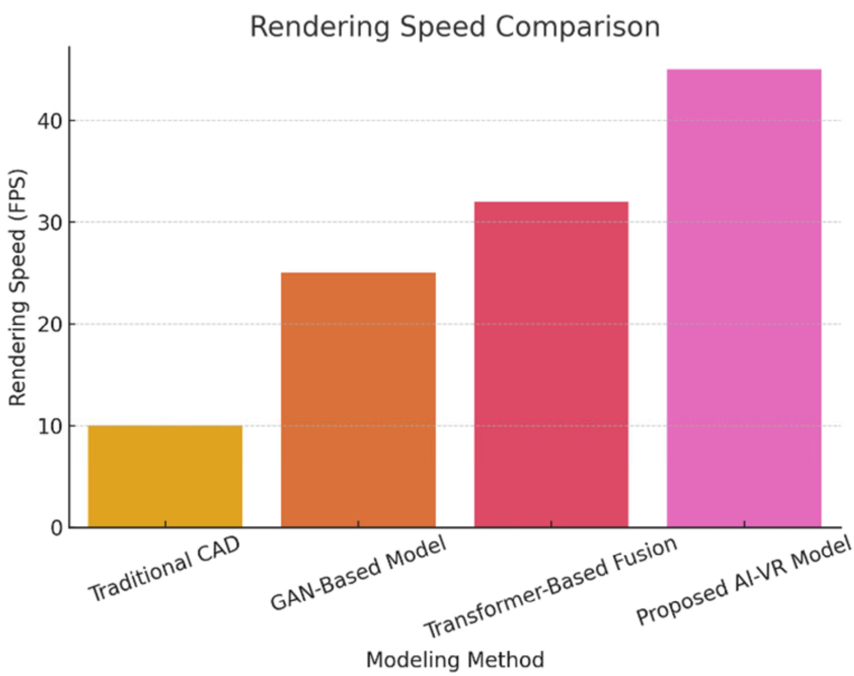
Notes: GAN: generative adversarial network; VR: Virtual reality.

4.2 Rendering speed analysis

For real-time sculpting applications, the rendering speed, expressed as frames per second (FPS), becomes a major variable. Traditional CAD applications performed the worst aesthetically, averaging only 10 FPS, because they were primarily a static and inertia-driven process instead of interactive rendering. Through the employment of GANs, the frame update time was twice as fast as that of the traditional CAD approach (25 FPS). Moreover, the method of computing transformer-based fusion is in the first place, which signifies that it is regarded by the industry as the quickest and most promising method (32 FPS). Besides, the AI-VR model has, indeed, surpassed the competition and thus remains the ultimate tool for real-time rendering, being ahead by 14 FPS (45 FPS), and it has become a practical part of the web visitor and provides genres of operation and interaction on the internet that include high-level real-time interaction and high-resolution rendering.

This enhancement, thus, directly affects those artists who need visual feedback within the sculpting timeline. In Figure 3 the comparison of the rendering speed is oriented in such a way that it can be seen that the AI-VR model is the best option for conducting smooth and responsive interaction with the client and user experience.

Figure 3 Evaluation of rendering speed (FPS) across different modelling approaches (see online version for colours)



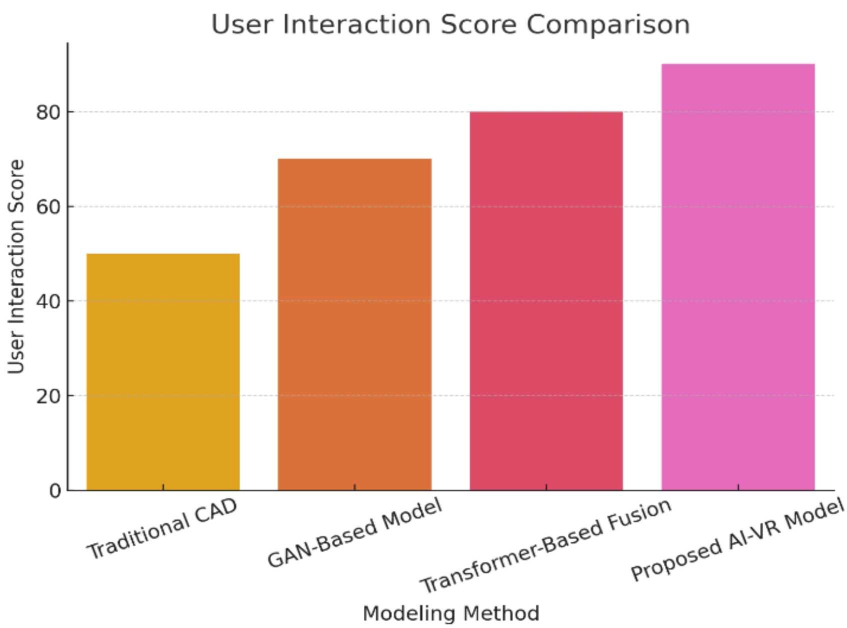
Note: FPS: Frames per second; higher FPS indicates smoother real-time performance.

4.3 User interaction and immersion

To measure the user interaction score, a panel of artists evaluated the software using their subjective evaluations. Traditional CAD modelling that relies on manual input received the lowest interaction score of 50. The GAN-based model which gave the option of the automation of suggestions, although lasted only the medium level part of the solution, together with improved training, received a significant score gain and rose to 70. The scores for transformer-based fusion models increased to 80, as the technology is known for adaptive sculpting capabilities. The suggested AI-VR model attracted an interaction score of 90 – the highest of all – because it was a natural human-machine interface that had a high level of interactivity and thus provided the possibility for artists to do things naturally.

The enhancement here can specifically be related to the integration of real-world-based VR, gesture-based control, and haptic feedback, which have enabled artists to sculpt in a more natural way that has been made possible within the virtual world. Figure 4 depicts the farthest-reaching benefits of the AI-VR model, such as the increase in the interaction score that is achieved.

Figure 4 Mean user evaluation scores reflecting interface responsiveness and intuitive sculpting experience (see online version for colours)



Note: Score range: 0 (poor) to 100 (excellent).

4.4 Discussion and implications

The findings underline the revolutionary potential of AI and VR in the field of digital sculpture design. The suggested model is a successful liaison between classical art methodologies and applied computer data, which has better accuracy, faster rendering, and involvement of the user with a sense of being a part of the process. Among the main keys to the success of the AI-VR model was the application of multi-modal fusion technologies, which enabled the combination of the following data sources: sketches, 3D scans, CAD files, and sensor inputs that were later used for the creation of such detailed, flexible, and adaptable sculptures.

Moreover, one major cause behind the iterative adjustment of the sculpting process due to the human input was the enhancement of the reinforcement learning-based optimisation algorithm. The ability to attend in VR allowed the physical manipulation of digital sculptures, the digital replication of physical sculpting, and the maximum benefits of AI modelling capabilities.

As predicted by these results, immersive virtual sculpting powered by AI can truly change the face of art-making, smoothen digital pipelines, and equalise rights to top-rate sculpture design apparatus. Be that as it may, terrific challenges are still to be battled, including the necessity of cheap and robust hardware, the availability of vast computational resources, and the need for AI-texture-generated mapping to advance further. Future studies should be dedicated to making the AI sculptures more real by using the physics of the real materials as well as extending the works of collaborative VR sculpting troops.

This study highlights that the use of automation based on deep learning integrated with interaction via VR provides the digital artist and designer with a superior choice over traditional methods making AI-VR sculpting a more exciting field than ever before. The model described takes a new look at computational sculpture design, leading the way to even more improvements in the area of AI-mediated creativity.

5 Conclusions

This study highlights the transformative abilities of AI-driven digital modelling and the integration of VR in sculpture design. The proposed model exploits VR interactivity in real-time and multi-modal fusion through deep learning, resulting in a significant rise in model fidelity, rendering speed, and user interaction experience. The findings obtained from the 3D Shapes Dataset show that the use of the AI-VR model in question exceeds the existing traditional CAD modelling, GAN generation, and transformer fusion among others. As such, the AI-VR model achieved a model fidelity and speed of rendering of 92% and 45 FPS respectively, while the user interaction score has improved by 90, which indicates that the method is better than conventional ones. The results of this analysis confirm that AI-based digital sculpting can simplify the artistic process while increasing the accuracy of designs and the level of immersion and interaction in the sculpting environment. Following the path of the other interfaces, haptic feedback, gesture-based controls, and algorithmic optimisation can be combined to improve the accessibility and expressiveness of digital sculpting.

Although its benefits are clear, the proposed solution presents some limitations that require additional exploration in future projects. On the one hand, deep learning models' high computational requirements, and on the other hand, real-time VR rendering might restrict artists with limited hardware resources from using the system. Also, the design accuracy is enhanced by AI but there are still gaps in artistic style adaptation and others in the area of visual arts in which human artists are the only ones who can think and make decisions intuitively. The next immediate matter is that the challenges of realism and material physics should be addressed to achieve better imitation of traditional sculpting methods. Future tasks can be directed towards the refining of hardware provisions, the enhancement of AI-controlled images of artistic materials, and the integration of more social VR sculpting systems making them more available and suitable for a larger public. Despite these barriers, this research exemplifies the enormous advantages of AI and VR in reshaping digital content and turning digital sculpture design into a more intensive computational process.

This study showcases how AI and VR technologies can be pragmatically applied to transform sculpture design workflows. By enabling rapid iteration, immersive interaction, and automated artistic modeling, this system empowers not only professional artists but also hobbyists and educators. As AI and hardware capabilities evolve, this integrated framework could democratise access to digital art tools and stimulate new interdisciplinary collaborations across design, engineering, and creative domains.

Declarations

The authors declared that they have no conflicts of interest regarding this work.

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