Progressive 3D Reconstruction for Collaborative Construction of Digital Twins

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Abstract

Digital twins are increasingly useful in metaverse-related applications, but their construction process usually involves deep technical expertise and costly resources. This position paper demonstrates an early prototype (see Figure 1) of a web-based digital twin authoring system to enable untrained users to collaboratively build digital twin environments. The system aims to explore the combination of photogrammetry and GAN-based machine learning models to enable near-real-time collaboration between capture client (scanning objects using common smartphone cameras) and editing client (constructing 3D scenes on thin client devices) users.

Introduction

A digital twin can be described as a virtual replica of a physical entity with a bi-directional data flow cycling between each other for mirroring their states (Jones et al. 2020). With the integration of XR experiences, digital twin technology has shown tremendous promise in improving the Industry 4.0 movement (Cárdenas-Robledo et al. 2022) and has been gaining increasingly more interest in other application fields, such as aviation, healthcare, smart cities and education (Barricelli, Casiraghi, and Fogli 2019; Singh et al. 2022).

To accurately mirror the physical counterpart's characteristics and functionalities, high-fidelity modelling is core to building digital twins (Liu et al. 2021; Tao et al. 2022). Building high-fidelity digital twin environments is a mix of different technically-involved practices typically performed by trained technical artists and/or computer vision researchers, including two key processes:

- replication of real-world objects into 3D virtual objects;
- manipulating these virtual objects to build virtual scenes.

However, both processes typically require expertise and resources that are not easily accessible to the common consumer. For most development tasks, it is not uncommon to require experienced 3D technical artists or specialized digital professionals working with expensive 3D software on high-performance workstations. This hinders the adoption of such technologies, especially in the manufacturing domain that traditionally does not possess such deep technological expertise.

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Much prior research has targeted the use of automated 3D reconstruction algorithms to enable more accessible solutions in replicating real-world objects, but they mainly focus on foundational research of the algorithms, and not on the usability aspects for actual applications (Guven and Feiner 2003; Seichter, Looser, and Billinghurst 2008; Tefera et al. 2018).

To bridge the translational research gap, we hence present an initial prototype of a novel collaborative 3D authoring system to explore the enabling of untrained users to participate in the effective construction of high-fidelity 3D environments for digital twins. The prototype will facilitate the exploration of various progressive 3D reconstruction methods and edge computing architectures to enable accessible and usable near-real-time collaborative authoring features.

In other words, our research aims to democratize the construction of digital twin environments. To the best of our knowledge, there is presently no focus on making digital twin creation more accessible, as it has always been viewed as an endeavour for experts with deep technical knowledge. The novel tool will significantly enhance the accessibility of 3D authoring for untrained users. *Accessibility* in this context refers to the greater ease of adoption for the software and it's digital twin environment creation processes, especially amongst untrained users. This will greatly contribute to building technical capabilities for creating digital twins, and in turn improving the industrial adoption of digital twin technologies.

The Prototype

The prototype is made up of 3 main components - (1) capture client, (2) editing client, and (3) edge node, that are connected on a network (see Figure 2). Each component has it's own role in the digital twin environment creation workflow. The capture client and editing client act as front-end web-based interfaces that users can interact with. The edge node is a high-performance server that provides remote graphical processing services to capture and editing clients within a local jurisdiction.

The capture client is a browser-based application that enable users to capture images and create 3D models using captured imagery. There is currently a wide variety of commercially available 3D reconstruction software and applications such as Polycam (Polycam 2022), and Reality Cap-

Figure 1: The prototype of the capture client (left) showing imagery being captured, and a 3D reconstruction of using the captured imagery. And, a prototype for the editing client (right) showing how 3D reconstruction models can be manipulated and used to populate virtual environments.

ture (RealityCapture 2016) which allow untrained users to perform capture and 3D model creation operations similar to that of the capture client here. However, many lack proper integration with the scene creation software of choice and can be client-side hardware dependent. The capture client aims to overcome this by enabling better collaboration with editing software users, in this case the editing client here. Accessibility is also improved by off-loading the computationally-intensive process of 3D model creation to the remote edge node.

The editing client is also a browser-based application that enables users to utilize the 3D models created from the capture client to populate and create digital twin environments, and thereby export those digital twin environments. Many established digital twin environment creation pipelines already incorporate a variety of 3D scene editing and/or creation software such as Unity (UnityTechnologies 2023) and 3DS Max (Autodesk 2023). However, these software tend to include complex features with steep learning curves, which can impact the usability for users unfamiliar with them, as with the case of earlier 2012 versions of Autodesk AutoCAD (Peng et al. 2012). Many also lack collaborative features, making it challenging for untrained users to effectively co-create digital twin environments in teams. The editing client aims to overcome these issues by simplifying and redefining the processes from established traditional creation workflows.

The edge node can be seen as a performant back-end to off-load computationally-intensive tasks from capture and editing clients. The prototype only off-loads the 3D model creation process from the capture client user's device. This 3D model creation process is currently implemented with Meshroom's (Griwodz et al. 2021) photogrammetry Structure From Motion (SfM) algorithm for reconstructing 3D models from images captured via the capture client.

Prototype Workflow

The goal of the prototype is to aid the investigation of ways to reduce task complexity and enable better collaboration between users, by revising the processes present within typical virtual environment creation workflows as mentioned above. Prior research have explored novel approaches towards development of 3D software or designs. One such approach is the incremental 2D to 3D design and development workflow introduced in AgentCubes (Ioannidou, Repenning, and Webb 2009) which targets young users to introduce them to the science of 3D game development. Another is the collaboration and team-first 3D ideation tool, Co-3Deator (Piya et al. 2017).

To aid our investigation, the tasks in the prototype will also be categorized as *individual*, *cooperative*, or *collaborative* (see Figure 3) according to the Collaborative Interactive Application Methodology (CIAM) (Molina Díaz et al. 2008). Individual tasks refer to work that is performed alone with the intention of achieving one's own goal. Cooperative tasks refer to work that can be performed together synchronously or asynchronously, with the intention of achieving a non-shared goal held by only one specific cooperator. Collaborative tasks are similar to cooperative tasks in how work can be done, but instead focuses on achieving a shared goal that is held common amongst all collaborators. The categorization of tasks is one of the many initial steps aimed at analyzing and understanding the current workflow and areas where processes and co-working elements can improved or implemented.

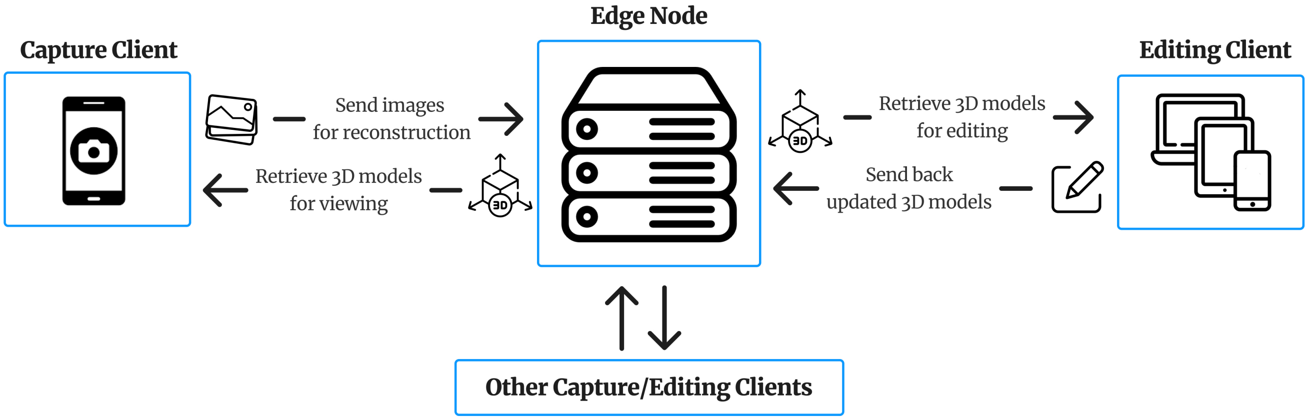

Figure 2: A high-level architecture diagram showing the interactions between each component of the prototype.

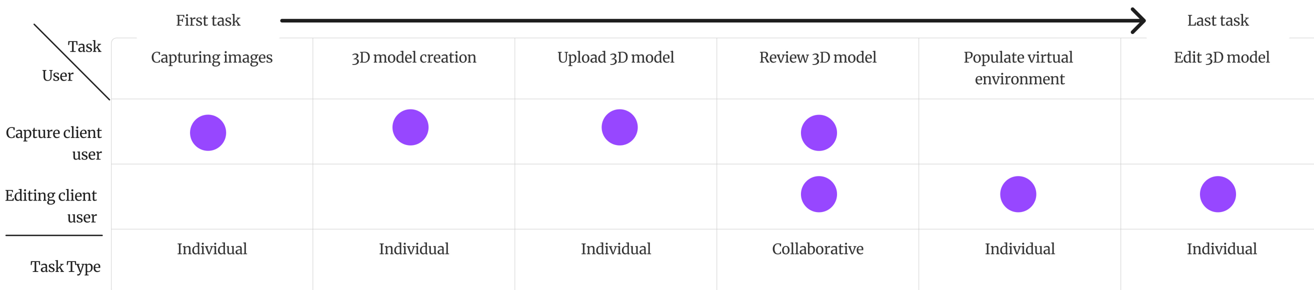

Figure 3: A participant table diagram based on the Collaborative Interactive Application Methodology (CIAM) (Molina Díaz et al. 2008), showing the task each user of the respective clients need to perform, and how some of the tasks may overlap and can have shared responsibilities.

Future Work

This position paper showcases the work-in-progress research of a 3D authoring system that aids the exploratory design of novel conceptual workflows for the accessible and usable collaborative construction of digital twins.

Future work will involve more in-depth research and development of the capture and editing clients to include features for enabling the easier creation and editing of digital twin assets and environments, such as designing simple 3D model geometric shape modification toolsets for the untrained user. This also includes the exploration of more productive and practical collaboration mechanisms between multiple users, such as enabling multiple editing client users to edit same digital twin environment in near-real-time.

This further development of the capture and editing clients applications will eventually lead to the development of specific research questions related to the user experience of the prototype, and henceforth the design of its associated user studies. For example, a between-subjects user study may be designed to evaluate the collaborative construction of digital twin environments using the prototype, against commonly used applications existing in traditional creation workflows.

Acknowledgments

This work is funded by the Future Communications Translational Lab at the Singapore Institute of Technology (SIT) which receives support by the National Research Foundation, Singapore and Infocomm Media Development Authority under its Future Communications Research & Development Programme. Preliminary concepts of this work were also contributed by our SIT colleagues Dr Indriyati Atmosukarto, Dr Alvin Chan and Dr Jeannie Lee, as well as our NVIDIA collaborators Ms Megani Rajendran, Dr Ng Aik Beng, Dr Simon See and Dr Tomasz Bednarz.

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