3D Forensic Reconstruction Assisted by a Forensic NPC: Pedestrian Accident Prototype in Unity with Conversational AI

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Abstract. *This paper presents an interactive 3D prototype for the forensic reconstruction of a real vehicle-pedestrian collision. This technique made it possible to position the 3D model in close visual correspondence with the anatomical coordinates described in the forensic report,so that the visual points of contact were aligned with the areas of interest reported by the forensic expert. The core innovation is the integration of a 'Medical Examiner NPC', a conversational Artificial Intelligence (AI) developed via the ConvAI platform, that acts as a tutor. The agent prompts the user to correlate bodily traumas with the corresponding vehicle damage. The results validate this proof of concept as demonstrative evidence, highlighting its high pedagogical and immersive potential for forensic medicine education.*

1. Introduction

In recent decades, the forensic sciences have experienced a revolution through the integration of three-dimensional (3D) and immersive technologies. The emergence of a field called "3D Forensic Science" has integrated 3D imaging, modeling, and printing to maximize accuracy in crime scene reconstruction [Carew et al. 2021]. Tools such as Virtual Reality (VR), Augmented Reality (AR), and 3D printing, enabling the creation of precise digital models of victims, crime scenes, and forensic objects [Maneli and Isafiade 2022, Thali et al. 2005, Villa et al. 2023].

These technologies expand the capacity for documentation, analysis, and demonstration of evidence. The transition from traditional methods to immersive environments has transformed criminal investigation, offering new perspectives for the analysis of bloodstain patterns, ballistics, and pathology [Chango et al. 2024]. This evolution enables more precise investigation and communication of facts before the judicial system, acting

as crucial demonstrative evidence for the understanding of laypersons, such as members of a jury [Thali et al. 2005, Villa et al. 2023, Baier et al. 2018].

In the specific context of traffic accident analysis, recent studies also emphasize that accidents involve complex dynamics and multiple contributing factors, making 3D reconstruction valuable for representing the chain of events, preserving evidence, and supporting accident process analysis [Chen et al. 2025].

Artificial intelligence (AI) has been applied to the automated generation of forensic animations and the interpretation of textual and visual information. Software such as **CarSim** and **CONFUCIUS** transforms written descriptions of accidents into animated 3D reconstructions.

More recent Prompt-to-VR approaches extend this logic by using LLMs to extract forensic-relevant entities and events from textual inputs and transform them into interactive VR scenes, although their reliability remains dependent on prompt quality, spatial consistency, and control of hallucinated content. Through Natural Language Processing (NLP), they analyze reports, extract crucial data, and use them to visually represent trajectories and collisions [Krafft et al. 2025].

In addition, the combination of 3D models with virtual reality has shown significant potential not only in investigation, but also in the teaching of anatomy and forensic medicine, improving learning efficiency and spatial understanding of trauma.[Niu et al. 2025].

The applicability of 3D visualization was also demonstrated by [Koller et al. 2019], who compare the measurement of forensic injuries between traditional methods and reconstructions that were visualized in VR. They concluded that the 3D method allows for more precise documentation than standard photographs and is much closer to those obtained in specialized technical software. However, the literature points to the need to validate these virtual reconstructions as reliable prototypes for crime scene assessments [Pulgar Haro et al. 2024].

In this context, this paper presents the development of a prototype for conducting investigative and forensic-based analyses, whose objective is to provide an interactive experience of accident reconstruction based on three-dimensional evidence and with the assistance of a conversational artificial intelligence NPC (Non-Playable-Character). For the construction of the prototype, the ***Unity*** game engine[1] was used to enable interaction and navigation in the environment, with models and objects developed in ***Blender***[2], in addition to the integration of the ***ConvAI*** platform[3] which allows the creation and management of artificial intelligence characters for virtual environments and games.

This prototype was inspired by the article *"VIRTOPSY—Scientific Documentation, Reconstruction and Animation in Forensic"*, which introduces an innovative approach to forensic documentation, replacing traditional methods such as 2D photographs and verbal descriptions with three-dimensional digital records obtained through computed tomography, magnetic resonance imaging, and optical surface scanning

[1]Unity. Available at: `https://unity.com/pt`.

[2]Blender. Available at: `https://www.blender.org/`.

[3]ConvAI. Platform for creating and managing Artificial Intelligence (AI) NPC characters. Available at: `https://www.ConvAI.com/pipeline/dashboard`.

[Thali et al. 2005].

2. Related Work

The consolidation of 3D Forensic Science has changed forensic documentation and reconstruction protocols by integrating three-dimensional imaging techniques, digital modeling, and immersive visualization. These resources provide greater metric precision and scientific reproducibility, as stated by [Carew et al. 2021] and [Maneli and Isafiade 2022]. Beyond documentation, 3D environments have also been used as analytical spaces for examining spatial interrelations between bodies, objects, injuries, and the surrounding scene, allowing researchers to test investigative hypotheses that would be difficult or impossible to reproduce under real conditions [Maksymowicz et al. 2024].

In this sense, forensic virtualization finds its methodological foundation in the project proposed by [Thali et al. 2005], which introduces three-dimensional digital documentation as a systematized alternative to traditional two-dimensional records. In the field of animated visualization, [Ma et al. 2010] demonstrate that 3D reconstructions based on real data reduce misunderstandings and enhance the spatial clarity of complex events.

Furthermore, when associated with dynamic simulation based on the laws of motion, these reconstructions tend to offer a more realistic representation of the facts analyzed. Experimental evidence presented by [Koller et al. 2019] confirms this hypothesis by indicating the superiority of the analysis of immersive environments compared to isolated photographs.

Incorporating artificial intelligence into the reconstructive process, as discussed by [Chango et al. 2024], expands the potential for interpretative automation and integrated analysis of visual and textual data. By employing computer vision techniques and generative AI models, it becomes possible to relate relevant information from forensic reports to three-dimensional evidence and to structure more systematized narratives.

In this direction, PTVR was recently proposed as a forensic Prompt-to-VR pipeline that uses LLMs to extract entities, objects, and events from testimonies and encode them into structured Unity inputs. Unlike that approach, which emphasizes automated scene generation, the present prototype uses AI mainly as an interpretive conversational layer over a manually reconstructed event grounded in a forensic report [Krafft et al. 2025].

XR research has increasingly treated LLM-powered NPCs as conversational user interfaces, especially when speech-to-text, language models, and text-to-speech modules are combined to create more natural interaction than conventional scripted characters [Buldu et al. 2025].

In the educational field, [Niu et al. 2025] demonstrate that interactive three-dimensional models contribute to greater cognitive retention and better spatial understanding of the event. On the other hand, recent reviews, such as that of [Pulgar Haro et al. 2024], highlight the need for rigorous methodological validation for these technologies to be consolidated as formal forensic instruments.

3. Methodology

This work proposes the digital creation of a forensic hit-and-run case, with emphasis on the deformation of the victim's body structure through three-dimensional modeling and forensic animation, as suggested by [Ma et al. 2010], using computer graphics techniques to visualize the narrative of the accident documented in the literature. The methodology was structured into three fundamental technical stages, detailed below alongside the specifications of the development environment.

3.1. Development Environment

The prototype was developed in **Unity 2022.3.0f1 LTS** with the **Universal Render Pipeline (URP) 14.0.7** rendering pipeline, configured at the *Ultra* quality level for desktop execution — which implies MSAA 2x anti-aliasing, a shadow distance of 150 units, four shadow cascades, and a shadowmap resolution of 4096 pixels. The input system adopted was the **New Input System (v1.7.0)**, responsible for capturing movement commands (WASD), camera control (right mouse button), and NPC interaction (*Enter* and *T* keys). The ConvAI SDK was integrated through manual local package import (`.unitypackage`) into the `Assets/Convai/` folder, and is not registered in the Unity Package Manager. Table 1 summarizes the complete technology stack of the prototype.

Table 1. Technology stack of the prototype

Component	Version / Detail
Unity Editor	2022.3.0f1 (LTS)
Universal Render Pipeline	14.0.7
Input System (New)	1.7.0
TextMeshPro	3.0.9
AI Navigation (NavMesh)	1.1.5
Animation Rigging	1.2.1
ProBuilder	5.2.4
Timeline	1.7.6
ConvAI SDK	Imported via `.unitypackage`
3D Modeling	Blender

3.2. Scene Construction and Keyframe Animation

The first stage consisted of modeling the urban environment, the vehicle, and the victim's avatar using **Blender** software, with models exported to Unity in `.fbx` format. The accident dynamics were entirely constructed through **manual keyframe animation**. This decision is consistent with forensic reconstructions in which keyframe animation is not treated as a purely automatic simulation, but as a frame-by-frame reconstruction guided by expert interpretation of the available evidence [Maksymowicz et al. 2024].

The victim's trajectory was described frame by frame to replicate the exact sequence of events that occurred in the real case of [Thali et al. 2005], including the positioning of the initial impact on the rearview mirror, the rotation of the body over the hood,

and the final position on the ground. Within Unity, animation playback was managed by the **Animator** component, with sequences organized in **Timeline 1.7.6**, synchronizing collision events with NPC interactions. This technique made it possible to position the 3D model with millimetric precision, ensuring that the visual points of contact coincided with the areas of interest described in the forensic report. User navigation occurs in first-person with a walking speed of 4 units per second, a running speed of 8 units per second, and a vertical camera limit of 80°.

3.3. Visual Representation of Lesions (Texture Mapping)

For the representation of injuries, a texture mapping and digital painting approach was chosen. Based on the anatomical coordinates provided by the case study (lumbar region and costal arches), the injuries — specifically the rearview mirror mark and the abrasions — were drawn directly onto the skin texture of the avatar. This technique made it possible to illustrate the morphology and coloration of the hematomas described in the autopsy through 2D graphic representation projected onto the 3D model, ensuring the visual identification of the trauma without altering the mesh geometry. A similar logic has been reported in forensic 3D reconstruction workflows in which injuries are projected onto scaled virtual bodies to support later spatial comparison with the scene geometry [Maksymowicz et al. 2024].

3.4. Conversational AI Integration

The final stage involved importing the models and animations into the Unity graphics engine and integrating the ConvAI NPC. This stage represents the main technical contribution of the prototype and was structured into three interdependent layers: the configuration of SDK components within the Unity scene, the real-time interaction pipeline, and the configuration of the forensic agent on the ConvAI platform.

STT–LLM–TTS Interaction Pipeline

The interaction pipeline follows three chained phases, illustrated in Figure 1. NPC activation occurs through *raycast* detection continuously emitted from the main camera, with a configured range of 2 to 5 units and a vision cone angle of 45°. Once the NPC is detected, the user presses **Enter** to open the chat interface and holds the **T** key to activate voice recording. The captured audio is transmitted to the ConvAI API, processed by the Gemini model, and returned to the environment as synthesized speech (*Text-to-Speech*) through the NPC.

Character Configuration and Forensic *Grounding*

The "Virtual Forensic Pathologist" character was created on the **ConvAI platform's web dashboard**, where two essential fields are defined and referenced in the Unity Inspector: the `Character ID` (the character's unique identifier) and the `API Key` (the authentication credential). This configuration follows a broader XR interaction model in which user input is processed through a conversational pipeline and returned through an embodied agent, allowing the NPC to function as a speech-based interface between the user and the virtual forensic scene [Buldu et al. 2025, Korkiakoski et al. 2025].

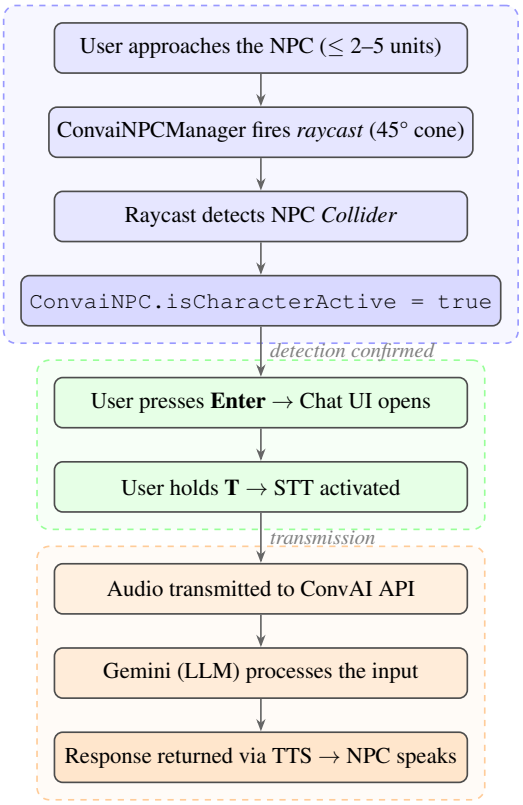


Figure 1. Complete interaction pipeline: *raycast* detection, chat activation, and STT–LLM–TTS processing.

The forensic context — based on the textual data from the article by [Thali et al. 2005] — was provided as a *system prompt* directly in the character's dashboard configuration, instructing the agent on the accident's sequence of events, the documented injuries, and its pedagogical role as an active investigative tutor. The NPC's forensic *grounding* is therefore carried out entirely on the ConvAI platform's remote layer, with no dynamic context injection by the Unity code, allowing the agent to act as an interactive guide that verbally describes the injuries and the sequence of events as the user views the animation.

4. Results

The development of this work resulted in the creation of a functional prototype for forensic reconstruction, validating the technical feasibility of integrating evidence-based 3D animation with generative artificial intelligence. The results of the visual modeling and the dynamics of investigative interaction are discussed below.

4.1. Visual Reconstruction and Scene Validation

Figure 2 presents the finalized three-dimensional environment in the Unity Engine, displaying the spatial arrangement of the critical elements: the vehicle, the roadway, and the victim's body. The scene was constructed to strictly replicate the narrative described by [Thali et al. 2005]. By using manual animation, it was possible to ensure that the final position of the victim and the damage to the vehicle corresponded with millimetric precision to the forensic report. The injuries, applied through texture mapping, are visible in the 3D

model and serve as demonstrative evidence, corroborating the view that 3D visualization eliminates the ambiguity of textual descriptions, allowing for an immediate understanding of the mechanics of the trauma [Ma et al. 2010].

This analytical role is reinforced by forensic studies showing that virtual environments can be used to test spatial correlations between injuries, body positioning, objects, and the surrounding geometry, thereby supporting the evaluation of competing investigative hypotheses [Maksymowicz et al. 2024].



Figure 2. Modeled accident.

4.2. Immersion and Forensic Analysis with NPCs

The innovation of the prototype lies in its integration with the "Virtual Forensic Pathologist" (NPC), as illustrated in Figure 3. Figure 4 represents the decisive moment of the investigation, in which the AI, after processing the case data, correctly performs the forensic verification of the accident. Unlike passive systems in which the user receives information, the NPC was configured to assume an active "tutor" role. As shown in the image, the character questions the user, prompting them to engage with the narrative and reach a coherent conclusion through the observation of visual facts.

This approach promotes deep cognitive immersion, as stated by [Agrati 2023]. The user ceases to be a spectator of the animation and becomes an investigative agent who must validate the hypotheses raised by the AI. The NPC's ability to describe the cause of death and correlate fractures with the lateral impact demonstrates the tool's potential to simulate the real experience of a forensic discussion.

Empirical research on AI-controlled NPCs in VR supports this design direction by showing that LLM-based agents may achieve good usability and moderate-to-high perceived believability, especially in behavior, social interaction, and intelligence. However, the same studies indicate that latency and limited emotional or personality expression remain relevant challenges for maintaining realism [Korkiakoski et al. 2025].

To assess the reliability of the conversational agent, the NPC's responses were compared against the facts documented in the forensic report of [Thali et al. 2005]. The agent was configured through a narrative design on the ConvAI platform, in which the sequence of events of the case was described in the system prompt. This narrative grounding constrained the agent to the scope of the documented accident, preventing it from producing responses outside the forensic context of the case.

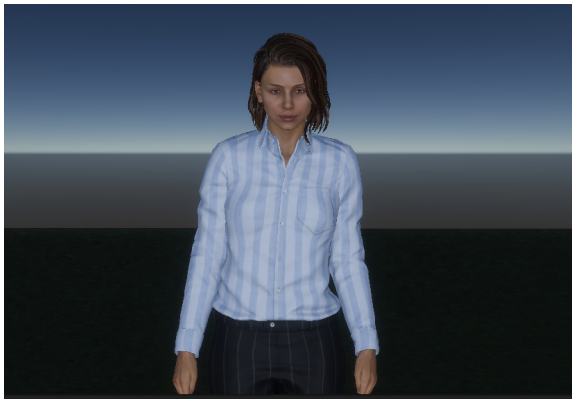


Figure 3. Conversational Virtual Human Model.



Figure 4. Conversational Virtual Human Interaction.

Within this scope, the agent's statements were consistent with the report. In its tutor role, the NPC did not merely restate information: it questioned the user about the correlation between the bodily traumas and the corresponding vehicle damage, guiding the interaction toward a coherent reconstruction of the event.

However, verification also revealed a structural limitation: the agent operates exclusively on textual input, without interpreting the 3D scene or visual evidence rendered in Unity. Its knowledge is limited to the textual descriptions of trajectories and events it was given, so when questioned beyond this scope, it could not respond clearly. This follows from its static, text-based grounding — since the forensic context is fixed in the system prompt with no runtime access to the visual scene, responses are bounded by the provided textual narrative. These cases reinforce the need for empirical validation, discussed in the final considerations, as well as the potential value of multimodal agents capable of interpreting both textual and visual evidence.

4.3. Limitations and Applications in Forensic Training

As this work is an initial proof of concept, the absence of extensive usability testing with end users (students or experts) is a natural limitation at this stage. Future validation could incorporate usability scales, virtual agent believability measures, social presence questionnaires, and latency analysis, since these instruments have been used to assess how AI-powered NPCs affect realism, engagement, and interaction quality in VR [Korkiakoski et al. 2025].

Still, the system's observed behavior shows strong potential for investigative training. Using an NPC not only to convey information but also to challenge and engage the

user aligns with [Niu et al. 2025], who showed that interactivity in 3D models substantially improves learning efficiency and spatial understanding in complex disciplines such as anatomy and forensic medicine.

This points to a paradigm shift in evidence interpretation: the virtual environment moves beyond graphical illustration to become a cognitive simulation laboratory. The animation's high fidelity — grounded in the descriptive rigor of [Thali et al. 2005] — gives the AI a precise visual foundation for its inquiries, enabling a shift from static textual reports to active methodologies where students solve the case in real time.

5. Final Considerations

TThis work presents an interactive 3D forensic reconstruction prototype based on a real case documented by [Thali et al. 2005], combining 3D modeling, animation, and a conversational AI embedded in a forensic pathologist NPC. The main contribution is this AI: rather than simply displaying animations, the NPC acts as an active tutor, prompting users to connect visual evidence with causal hypotheses and fostering investigative participation and active learning [Zhu et al. 2025].

As a limitation, no empirical validation with end users was conducted; the NPC's evaluation was limited to checking its responses against the forensic report (Section 4.2). Future work includes a small-scale usability pilot with forensic medicine students and professionals, using instruments such as the SUS, a virtual agent believability questionnaire, and a social presence questionnaire, along with latency measurements of the STT-LLM-TTS pipeline, further validating forensic accuracy and interaction quality.

Overall, this paper advances 3D Forensic Science by reconstructing events with visual fidelity while integrating AI as a mediator, moving toward more interactive, accessible, and pedagogically effective forensic systems.

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