

Hybridizing Real and Virtual Worlds: A Workflow-Based Approach Using 3D Scanners and Printers

Guilherme C. Franco¹, Hugo A. D. Nascimento¹, Laurita R. Salles²,
Arlindo R. G. Filho¹, Sergio T¹. Carvalho¹, Luciana O. Berretta¹

¹ Instituto de Informática
Universidade Federal de Goiás (UFG)
Goiânia, GO, Brasil

²Media Lab / UFG
Universidade Federal de Goiás (UFG)
Goiânia, GO, Brasil

guilherme_carvalho@discente.ufg.br

laurita.salles@gmail.com

{hadn, arlindogalvao, sergiocarvalho, luciana.berretta}@ufg.br

Abstract. *Extended Reality (XR) is an immersive technology that integrates physical and digital environments. XR applications are being increasingly adopted across various sectors, including education, healthcare, entertainment, and industry. These applications leverage diverse interaction modalities, including gestures, voice commands, haptic feedback, and motion-based interfaces, allowing users to manipulate virtual objects, navigate simulated environments, and interact with digital content. The choice of interaction depends directly on factors such as the level of immersion, available technological resources, and the physical conditions of the environment. To achieve a convincing sense of immersion, virtual objects and environments must exhibit visual and geometric properties consistent with the physical world. This work in progress investigates an integrated model that combines tools and techniques for digitizing real objects and manufacturing their virtual counterparts. The research assesses both the quality of the generated models and their suitability for use in immersive XR environments. The proposed workflow comprises two independent initial stages: (i) the virtualization of physical objects and (ii) the manufacturing of objects represented in the Metaverse.*

1. Introduction

Extended Reality (XR) applications are present in various sectors, including education, healthcare, entertainment, and industry, contributing to immersive experiences in industrial training, movement retraining, and information visualization [Zhang et al. 2023, Kašela et al. 2021, Turchet et al. 2021]. These contexts demand increasingly accurate and interactive digital representations, requiring the integration of technologies that enable realistic and precise capture of real-world objects and environments [Javaid et al. 2023].

These applications explore various forms of interaction, including the use of gestures, voice commands, haptic devices, and motion-based interfaces, which enable users

to manipulate virtual objects, navigate simulated environments, and interact with digital content [Dangxiao et al. 2019, Aldhous et al. 2024]. The choice of interaction method depends on the application’s characteristics and directly influences how the user perceives and engages with the immersive environment [Najm et al. 2024].

The choice of interaction method varies according to the application’s purpose and the environment’s limitations [Alhakamy 2024]. Factors such as the level of immersion, available resources, and the physical conditions of the space directly influence which forms of interaction are adopted [Wee et al. 2021, Vermeulen et al. 2023]. To provide an immersive experience, one essential aspect is realistic interaction with objects and the environment, allowing forces, masses, and textures to be perceived during the interaction [Zhou and Aburumman 2024, Shi et al. 2022].

For users to perceive interaction in XR as immersive, virtual objects and environments must exhibit visual and geometric characteristics compatible with the physical world [Sra 2023]. When manipulating objects, users rely directly on the shape and texture to guide their perception during interaction [De Paolis and De Luca 2022, Wölfel et al. 2021]. Well-defined surfaces, precise contours, and detailed textures reinforce the sense of presence, helping users visually and tactually interpret virtual elements [Mizuho et al. 2023].

This work in progress addresses the challenges of virtual object manipulation by proposing an integrated model that combines digitization tools and techniques. The research problem is defined as follows: how to integrate different virtualization tools and techniques to generate objects with visual and geometric properties consistent with the physical world, ensuring their practical use in immersive digital environments. Accordingly, the study aims to evaluate this model by assessing the quality of the generated objects and their suitability for use in immersive environments.

2. Methodology

Given the concept of verifying an integrated model of tools and techniques that enables the digitization of real objects and the manufacturing of virtualized objects, the proposed workflow consists of two (2) initial independent stages. The first stage corresponds to the virtualization of a real object (a), while the second stage refers to the manufacturing of objects present in the Metaverse (b). Figure 1 illustrates a communication flowchart of this workflow.

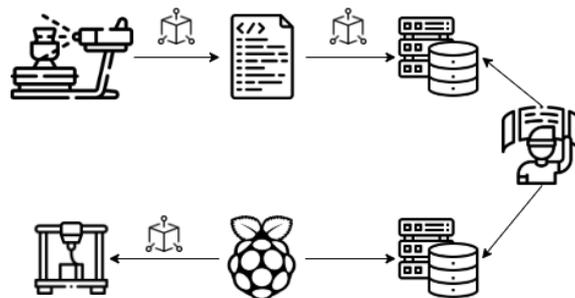


Figure 1. Digitization and manufacturing workflows.

The Digitization stage (a) is carried out through the integration of specialized hard-

ware and software, ensuring that the scanning process remains within the device's operational limits. This process captures objects with high precision and stores them directly in a dedicated database hosted on an external server, thereby optimizing the communication flowchart and digital model management.

After storing the digital model in the dedicated database, the Metaverse application accesses it whenever the object needs to be visualized within the virtual environment. This approach eliminates the need to rescan the model each time it is displayed, enabling dynamic and efficient rendering of the objects.

The Manufacturing step (b) produces the selected virtualized object. This process requires a stable connection between the 3D Printer and the dedicated database. For printing, the system links the virtualized object to the model stored in the 3D Printer. The Printer then builds the model progressively, layer by layer, using thermoplastic material that it carefully melts and cools. This method ensures the accuracy, structural integrity, and overall quality of the final object.

After implementing the proposed workflow, we carried out a validation process by executing specific tasks guided by a predefined interaction script. Our objective was to evaluate the system's effectiveness and usability through a Likert scale questionnaire, gathering both qualitative and quantitative feedback from the participants.

2.1. Workflow Implementation

To enhance interconnectivity between devices, it is necessary to expand the steps outlined in the presented flowchart. To promote smoother communication, it is essential to integrate the steps of digitization, manufacturing, storage, and the Metaverse application. A more automated and interconnected communication enables information to flow continuously and seamlessly. To achieve this, conversions and transformations must be performed, encompassing hardware, software, and interactions with servers and external devices. This integration ensures a cohesive and efficient communication flow, minimizing delays and improving the overall user experience.

In the proposed workflow, we use a sequence of automated commands with AutoHotkey¹ to control the proprietary software of an EinScan-SP V2 scanning device. Once the scanning process finishes, the software consolidates the generated point cloud into a single Polygon File Format (PLY) file. We select this format because it requires minimal storage and simplifies mesh editing, enabling more efficient and flexible processing in subsequent steps.

After exporting the final file in PLY format, it is converted to GL Transmission Format Binary (GLB) to ensure better compatibility and integration with the Metaverse. This conversion is essential as the GLB format optimizes performance, reduces loading times, and efficiently preserves materials, textures, and animations. Widely supported by virtual and augmented reality platforms, GLB facilitates the visualization and interaction of models within immersive environments. Thus, transitioning to this format ensures a smoother, more accessible experience within the digital ecosystem.

After the conversion, the generated file is stored in a centralized database, ensuring

¹AutoHotkey (AHK) is a free, open-source scripting language for Windows, commonly used to create custom keyboard shortcuts, macros, and other automation tools.

its availability for querying in Metaverse applications whenever the virtualized files need to be loaded. This centralized storage enables quick and efficient access to 3D models, optimizing the user experience by reducing load times and ensuring data integrity. As a result, the process provides both the reliability and performance of interactions.

The proposed digitization workflow, combined with conversion to the GLB format and storage in a database, significantly enhances the system interoperability. Moreover, automating the process from cloud capture to final model export reduces manual intervention, increases efficiency, and improves compatibility across different software platforms and devices.

In the manufacturing workflow, the process follows a similar logic to that of digitization, necessitating an expansion to establish a connection with the 3D Printer. To facilitate this, a microcomputer was implemented as an intermediary, enabling the control and communication of the equipment through a local network. A Raspberry Pi 3B was used for this purpose, serving as the bridge between the server and the 3D Printer by establishing a serial connection. This configuration allows for communication and efficient management of the printing process.

The microcomputer monitors the server for available objects, and when a request is made through the Metaverse application, the database updates the object’s status, allowing the Raspberry Pi to automatically initiate printing without manual intervention. Before starting, the system verifies the correct model in the printer’s memory and communicates via the OctoPrint REST API, ensuring remote control and high-precision manufacturing that aligns the printed object with the virtual design.

The implementation of digitization and manufacturing workflows, supported by automated communication between the Raspberry Pi 3B, the server, and the 3D printer via the OctoPrint REST API, enhanced system interoperability by enabling remote print management, reducing manual intervention, and improving efficiency. Converting models to GLB format and storing them in a database facilitated integration, visualization, and interaction with objects in the Metaverse, ensuring compatibility across devices and platforms.

3. Results

We digitized two objects to enable a detailed analysis of the results, including the number of vertices, faces, and total surface area of each model (Table 1). This quantitative data reveals the geometric complexity and surface characteristics of the scanned models. By comparing these metrics, we assess the fidelity of the digitization process, identify potential inconsistencies, and evaluate how accurately the 3D models represent the original objects’ structural properties.

Tabela 1. Digital Object properties, vertices, faces, and area

Objects	Properties		
	vertices	faces	area
R1	295955	591910	8085.79
R2	335999	671994	24875.88

This evaluation verified the fidelity of the digitization process for a real object

(R1.1/R2.1), confirming that the virtualized models accurately preserved their geometric characteristics. This accuracy facilitated both the analysis of the objects and their integration into the digitization workflow (R1.2/R2.2), ultimately enabling their 3D printing (R1.3/R2.3).



Figura 2. Real objects, their respective digital and printed visualizations.

4. Conclusion

We designed and validated a workflow to capture the shapes of real-world objects and reinterpret them digitally, while simultaneously manufacturing new digital objects. This flow facilitates the digitization of real objects for use in Metaverse applications and supports the manufacturing of objects created within the Metaverse. Furthermore, it enables interoperability between distinct systems through an IoT communication architecture, connecting scanners, 3D modeling tools, and printers within a controlled environment defined by the Metaverse.

As future work, an empirical validation of the questionnaire is proposed in immersive environments. This phase will involve applying the instrument in real interaction scenarios with digital objects to evaluate its effectiveness in collecting data on usability, cognitive load, presence, and immersion. The results analysis will verify the clarity of the questions, the internal consistency of the scales, and the questionnaire's ability to capture relevant user experience perceptions.

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