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DEVELOPMENT OF AN INTERACTIVE DIGITAL REPLICA OF NARVA TOWN HALL SQUARE IN A VIRTUAL REALITY ENVIRONMENT

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NARVA RAEKOJA PLATSI INTERAKTIIVSE DIGITAALSE KOOPIA LOOMINE VIRTUAALREAALSUSE KESKKONNAS

Lõputöö

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AUTHOR’S DECLARATION OF ORIGINALITY

I hereby certify that I am the sole author of this thesis. All the materials used, references to the literature, and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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ABSTRACT

This thesis investigates how a historically and architecturally significant urban space can be reconstructed as an interactive, accessible and pedagogically meaningful virtual reality environment. Focusing on Narva Town Hall Square - with Narva Town Hall and Narva College as key landmarks - the project responds to the absence of a high-fidelity, publicly accessible VR representation of the square and to broader debates in digital heritage, virtual architecture and immersive media. A comparative analysis of social VR platforms identifies VRChat as the most suitable environment, combining technical openness, cross-platform access and an active creator community. The empirical work follows a six-stage, practice-based workflow: conceptual planning; collection of architectural drawings, archival and contemporary photographs and on-site observations; 3D modelling and texturing in Blender; integration and optimization in Unity and VRChat using the VRChat SDK and Udon; and iterative testing and evaluation. The resulting VRChat world offers a recognizable, human-scale reconstruction of Narva Town Hall Square that meets the main functional and non-functional requirements in terms of spatial authenticity, navigability, performance and basic interactivity. Internal testing indicates that the environment can enhance spatial understanding, presence and remote accessibility compared with traditional two-dimensional media. The thesis contributes a working VRChat reconstruction of Narva Town Hall Square and a documented workflow that translates theoretical principles into a concrete social VR practice, providing a foundation for future educational use and further development.

ANNOTATSIOON

Käesolev lõputöö uurib, kuidas ajalooliselt ja arhitektuuriliselt olulist linnaruumi saab rekonstrueerida interaktiivse, ligipääsetava ja pedagoogiliselt tähendusliku virtuaalreaalsuse keskkonnana. Keskendudes Narva Raekoja platsile, kus peamiste maamärkidena toimivad Narva raekoda ja Narva kolledž, vastab projekt nii platsist lähtuva kõrge detailsusega ja avalikult kättesaadava virtuaalreaalsuse rekonstruktsiooni puudumisele kui ka laiematele aruteludele digipärandi, virtuaalarhitektuuri ja immersiivse meedia üle. Sotsiaalse virtuaalreaalsuse platvormide võrdlev analüüs toob VRChati esile sobivaima keskkonnana, mis ühendab tehnilise avatuse, platvormideülese ligipääsu ja aktiivse loojakogukonna. Empiiriline töö järgib kuuest etapist koosnevat, praktikapõhist töövoogu: kontseptuaalne planeerimine; arhitektijooniste, arhiivi- ja nüüdisaegsete fotode ning kohapealsete vaatluste kogumine; 3D-modelleerimine ja tekstuurimine programmis Blender; integratsioon ja optimeerimine Unitys ja VRChatis, kasutades VRChati SDK-d ja Udonit; ning korduv testimine ja hindamine. Valminud VRChati maailm pakub äratuntavat, inimskaleeritud Narva Raekoja platsi rekonstruktsiooni, mis vastab peamistele funktsionaalsetele ja mittefunktsionaalsetele nõuetele ruumilise autentsuse, navigeeritavuse, jõudluse ja elementaarse interaktiivsuse osas. Sisemine kasutajatestimine näitab, et keskkond võib traditsiooniliste kahemõõtmeliste meediumidega võrreldes parandada ruumilist arusaamist, kohalolutunnet ja kaugjuurdepääsu. Töö tulemuseks on toimiv VRChati keskkonnas loodud Narva Raekoja platsi rekonstruktsioon ning dokumenteeritud töövoog, mis tõlgib teoreetilised põhimõtted konkreetseks sotsiaalse virtuaalreaalsuse praktikaks ja loob aluse edasiseks hariduslikuks kasutamiseks ning edasiarenduseks.

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INTRODUCTION

Over the last decade, virtual reality (VR) technologies have evolved from experimental prototypes into widely used platforms for collaboration, education, entertainment and creative practice. Recent research shows that immersive VR environments can support complex learning, social interaction and collaborative problem-solving by enabling users to share the same three-dimensional space, manipulate objects together and communicate in real time (van der Meer et al., 2023; Zekeik et al., 2025; Kellems et al., 2025). In parallel, social VR platforms such as VRChat are increasingly explored as learning spaces where participants co-create environments and narratives rather than only consume pre-designed content. These developments make VR a promising medium for digital heritage and virtual architecture, where immersive, multi-user spaces can support both experiential learning and informal public engagement.

The research problem of this thesis is absence of an accessible interactive virtual reality representation of the present-day Narva Town Hall Square. Narva Town Hall is one of the city's key Baroque civic buildings, reflecting the development of early modern urban self-government, whereas Narva College is a prominent contemporary landmark that symbolizes the University of Tartu's long-term commitment to education and regional development in north-eastern Estonia. This spatial and symbolic proximity of two recognizable landmarks makes the square a suitable case study for examining how different architectural periods can be brought together within a single immersive environment.

A further reason for choosing these buildings is the uneven availability of digital documentation. Narva College is relatively well documented through architectural drawings, public photographs and university archives, while Narva Town Hall - despite recent restoration efforts - remains less accessible in digital form. This asymmetry reflects a common situation in digital heritage projects, where creators must combine heterogeneous and sometimes incomplete reference materials when reconstructing built environments (Champion, 2015, 2021). Working with both well-documented and only partially documented objects within the same project makes it possible to analyze and compare different workflows, and to discuss how gaps or uncertainties should be represented in a public VR experience.

The relevance of the topic is reinforced by the growing institutional interest in virtualizing educational, historical and civic spaces in Estonia. At the University of Tartu, the DeltaVR project demonstrates how a detailed virtual representation of the Delta Centre can be used to communicate research, showcase laboratories and provide visitors with an exploratory tour of the building (Tamm, 2021). DeltaVR, which is built in Unity and supports multi-user exploration of the building, illustrates how university-affiliated digital twins of campus spaces can enhance outreach, accessibility and science communication. Similar approaches are spreading internationally in the field of virtual heritage, where museums, universities and cultural organizations rely on engines such as Unity and Unreal Engine to create realistic, interactive reconstructions of monuments, museum collections and archaeological sites (Champion, 2015; Champion, 2021; Malla et al., 2025). In this literature, a "digital twin" is generally understood as a virtual representation of a physical system or artefact that is intended to maintain a close relationship with its physical counterpart (Grieves, 2014; Trauer et al., 2020).

Within the context of Narva, however, existing digital reconstructions focus mainly on the medieval castle and fortifications, whereas Narva Town Hall Square currently has no widely accessible, high-fidelity VR representation. This gap is noteworthy, as architectural heritage - whether historical, modern or transitional - plays an important role in shaping civic identity, yet access to key sites can be limited by geographical distance, economic constraints or restricted mobility. Narva's peripheral location on Estonia's eastern border means that many residents of other regions, as well as international visitors, may never visit the square in person. Creating a virtual replica of Narva Town Hall Square therefore has a dual purpose: it documents these buildings in a durable, shareable digital form and expands public access to them by allowing remote, immersive visits. Such an approach is consistent with broader trends in digital heritage, which emphasize using immersive technologies to democratize access to cultural environments and to engage diverse audiences, including students, teachers, researchers and local communities (Champion, 2021; FusionVR, 2024).

The aim of this thesis is to design and implement a technically functional and visually plausible interactive digital replica of Narva Town Hall Square on the VRChat platform, using Blender and Unity as the main content-creation tools. To achieve this aim, the thesis addresses the following research questions:

1. Which virtual reality platform is most suitable for developing a multi-user, explorable version of Narva Town Hall Square?
2. What technical and creative considerations are involved in reproducing real buildings for a social VR environment such as VRChat?

3. In what ways can a VR version of a real-world public square improve user experience and accessibility compared to traditional two-dimensional representations such as photographs, maps or videos?
4. What challenges and ethical considerations arise when digitizing real-world spaces for public virtual reality use?

The theoretical framework of the thesis is grounded in digital heritage studies, immersive media research and architectural visualization. Concepts such as virtual embodiment and spatial presence help to explain how users experience agency, co-presence and orientation in immersive environments, while the notion of the digital twin is used to discuss the relationship between the virtual model and its physical counterpart in Narva (Champion, 2021; Grieves, 2014). The empirical part of the work combines the collection and analysis of reference materials (architectural drawings, archival and contemporary photographs, and publicly available documentation) with iterative 3D modelling and optimization in Blender and Unity, followed by integration and testing on VRChat.

The thesis consists of five main chapters. The first chapter introduces the theoretical foundations of virtual architecture, social VR and digital heritage. The second chapter presents the methodology, including data collection, modelling workflow and evaluation methods. The third chapter describes the development of the VRChat world representing Narva Town Hall Square, focusing on key design decisions and technical challenges. The fourth chapter analyses the results, highlighting both the strengths and limitations of the implemented environment in terms of fidelity, performance and user experience. The fifth and final chapter summarizes the main findings, discusses the contribution of the project for digital heritage practice and outlines directions for further development and possible extensions of the virtual square.

By preserving Narva Town Hall Square as an immersive, explorable VRChat environment, this thesis proposes a concrete example of how social VR can be used to create accessible, interactive cultural spaces that can be visited, studied and experienced from anywhere in the world.

1. THEORETICAL CHAPTER

1.1. Choosing the Right Social VR Platform for the Project

The rise of immersive media has marked a fundamental shift in how people communicate, socialize and co-experience digital environments. Immersive media - including virtual reality (VR), augmented reality (AR) and mixed reality (MR) - goes beyond traditional screen-based interaction and enables spatial, interactive experiences where users can feel as if they are physically present in simulated environments. As these technologies become more accessible, their use in education, entertainment, design, healthcare and cultural heritage continues to grow.

Within this broader landscape, social VR platforms constitute a specific category where users appear as avatars in shared 3D spaces, interact in real time and often contribute their own content. Research on social VR highlights that platforms differ significantly in terms of technical capabilities (supported devices, performance), social affordances (avatar systems, communication tools) and the extent to which users can create and control their own environments (Liu & Steed, 2021; Schultz, 2023). For a project that aims to build a custom virtual environment rather than simply visit existing worlds, the choice of platform becomes a key design decision.

The overall pool of candidates was informed by existing lists of social VR platforms and virtual worlds, which include long-standing desktop worlds, newer social VR applications and blockchain-based metaverses (Schultz, 2023). From this wider ecosystem, seven platforms were selected for closer comparison:

1. VRChat - a highly popular social VR platform built on Unity, known for extensive user-created avatars and worlds and strong community culture (VRChat, 2025).
2. Meta Horizon Worlds - Meta’s first-party social VR platform tightly integrated with the Meta Quest ecosystem and, increasingly, with mobile and desktop access (Meta Platforms, 2025).
3. Rec Room - a free, cross-platform social, with millions of player-created rooms and a strong focus on casual, family-friendly play (Rec Room Inc., 2025).
4. Second Life - a long-running desktop virtual world with a mature user-driven economy and extensive user-generated content (UGC) tools, still used for socialization, education and events.
5. Vault Hill - a blockchain-based XR metaverse centered on virtual land ownership and "human-centric" urban-planned virtual districts (Linden Lab, 2025; Second Life, 2025).
6. MootUp - a browser-based 3D events platform that runs on almost any device and supports large-scale conferences, hybrid events and persistent branded spaces (MootUp, 2025).

7. BanterVR - a newer social VR sandbox developed by SideQuest, emphasizing advanced physics, cross-platform PCVR/standalone support and community world building (SideQuest Ltd., 2025).

These platforms were chosen because they:

1. Support multi-user 3D social interaction with avatars in shared spaces.
2. Offer some form of world or space creation to end users, not only to enterprise customers or developers (Liu & Steed, 2021; Rec Room Inc., 2025; Linden Lab, 2025.; VRChat Inc., 2025).
3. Provide at least partial VR support (native VR client or VR mode), while often also supporting non-VR access (Meta Platforms, 2025; VRChat Inc., 2025; MootUp, 2025; SideQuest Ltd., 2025).
4. Are currently active and accessible to users at the time of writing (which excludes, for example, AltspaceVR and NeosVR, both of which have shut down or drastically reduced online services) (Schultz, 2023; University of Rochester River Campus Libraries, 2025).

In other words, the comparison focuses on platforms that a project like this could realistically adopt today to host a custom social space.

Well-known alternatives such as Mozilla Hubs, Bigscreen, Resonite or purely browser-based 3D environments were not included for three main reasons. First, some are primarily designed as lightweight, web-based meeting tools with limited world-building depth. Second, others currently target more technical audiences and require significant in-world scripting or complex toolchains that exceed the scope of this project. Third, including every possible platform would make the comparison unwieldy and dilute the focus on the platforms most relevant to the project's requirements.

The rows in the table of Appendix 1 reflect criteria derived from both the literature and the practical needs of the project:

1. Platform support: Access from different devices (VR headsets, desktop, mobile) determines how inclusive the experience can be, especially when participants do not all own VR hardware. Multi-platform access is repeatedly mentioned as a key factor in cross-reality and metaverse deployments.
2. Primary focus / target audience: Platforms vary from open social sandboxes (VRChat, Banter) to family-friendly game hubs (Rec Room), corporate event spaces (MootUp) and blockchain metaverses (Vault Hill). This affects both culture and feature priorities.
3. Avatar and world creation: For a project that depends on building a specific environment, it matters whether creation happens via professional tools (e.g. Unity) or only via in-world editors, and how expressive these tools are.
4. Monetization model: The presence of in-world currencies, NFTs or subscription schemes shapes user expectations and long-term sustainability. For instance, Second

Life’s Linden Dollar can be exchanged for real currency, whereas VRChat currently relies more on external marketplaces and optional subscriptions.

5. Unique selling point: This summarizes what each platform does particularly well or is best known for (e.g. depth of UGC, integration with Meta’s ecosystem, advanced physics, or an established virtual economy).
6. Ownership / governance: The organization behind a platform - independent company, Big Tech corporation or blockchain start-up - influences issues such as moderation, data policies, long-term stability and the risk of sudden shutdown. The demise of AltspaceVR and NeosVR demonstrates that platform governance is not a purely theoretical concern.

Table in Appendix 1 shows that all of the platforms considered support multi-user 3D spaces with avatars and some form of world creation. However, they occupy very different positions on the spectrum between open social sandbox, game platform, enterprise tool, and Web3 metaverse (Liu & Steed, 2021; Schultz, 2023).

From the perspective of this project, the most important patterns can be summarized as follows:

Accessibility and device support:

MootUp, Rec Room and BanterVR all support non-VR devices, while VRChat has a mature desktop client and mobile apps in addition to VR headset support. This matters because not all potential participants will own VR hardware, yet the project aims to remain accessible beyond a narrow early-adopter community. Horizon Worlds is still most closely tied to the Meta Quest ecosystem, although mobile and desktop access is gradually expanding. Vault Hill and Second Life, by contrast, are either more oriented towards desktop or towards blockchain/Web3 communities and therefore less aligned with mainstream VR use.

Depth and flexibility of world building:

VRChat, Second Life and BanterVR share a strong emphasis on user-generated content and relatively open creation pipelines. VRChat and Banter rely on external tools (Unity, A-Frame, Blender) and SDKs, which allow for sophisticated, highly optimized worlds but also require more technical expertise. Second Life offers extensive in-world building and scripting, while Rec Room and Horizon provide more constrained, but easier-to-learn, in-world editors aimed at non-programmers. For a project that seeks both expressive control over environment design and acceptable performance on common VR hardware, VRChat and BanterVR are especially attractive.

Economic model and long-term stability:

Long-term sustainability depends not only on technical capabilities but also on how a platform is financed and governed. Second Life and Vault Hill integrate virtual currencies and land ownership into their core design, whereas VRChat and Banter currently rely on being free-to-play with optional subscriptions or future premium features. Horizon Worlds and Rec Room are backed by well-funded companies and tied to broader platform strategies (Meta's hardware ecosystem; Rec Room's cross-platform social gaming). Nonetheless, recent shutdowns of AltspaceVR and NeosVR illustrate that even established platforms can disappear, which is why ownership and governance are explicitly included as comparison criteria (VRChat, 2025; Schultz, 2023; Liu & Steed, 2021).

Fit with the project's goals:

The project requires a platform where it is possible to create a custom, high-fidelity environment, populate it with expressive avatars, and invite users from both VR and non-VR backgrounds. It should support informal exploration and social interaction rather than only structured events or gamified activities. In addition, the platform should have an active community and evidence of ongoing development, so that the created environment will not be trapped in a stagnant or soon-to-be-retired ecosystem.

For each criterion mentioned in the table of Appendix 1, each platform got 1 point if it matched the project-relevant condition, and 0 points if it did not:

1. Platform support (accessibility): 1 = supports both VR and non-VR access and is realistically reachable across common devices (PC + standalone VR and/or mobile/web).
2. Primary focus / target audience (fit): 1 = core use is open-ended social exploration/sandboxing (not mainly enterprise events, heavy mini-game hub design, or Web3 investment).
3. Avatar & world creation (fidelity/control): 1 = enables high-fidelity custom environments via robust creation pipelines (external tools/SDKs or powerful scripting) suitable for accurate real-place reconstruction.
4. Monetization model (barrier to participation/hosting): 1 = free for participants and does not require paying for land/regions/seats to host the experience (optional cosmetics/subscriptions are OK).
5. Unique selling point (USP relevance): 1 = USP directly strengthens this project's aims (custom world depth + expressive social presence + strong discovery/community pull).
6. Ownership / governance (stability risk): 1 = operated by an established organization with clear governance and demonstrated continuity (lower risk of sudden retirement).

Table 1. Binary scoring of selected VR platforms

Feature / platform	VRChat	BanterVR	Rec Room	Meta Horizon Worlds	Second Life	MootUp	Vault Hill
Platform Support	1	1	1	1	0	1	0
Focus Fit	1	1	0	0	1	0	0
Creation (fidelity / control)	1	1	0	0	1	0	0
Monetization barrier	1	1	1	1	0	0	0
USP relevance	1	0	0	0	0	0	0
Governance / stability	1	0	1	1	1	1	0
Total	6	4	3	3	3	2	0

VRChat (6/6) scores highest because it matches the project requirements across all criteria. It is playable in VR and without a headset and is available across major distribution channels (PCVR + standalone + mobile). (VRChat Inc., 2025). Crucially for a faithful reconstruction of a real public space, VRChat supports high-fidelity world creation in Unity using the VRChat SDK, plus interactive logic through Udon, which provides the level of control typically needed for accurate environments and optimized performance (VRChat Inc., 2024). It is free to use, with VRC+ positioned as optional rather than required (VRChat Inc., 2025). Finally, its best-known strengths - deep UGC culture and strong social discovery - directly support the goal of attracting visitors to an explorable environment rather than a closed event venue.

BanterVR (4/6) performs well on access, sandbox fit, creation potential, and free entry. It runs in VR and 2D modes and is positioned as free-to-play (SideQuest Ltd., 2025; Valve Corporation, 2025). It also supports creator workflows (e.g., Unity-based content/avatars and importing), which is promising for custom environments (SideQuest Ltd., 2025). It loses points here mainly because its standout USP emphasizes physics-driven experimental spaces rather than place-accurate cultural/architectural replication, and the platform is still comparatively “young”/fast-evolving, which typically increases long-term uncertainty versus more established hubs.

Rec Room (3/6) is excellent for accessibility and free entry - officially positioned as free and cross-platform across phones/PC/consoles/VR (Rec Room Inc., 2025; Rec Room Inc., 2023). However, its primary framing as a game-like hub and its creation tooling (Maker Pen) are optimized for quick in-world building and playful rooms rather than high-fidelity reconstruction pipelines (Rec Room Inc., 2025). So, it scores 0 on "focus fit" and "fidelity/control" for this specific thesis project (even though it can be great for other project types).

Meta Horizon Worlds (3/6) gets points for expanding beyond Quest into mobile/web access (Meta Platforms, Inc., 2025, 2023) and for being free to access. But it scores 0 for focus-fit and creation-fidelity in this rubric because creation is constrained to Meta's ecosystem/toolchain and tends to prioritize broad creator accessibility and platform strategy over the kind of fully custom, externally authored, professional pipeline typically used for accurate real-world replicas (Meta Platforms, Inc., 2025).

Second Life (3/6) remains strong in "open world" fit and in-world creation/scripting depth, building tools are well documented and mature (Linden Lab, 2022). It loses points mainly because it is not VR-first and because hosting persistent high-control spaces is typically tied to land/economic costs.

MootUp (2/6) is highly accessible (browser-based, no headset required) (MootUp, 2025) and offers stable governance as a commercial product. But it scores 0 on fit, creation, monetization barrier, and USP relevance because it is primarily a host-paid SaaS event platform with template-led spaces, which mismatches an open, community-discoverable social sandbox world (MootUp, 2025).

Vault Hill (0/6) scores lowest under this specific rubric because it is positioned around Web3 land ownership and an emerging ecosystem - meaning higher barriers and weaker evidence of mainstream, low-friction, cross-device participation and mature creator tooling for a thesis-built public-space replica.

Comparison made in Table 2 shows that VRChat stands out as the platform that best meets the project's requirements. It combines a large, active and creative user community with extensive possibilities for custom avatar and world creation, using established tools such as Unity and industry-standard 3D formats. Unlike platforms that restrict creation to in-world editors, VRChat allows creators to develop content offline with professional modelling and game-development software, which is crucial for accurately reproducing real buildings and public spaces. The platform's focus on user-generated worlds and informal social interaction aligns well with the aim of presenting Narva Town Hall Square as an open, explorable environment rather than a closed, event-based venue.

From the perspective of sustainability and visibility, VRChat also offers clear advantages. External statistics based on Steam data report tens of thousands of concurrent players and an all-time Steam peak of around 66,000 simultaneous users on 1 January 2025 (SteamDB, 2025). Analyses based on VRChat's own API suggest that, when all platforms are considered, concurrent usage has at times exceeded 100,000 users (VRChat, 2025). While the precise figures vary between data sources, they consistently indicate that VRChat is one of the largest and most active social VR platforms currently available.

In summary, VRChat offers the most favorable combination of technical openness, creative freedom, VR-optimized performance and community size among the platforms examined in the table of Appendix 1. Its support for detailed, custom-built worlds, together with an established base of VR-capable users, makes it a suitable foundation for developing the virtual replica of Narva Town Hall Square that is central to this thesis.

1.2. VRChat and Its Role in Modern Social Interactions, Education and Creativity

VRChat is a social virtual reality (social VR) platform that enables users to create, share and explore three-dimensional worlds through customizable avatars (Kim, 2021). Social VR environments differ from traditional social media because interaction is experienced as co-presence in a shared spatial setting rather than as the exchange of text or images on a flat interface (Freeman et al., 2020; Rogers, 2022). In VRChat, real-time voice communication, spatial audio, hand and body tracking and, for some users, full-body tracking cause the avatar to be perceived as an embodied extension of the physical self. This strengthens immersion and social presence and makes interactions feel closer to face-to-face encounters (Freeman et al., 2020; Rogers, 2022). Such embodied interaction has implications for how users form relationships, negotiate their identities and participate in online communities.

A defining characteristic of VRChat is its reliance on user-generated content. The platform provides a software development kit (SDK) tightly integrated with the Unity game engine, enabling users to create avatars, environments and interactive systems instead of being restricted to pre-made assets (Kim, 2021). This design has produced a vast ecosystem of user-built spaces ranging from simple private rooms and game arenas to complex architectural reconstructions and highly stylized fantasy landscapes (Kim, 2021). In this sense, VRChat functions less as a game and more as a participatory infrastructure for worldmaking, where users assume roles as designers, performers, educators and curators of digital experiences.

Architecture in VRChat is not constrained by gravity, material cost or building regulations. Both professional designers and hobbyists can experiment with spatial composition, circulation and atmosphere in ways that are difficult or impossible to realize physically (Kim, 2021). Social VR also provides a fertile context for performance practices. Theatre, dance, stand-up comedy and live music have all emerged as native genres in VRChat, often taking advantage of the possibility to place the audience inside the scene and to blur the boundaries between performers and spectators. These practices align with broader observations that embodiment and interactive narrative design are central to how users experience presence and engagement in immersive environments (Champion, 2021).

VRChat is increasingly discussed in connection with learning and education. Research on immersive and collaborative virtual reality environments indicates that spatial, experiential interaction can support cognitive engagement, conceptual understanding and long-term retention when learning tasks are appropriately designed (van der Meer et al., 2023). Collaborative VR learning studies also underline the importance of social presence and peer interaction for sustaining active and constructive learning behaviors. In VRChat, educational activities may take the form of guided tours through historical reconstructions, interactive simulations of physical or chemical processes, or more abstract conceptual spaces designed to visualize otherwise invisible phenomena. Because these activities are embedded in a social context, they can combine experiential exploration with discussion, group problem-solving and feedback.

These characteristics make VRChat relevant to the broader field of digital heritage. Immersive VR has become an important medium for documenting, reconstructing and communicating cultural heritage, allowing users to experience lost or inaccessible places (Pietroni, 2021). Virtual heritage projects use three-dimensional reconstruction, spatialized narration and embodied interaction to connect tangible structures with intangible narratives such as memories, rituals and oral histories (Champion, 2021). In principle, similar approaches can be implemented within social VR platforms: architectural replicas, re-imagined historical environments or community-curated memorial spaces in VRChat can host collective visits, storytelling sessions and intergenerational encounters. Because users experience these environments together, virtual heritage is not only observed but also negotiated and re-enacted through ongoing social interaction. Immersive VR therefore offers forms of interactivity and emotional engagement that complement, and in some cases surpass those available in conventional two-dimensional media (Zekeik et al., 2025).

1.3. Asset File Formats and Interchange Pipeline in VRChat World Development

VRChat world development is rarely a single-software workflow. A typical pipeline combines content creation tools (for example Blender for modeling), a real-time engine (Unity for scene assembly, lighting, and interaction), and a platform-specific toolchain (the VRChat SDK for validation, building, and uploading). Because each stage uses different internal data structures, assets must be transferred through well-defined file formats, usually identified by file extensions (e.g., .fbx, .png, .unity). File format choices therefore act as "compatibility contracts" between tools: they determine what information survives the transfer (geometry, UVs, hierarchy, animation, texture references) and what must be rebuilt later (materials, shaders, light baking settings, interaction logic).

From a theoretical perspective, it is useful to distinguish between three categories of files used in VRChat world production:

1. Authoring (source) files - project-native formats that preserve the most editable information (e.g., .blend for Blender). These are optimal for iteration, but are not always ideal for cross-software transfer and collaboration.
2. Interchange (delivery) files - formats intended to move data between tools (e.g., .fbx, .obj, .dae, image and audio formats). Unity's import pipeline is heavily centered on interchange formats. In fact, Unity uses .fbx as its internal "importing chain" and explicitly recommends using .fbx whenever possible instead of proprietary formats (Unity Technologies, 2024).
3. Engine-/project-native asset files - Unity's own scene and asset serialization (e.g., .unity scenes, prefabs, materials), plus Unity metadata files that preserve stable references and import settings.

In VRChat specifically, the "target environment" is Unity, because VRChat worlds are created and assembled there using the VRChat SDK. VRChat's creator documentation states that avatars and worlds are created in Unity and that the SDK enables this workflow (VRChat Inc., 2024). Importantly, VRChat also pins creators to a specific supported Unity editor version; using a different editor version can break compatibility (for example, content may fail to load after upload) (VRChat Inc., 2025). This requirement is not only a software-policy constraint, but also a file/serialization constraint: Unity projects and serialized assets can change across versions, so consistent versioning reduces the risk of import or build-time errors.

A VRChat world's visible structure (buildings, props, terrain) is ultimately a set of meshes with transforms, plus supporting data such as normals and UV coordinates. When transferring a 3D model from Blender to Unity, the interchange format controls which of these components arrives intact. Unity lists several standard model formats it can read, including .fbx, .obj, and .dae (Collada) (Unity Technologies, 2024). Among them, .fbx is widely used for game-engine pipelines because it can preserve a broader range of data (object hierarchies, smoothing, multiple meshes, and optionally animation), and Unity itself recommends .fbx as best practice for production (Unity Technologies, 2024).

Using Blender's native .blend file as a direct "import" into Unity is technically possible in some setups, but Unity treats many proprietary formats as sources that are converted during import (and they require the authoring software to be installed on each workstation). This creates a fragility in collaboration and long-term reproducibility, because the project's successful import becomes dependent on external tool availability and version matching (Unity Technologies, 2024). For this reason, VRChat world pipelines typically keep .blend as the editable master file, but export .fbx as the stable interchange artifact for Unity.

A recurring theoretical issue in cross-software model exchange is coordinate system convention. Some 3D packages treat the Z-axis as "up," while Unity's common scripting and world assumptions treat Y as "up." Unity explicitly notes that models can import with incorrect orientation because some tools export Z-up, while standard Unity scripts assume Y-up (Unity Technologies, 2016). In practice, this means the chosen export settings (forward axis / up axis) and transform application in Blender are not merely "workflow preferences," but a necessary step to ensure that the imported asset's orientation is semantically correct in Unity-and later in VRChat, where world navigation, physics, and interactions depend on consistent spatial meaning (gravity direction, player movement, collider alignment).

Textures are another area where file formats matter both for fidelity and performance. Unity can import a wide range of texture source formats (including .png, .jpg, .tga, .psd, .tiff, .exr, and others) (Unity Technologies, 2025). These are source formats: they describe how the texture is stored on disk for authoring and import. However, GPUs typically do not sample PNG or JPEG directly at runtime. Unity highlights that while it can import common formats like JPEG or PNG, runtime rendering relies on specialized GPU texture compression formats optimized for memory use and sampling speed (Unity Technologies, 2025).

This separation explains why file format requirements are not only about what Unity can read, but also about what makes sense for a VRChat world's constraints. For example:

1. Lossless formats (e.g., PNG, TGA) are often preferred for textures that need crisp edges, masks, or alpha transparency, because they preserve pixel accuracy at source import.
2. Lossy formats (e.g., JPEG) can be acceptable for photographic textures without transparency, where smaller source files speed iteration and reduce repository size, but they may introduce compression artifacts.
3. High dynamic range formats (e.g., EXR/HDR) are relevant for environment lighting workflows, though their use depends on the project's shading and lighting approach.

In VRChat production, these choices interact with platform targets (PC vs Quest) and with Unity import settings that ultimately decide runtime compression, mipmapping, and memory footprint. The theoretical takeaway is that a texture's extension signals initial decoding and import behavior, but performance outcomes depend on how the engine re-encodes that data for the target platform.

World ambience, spatial audio cues, and interactive sound effects are typically imported as audio clips. Unity supports importing common audio formats such as .wav, .aif/.aiff, .mp3, and .ogg (with additional support depending on Unity version and platform) (Unity Technologies, 2025). From a theoretical standpoint, the key trade-off is between uncompressed formats (e.g., WAV) that preserve editing quality and compressed formats (e.g., OGG/MP3) that reduce size. Similar to textures, Unity can re-encode audio according to platform settings during import/build, so the file extension indicates the source container, while engine settings and build targets determine the runtime encoding (Unity Technologies, 2017).

For VRChat world development, audio formats matter because they affect project size, iteration speed, and runtime memory. They also intersect with validation and optimization practices (for example, avoiding unnecessarily large uncompressed clips when compression is acceptable).

Once assets are inside Unity, VRChat world development relies heavily on Unity's own project-native assets. Two particularly important examples are:

1. Scene assets (commonly saved as .unity) that store the world layout (GameObjects, components, lighting references, VRChat descriptors).
2. Prefabs (commonly .prefab) that package reusable object hierarchies and component configurations.

These are serialized formats controlled by Unity; for example, Unity documentation notes that a .unity scene file can be saved in text form (YAML-backed) when text serialization is enabled, which is relevant for version control and collaboration (Unity Technologies, 2025).

An often-overlooked format requirement in Unity-based pipelines is the .meta file that accompanies assets. Unity’s manual explains that .meta files contain the unique ID (GUID) for an asset and store import settings; they must remain paired with the asset file to preserve references across the project (Unity Technologies, 2024). In other words, even though creators rarely edit .meta files directly, they are a core part of Unity’s asset identity system-meaning file handling rules (moving/renaming assets) directly affect project integrity.

Finally, VRChat’s toolchain adds an additional packaging layer through the Creator Companion and its package manager workflow. VRChat’s Package Manager documentation describes how it manages SDK packages and projects, and it also references migration from older “.unitypackage-style” SDK projects into a package-managed format (VRChat Inc., 2025). This matters because importing third-party assets into a VRChat world is not just “dropping files into Unity,” but also managing package versions so that the SDK, dependencies, and Unity project settings remain compatible.

File formats and extensions in VRChat world development are best understood as part of an asset interchange and serialization ecosystem rather than as isolated upload requirements. Blender source files preserve editability; interchange formats (especially .fbx) provide stable transfer into Unity; Unity-native formats and metadata preserve references, import settings, and scene structure; and VRChat’s SDK + package tooling imposes version compatibility constraints that influence which Unity project and asset formats are valid. Together, these considerations explain why implementing a Blender-developed 3D model into a VRChat world is not only an artistic step, but also a technically constrained translation between file formats, coordinate conventions, and engine-specific serialization.

1.4. Alternative Approaches and Justification for Using a VRChat World

A project such as the virtual reconstruction of Narva Town Hall Square can be implemented through multiple technical and presentation pathways. In theoretical terms, selection is not only a matter of what technology can produce the most detailed model, but what approach best matches the project's goals: broad accessibility for non-expert audiences, interactive and embodied spatial experience, multi-user social presence, and real-time performance and usability. When alternatives are assessed against these criteria, a VRChat world is the most suitable solution, while approaches such as 3D scanning, passive tour formats, or standalone applications introduce trade-offs that are less aligned with the intended outcome.

A frequently proposed alternative to manual environment creation is 3D scanning, usually implemented through photogrammetry (Structure-from-Motion). Photogrammetry is accessible and can produce convincing textured surfaces when capture conditions are controlled and coverage is sufficient (Luhmann et al., 2019). Scanning therefore appears attractive: it can reduce reliance on interpretive modelling and can strengthen the evidential basis of the reconstruction.

However, scanning does not automatically produce an asset suitable for real-time social VR. Scan-derived outputs typically require extensive post-processing - registration/cleanup, hole filling, meshing, decimation, UV reconstruction, texture consolidation, and the creation of level-of-detail strategies - before they become efficient, stable, and readable in an interactive environment (Luhmann et al., 2019). Scanning may improve capture fidelity, but it does not remove the need for authoring decisions-and it often increases the technical burden of optimization if the destination is a performance-constrained platform.

These constraints are particularly relevant in VRChat, where worlds must run reliably across varied consumer hardware. VRChat creator documentation repeatedly emphasizes optimization concerns such as draw calls, materials, and platform constraints (VRChat, 2024; VRChat, 2025). Scan-first environments commonly begin with dense geometry and fragmented material setups, which conflicts with the performance discipline required for smooth multi-user sessions. By contrast, a manually modelled environment can be designed "performance-first" from the start: topology, materials, lighting, and collider logic can be authored intentionally for stable runtime behavior and comfortable navigation. In this sense, scanning is better understood as a supporting method-useful for validating proportions or capturing selected details-rather than a replacement for game-ready environment construction when the target is social VR at scale (Guarnieri et al., 2004; Luhmann et al., 2019).

Another alternative is to change the delivery format rather than the capture method. A 360° photo/video tour or a simple web-based viewer can reach large audiences with minimal installation friction, and such formats can be effective for basic presentation. Yet these approaches are typically limited in embodied navigation and interaction. Passive tours tend to reproduce an “ocular-centric” experience rather than enabling collaborative inhabitation of a space at human scale. If the project’s intention includes social presence and shared exploration, these formats provide weaker support for the core experiential goal than a social VR environment (Rahaman & Tan, 2011).

A further alternative is to build a standalone Unity/Unreal application or to publish the experience on another social VR platform. A standalone application offers maximal control, but it also transforms the project into a product-level undertaking: distribution, accounts, networking, hosting, moderation, QA across devices, and ongoing maintenance become central responsibilities. For a thesis-scale project, a platform that already provides identity systems, networking infrastructure, and a stable multi-user layer reduces operational overhead and increases the likelihood that the experience remains usable beyond the development period. Comparative research on social VR platforms also shows that the effectiveness of multi-user walkthroughs depends on robust social affordances-group coordination, communication, and shared activity-features that are not trivial to implement equivalently in a custom application (Liu & Steed, 2021).

Table in Appendix 2 summarizes the main trade-offs between 3D scanning (photogrammetry), 360° tour formats, a standalone application, and a VRChat world. While scanning and passive tour media can be effective for visual presentation, they either increase optimization burden for real-time use or limit embodied, collaborative exploration. In contrast, VRChat best matches this project’s priorities of accessible participation (VR and desktop), multi-user social presence, and feasible deployment within a thesis-scale scope.

Accordingly, VRChat offers several decisive advantages that make it the most appropriate solution for this project’s specific aims. First, it supports participation in both immersive VR and non-VR “desktop mode,” widening access beyond headset owners (VRChat, 2025). Second, it is fundamentally structured around multi-user presence, enabling real-time co-exploration, discussion, and shared interpretation - an aspect closely tied to how cultural meaning is negotiated socially rather than consumed individually (Rahaman & Tan, 2011). Third, VRChat's creator ecosystem provides established publishing and iteration pathways (including guidance related to world publication and visibility), which reduces the deployment burden compared to standalone distribution (VRChat, 2024). Fourth, the platform's explicit optimization guidance reinforces the importance of authoring worlds that remain comfortable and stable during social use, which supports the argument that a model-authored, performance-aware environment is more appropriate than a heavy 3D scanning replica for this context (VRChat, 2024; VRChat, 2025). Finally, VRChat's large active user base supports the goal of public reach and discoverability more directly than a standalone build hosted independently (SteamDB, 2025).

For these reasons, while 3D scanning and alternative delivery formats can be valid choices in other contexts, they are less suitable for a thesis project that prioritizes interactive, socially shared, and widely accessible exploration of a reconstructed urban environment. A VRChat world best aligns with the theoretical criteria of access, embodied engagement, social interaction, real-time feasibility, and transparency-making it the strongest option among the considered alternatives for this specific application (ICOMOS, 2017; Liu & Steed, 2021; London Charter, 2009; VRChat, 2024).

2. METHODOLOGY CHAPTER

The research design for this project follows a structured yet iterative workflow that balances conceptual planning, technical execution, and user - centered evaluation. Given the nature of the study - the reconstruction of Narva Town Hall Square in VRChat - the methodology follows a hands-on research approach, where the creative process serves as the primary source of knowledge generation. This approach is particularly well suited to projects at the intersection of architecture, digital heritage, and immersive media, as it allows us to explore both theoretical and technical issues in real - time while developing a virtual environment.

The empirical work combines three main groups of data:

1. Reference materials for reconstruction, used to ensure architectural plausibility and spatial accuracy.
2. Process data from the development workflow, including intermediate models, test builds and field notes about technical and design decisions.
3. User evaluation data, gathered through testing sessions in the completed VRChat world.

The reference materials consist of architectural drawings and plans, archival and contemporary photographs, and other publicly available documentation related to Narva Town Hall Square. These sources provide information about geometry, proportions, facade composition, materials and the broader urban context. Whenever possible, multiple images of the same facade or space were cross-checked to avoid errors caused by perspective distortion or partial occlusion. This triangulation of sources follows common practice in digital heritage, where laser scanning, photogrammetry and multi-angle photography are combined to support metrically reliable models (Guarnieri, 2004 et al.; Galeazzi, 2018; Goodwin, 2023).

In addition to documentary sources, site visits to Narva Town Hall Square were carried out to observe the atmosphere, light conditions, typical viewpoints and movement patterns. On-site sketches, photographs and written notes captured details that are rarely visible in formal plans - for example, wear patterns on stairs, the relative heights of people in the space or the way facades are perceived from ground level. While the virtual reconstruction does not aim to reproduce every detail one-to-one for security and performance reasons, these observations informed decisions about which features are essential for recognizability and spatial authenticity.

Finally, experience is examined through testing sessions in the completed VRChat world. The evaluation focuses on navigability, perceived realism and presence, technical performance and perceived educational value. The user study provides empirical data for answering research questions about how a VR version of a public square supports experience and accessibility compared with traditional two-dimensional media.

The empirical work follows a structured but iterative six-stage workflow:

1. Conceptual Planning
2. Data Collection
3. 3D modelling and Asset Creation
4. Integration and Optimization in VRChat
5. Testing
6. Evaluation and Refinement

These stages are analytically separated here for clarity, but in practice they partially overlap, insights from later stages feed back into earlier ones through iterative revision.

In the conceptual planning stage, the overall goals, research questions and scope of the reconstruction were defined. On the design side, this involved specifying functional requirements (e.g. free navigation at human scale; multi-user access for both desktop and VR devices; interactive information elements) and non-functional requirements such as performance, usability and authenticity. Performance constraints included VRChat's limits on polygon counts, draw calls and texture memory, which required careful planning of the level of detail for facades, interiors and street furniture. Usability requirements covered locomotion options, clear spawn points, readable UI elements and lighting that supports comfortable long-term use in VR. Authenticity requirements specified that key building volumes, facade rhythms and material impressions should reflect the real square as documented in plans and photographs, while allowing modest simplifications where necessary for performance and safety.

At the same time, the conceptual stage established the platform decision and methodological stance. Building on the theoretical comparison of social VR platforms in Theoretical Chapter, VRChat was chosen because it allows custom worlds built in Unity with industry-standard 3D formats, supports both VR and desktop clients, and has an active community that makes long-term accessibility more likely. The project adopts a practice-based research approach where modelling and world-building are treated as cycles of designing, testing and reflecting, rather than a linear production pipeline.

In the data collection stage, the reference materials described above were assembled, organized and annotated. Architectural drawings and site plans provided base geometry; archival photographs clarified historical features and changes; contemporary photographs documented the current state and everyday use of the square. When multiple conflicting sources existed, priority was given to the most recent, high-resolution and contextually documented materials. A simple catalogue was maintained, noting for each source its origin, date (where known), viewpoint and the specific modelling decisions it supported. This catalogue forms part of the data that can be consulted by future users interested in how the virtual environment was constructed.

The 3D modelling and asset creation stage translated these materials into a navigable 3D environment. Using Blender as the main modelling tool, the space was first blocked out with low-poly volumes to establish proportions, alignments and circulation routes. The models were then refined with architectural details such as window and door frames, cornices, staircases and roof forms. Texturing combined image-based textures derived from photographs with more generic materials for less prominent elements. Throughout this process, geometry and textures were systematically optimized to remain within VRChat's performance recommendations; for example, decorative elements were often baked into normal maps instead of modelled as separate geometry. Intermediate models were regularly exported to Unity and loaded into local VRChat test instances to verify scale, visibility and performance.

During integration and optimization, the finalized models were imported into Unity, configured with colliders and navigation meshes, and combined with lights, reflection probes and basic interactive elements. The VRChat SDK and Udon scripting system were used to define spawn points, instance settings and simple interactions such as opening doors, triggering ambient sounds and displaying informational panels. Further optimization techniques - such as occlusion culling, level of detail (LOD) groups and baked lighting - were applied to balance visual fidelity with frame-rate stability on mid-range hardware. As recommended in VRChat's creator documentation, the world was repeatedly built and uploaded as a private instance for internal testing before any broader release. The detailed technical implementation of these steps is presented in Practical Chapter; here they are described as part of the empirical procedure that produces the research object for evaluation.

Throughout the study, ethical and legal requirements of the University of Tartu and Narva College were followed. The reconstruction uses only reference materials that are publicly available, belong to institutional archives that allow such use, or are otherwise used with permission.

3. DEVELOPMENT CHAPTER

3.1. Conceptual Planning

The conceptual planning process served as an essential foundation for the entire digital reconstruction project of Narva Town Hall Square in the VRChat platform. As the initial and perhaps most crucial stage, it involved establishing the creative vision, technical direction, theoretical rationale, and project management structure to guide subsequent stages. While later phases would shift toward practical execution, this early stage was dedicated to careful decision-making, intellectual orientation, and structured problem-solving. It laid the groundwork for production, research impact, and cultural relevance by clarifying why the selected landmark should be reconstructed and how they ought to be represented in a virtual environment.

First, the main goal of the conceptual planning stage was to define the purpose and scope of digital reconstruction. Several guiding questions helped frame the project's conceptual boundaries, beginning with the challenge of determining which landmark deserves to be ported to a virtual reality environment and why. Not every building in Narva carries the same historical weight or cultural visibility, so the selection process required careful consideration of heritage value, recognizability, and the availability of reliable reference materials. After reviewing Narva's architectural landscape and examining diverse archival and contemporary sources, several potential landmarks were evaluated according to four main criteria: cultural and historical significance, recognizability and symbolic value, availability of references such as photographs, architectural plans, or 3D data, and suitability for VR interaction and user experience design. Through this analytical process, two landmarks clearly emerged as the most meaningful and feasible choices for VR reconstruction. Narva Town Hall, one of the city's most iconic civic structures. Its central location, and well - documented restoration history make it highly suitable for a historically oriented virtual environment. Narva College of the University of Tartu, as a striking example of contemporary architecture, symbolizes the city's ongoing educational and cultural revitalization, offering a visually modern counterbalance to the older structures while benefiting from excellent reference availability.

Once the goals were outlined, the next primary consideration was identifying the most suitable platform for hosting detailed, multi-site reconstructions. Numerous VR platforms were evaluated, including Mozilla Hubs, NeosVR, Meta's Horizon Worlds, and even standalone Unreal Engine - based builds. Each was assessed on attributes such as ease of access, support for multi-user environments, performance scalability, content creation pipelines, and community support. After careful comparison, VRChat emerged as the most appropriate platform. This decision was influenced by VRChat's mature and active user base, its strong integration with Unity, the extensive documentation available to creators, and its proven ability to host persistent, socially oriented virtual worlds. VRChat's inclusivity of both desktop and VR users ensured broader accessibility, while its culture of creativity and user - generated content aligned the project with ongoing developments in participatory digital culture, thereby reinforcing its academic significance.

Following the platform decision, the scope of the virtual environments themselves had to be defined. Because the project encompassed two distinct landmarks - each with unique spatial characteristics, historical contexts, and present-day functions - it was necessary to determine which architectural elements would be modeled in high detail and which would be simplified. As VRChat environments must adhere to memory, performance, and rendering limits, the decision-making process involved evaluating architectural significance, user experience potential, and technical feasibility. Highly repetitive or narrow functional spaces were selectively abstracted or omitted to maintain performance efficiency without compromising historical or cultural integrity.

Another critical component of conceptual planning involves defining the research methodology. The project adopted a practice-based research approach, in which the creation of digital assets is not merely a technical act but also a method of inquiry. Each design decision - ranging from degree of fidelity to spatial interpretation - was treated as both a practical and theoretical choice, carrying implications for how virtual architecture represents and communicates cultural heritage. The inherent differences among the two landmarks made this methodological stance even more relevant, as each structure required a distinct interpretive strategy reflecting its unique historical period, social function, and symbolic meaning. To support this methodology, a structured timeline and workflow were developed. The project was divided into interconnected phases (conceptual planning, data collection, 3D modeling, VRChat integration, testing, and evaluation), with defined milestones and expected outputs. This approach helped maintain cohesion and flexibility throughout development.

The conceptual planning phase also included early ethical and representational considerations. Since the chosen place carries cultural, historical, and symbolic importance, its depiction required sensitivity. Questions were raised about how to preserve the integrity of the buildings' identities in virtual form, how to avoid unintentional distortion or misinterpretation of architectural details, and how to present each site in a manner that acknowledges both its historical context and its present - day meaning. Safety, accessibility, and user comfort were also considered when designing virtual spaces. Diverse reference materials were utilized where possible, ensuring that each reconstruction was informed by reliable sources rather than speculation.

Overall, the conceptual planning stage provided the strategic, theoretical, and technical basis for a broad and interdisciplinary undertaking. It clarified the expanded project goals, established a coherent production logic, aligned the software tools and workflows with research aims. By expanding the project from a single institutional reconstruction to a multi - landmark exploration of Narva's architectural identity, this stage ensured that every subsequent step would proceed with deliberate, academically grounded, and culturally responsible design thinking.

The functional and non-functional requirements for the virtual reconstruction of Narva Town Hall Square were defined to ensure that the VR environment would be both technically robust and pedagogically meaningful.

Functional requirements:

1. The environment needed to allow users to freely navigate the square at human scale, explore both the exterior spaces and selected interior areas of Narva Town Hall and Narva College, and access interactive informational elements such as visual markers, textual annotations, or audio guides that communicate architectural and historical context.
2. VRChat world also had to support multiplayer interaction, enabling multiple users to occupy the space simultaneously, communicate, and share a collaborative learning experience.
3. Additional requirements included optimized collision systems, accessible spawn points and the integration of interactive objects (e.g., doors, panels, or guided pathways) that help structure the user journey without restricting exploration.

Non - functional requirements:

1. The environment had to be optimized to maintain stable framerates on a wide range of devices, from desktop clients to standalone VR headsets.
2. The models and textures needed to balance visual fidelity with performance constraints, ensuring that the square feels believable without overloading the platform.

3. Usability requirements emphasized intuitive navigation, readable information displays, comfortable lighting, and accessibility considerations such as avoiding motion sickness triggers and providing clear spatial orientation cues.
4. Authenticity requirements had to ensure that the digital replica remained a faithful and respectful representation of Narva Town Hall Square, supported by accurate architectural dimensions, correct material depiction, and historically informed visual choices.

Collectively, these functional and non-functional requirements created a framework that guided technical, artistic, and experiential decisions throughout the development of the virtual environment.

3.2. Data Collection

The data collection phase connected the conceptual and practical stages of the project. While the conceptual planning phase laid the theoretical framework and development roadmap, it was through data collection that the virtual reconstruction of Narva's Town Hall Square became grounded in material accuracy and architectural authenticity. This stage involved gathering, organizing, and interpreting a wide range of digital and physical reference materials that together informed the visual, spatial, and functional fidelity of the 3D models. Its purpose was to accumulate enough reliable data not only to accurately recreate the structures but also to develop a deeper, embodied understanding of each building's architectural identity, cultural significance, and experiential qualities.

Because the project scope includes two distinct landmarks - Narva Town Hall and Narva College of the University of Tartu - the data collection phase had to accommodate their different historical contexts, periods of construction, and availability of archival material. Each landmark required its own tailored strategy. Narva Town Hall, being a Baroque - era structure, depended heavily on historical documentation, restoration reports, and archival imagery; Narva College, as a contemporary building, offered more access to modern plans and digital references.

The process began with an extensive review of publicly available resources for all three buildings. This included architectural floor plans, historical blueprints, elevation drawings, site plans, engineering reports, and, where available, 3D scans. In the case of Narva College, contemporary architectural documents were accessible through public online sources and provided clear structural proportions and spatial relationships. For Narva Town Hall, the project relied on both historical restoration documentation and scanned architectural plans, as the building has undergone several periods of damage and renovation. These documents collectively formed the structural backbone for the reconstructions, establishing accurate dimensions, spatial logic, and architectural rhythm.

Alongside architectural drawings, photographic documentation served as a critical source of material and atmospheric information. The project gathered a diverse collection of images for each structure: high - resolution exterior photographs, interior corridor views, material close - ups (stone textures, plaster surfaces, brick patterns, window frames, wooden beams), lighting conditions at different times of day, and surrounding environmental contexts. For Narva Town Hall, historical and contemporary photographs helped identify restoration patterns and stylistic details not captured in technical plans. For Narva College, photographic sources helped verify modern material palettes and clarify details that do not always appear in simplified architectural drawings, such as ceiling structures, interior transparency, and furniture arrangements. These images were essential for developing accurate textures and for making informed stylistic decisions during modeling.

In cases where photographs or plans were insufficient, on-site observations and field documentation became necessary. Visiting the landmark provided irreplaceable data that was difficult to capture through secondary sources alone. During site visits, particular attention was given to human - scale perception: how large interior volumes felt in practice, how open courtyards shaped movement, how staircases or doorways influenced spatial flow, and how materials aged under natural lighting. Spatial relationships that appeared straightforward on paper often revealed subtleties when experienced physically, especially complex external geometries of the Narva College. These embodied observations confirmed or corrected assumptions made from 2D sources and helped guide interpretive decisions during modeling.

Despite the extensive efforts, the data collection phase inevitably encountered gaps, inconsistencies, and ambiguities, particularly for Town Hall. Some architectural drawings were outdated, incomplete, or reflective of earlier reconstruction stages rather than the present - day state. Photographs sometimes lacked the necessary angles or lighting to capture key architectural features. In such cases, interpretive modeling and inferential reasoning were used: estimating proportions based on symmetry and modularity, cross - referencing multiple low - quality images, or relying on similar historical structures as analogs. These interpretive steps were necessary to preserve overall coherence while acknowledging limitations in the available data.

Throughout the development process, data collection proved to be iterative rather than linear. As modeling progressed and new architectural issues emerged, fresh reference material was sought, and earlier assumptions were refined. This recursive relationship between data gathering and digital reconstruction was treated as an integral component of the creative research workflow, essential for maintaining accuracy and adapting to unforeseen challenges.

To summarize, the data collection phase was fundamental to the technical and scholarly integrity of the digital reconstructions of Narva Town Hall Square. By combining official architectural documentation, photographic evidence, on - site observations, and archival research, the project built a robust and diverse reference base capable of supporting detailed, culturally informed, and historically sensitive 3D modeling. The discipline and care exercised during this phase ensured that each subsequent stage - modeling, texturing, lighting, and interactive design - was grounded in a thoughtful engagement with the physical reality and cultural meaning of the buildings, allowing their identities to be translated respectfully and creatively into the virtual realm.

3.3. 3D Modeling and Asset Creation

The 3D modeling and asset creation phase marked a significant shift in the project, moving from research and conceptualization to full - scale digital production. This phase formed the core of the virtual reconstruction process, where abstract ideas, reference materials, and theoretical concepts were translated into tangible, interactive 3D forms. The modeling phase was not simply about creating a visual replica of Narva Town Hall Square; instead, it was a process of spatial interpretation, technical problem - solving, and aesthetic decision - making - anchored in architectural principles but responding to the specific requirements of virtual reality environments, especially those hosted by VRChat.

The first step in modeling involved importing and aligning the collected architectural reference materials. These were used as orthographic backgrounds in the Blender 3D workspace, allowing for precise alignment of the underlying geometry. This phase focused on establishing accurate proportions of external volumes. Given the importance of scale in VR, special attention was paid to real - world measurements and human - centered design principles; user height, reach, and movement were considered throughout the modeling process to ensure comfortable navigation and immersion.

Once the structural shell was in place, the detailed modeling of architectural elements such as window frames, doors, stair railings, columns, and ceiling panels began. Mirroring, array modifiers, and instancing were used where necessary to optimize repeating elements, maintaining both visual fidelity and performance optimization. Blender’s workflow allowed for iterative adjustments, which was critical when working in parallel with constant data refinement.

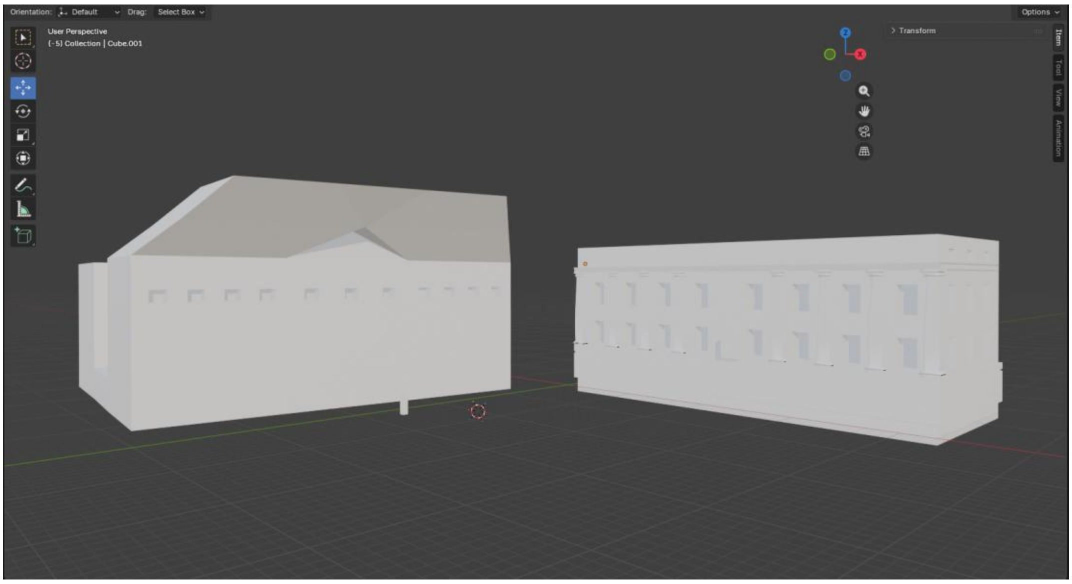

Figure 1. Early stages of the 3D modeling stage

A primary consideration during this phase was the level of detail. Given VRChat's memory and performance limitations, especially on standalone VR headsets like the Meta Quest, the model had to strike a careful balance between realism and efficiency. Polygon count was constantly monitored, and where possible, complex geometry, such as decorative architectural details like brickwork, facade ornamentation, and wall reliefs, was simplified to ensure optimal visual results without incurring excessive computational overhead.

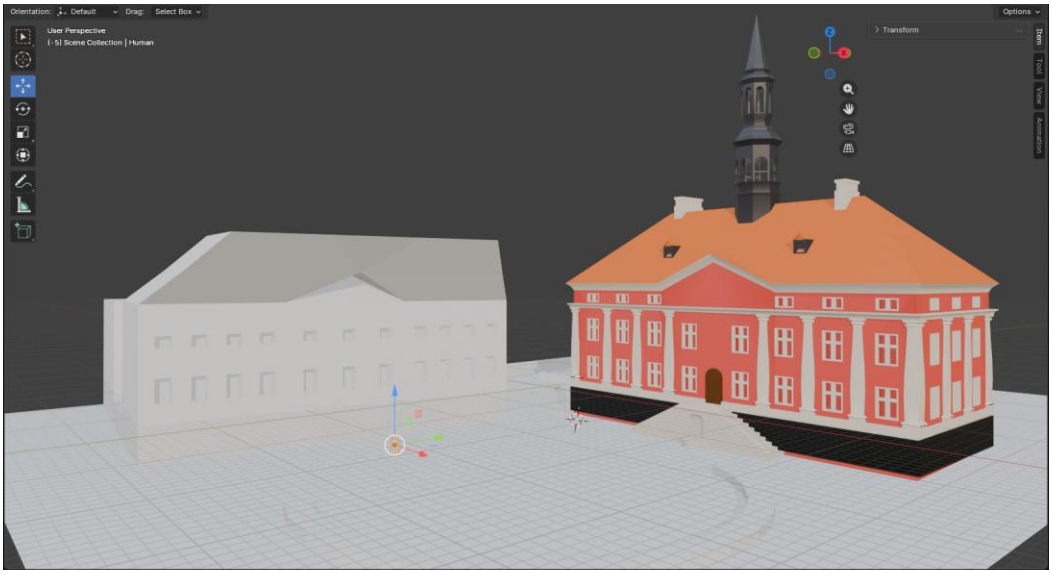

Figure 2. Completed 3D model of the Town Hall together with Narva College building in development.

In parallel with structural modeling, many additional assets were created. These included ambient props (e.g., benches, signs, potted plants), lighting, equipment, and other contextual elements that make a lively and authentic virtual environment.

Texturing and material creation were also essential to the project. Textures were taken from Creative Commons asset libraries and then processed in image editing tool called GIMP. Blender’s node - based material editor was used to create physically accurate materials, including albedo, roughness, metallicity, and normal maps. The materials were later adapted in Unity to be compatible with the VRChat rendering, often using Udon VRChat shaders or a standard shader with baked lighting.

An ongoing performance optimization process was woven into the modeling workflow at this stage. Polygon reduction, texture compression, mesh thinning, and UV mapping efficiency were critical to maintaining a smooth frame rate, especially in VRChat’s dynamic multiplayer environments. Special care was taken to ensure that no single object or material would break the stability of the runtime, especially on entry - level devices.

Frequent testing iterations were conducted during the modeling process. The model was regularly exported to Unity and loaded into a private VRChat instance, where it could be explored in both desktop and VR modes. These tests allowed for evaluating lighting, spatial proportions, and performance.

Figure 3. Release version of the 3D model in Blender editor.

The modeling and asset creation phase lasted several weeks and required a high level of coordination between creative, technical, and research tasks. It was an intensely iterative process that combined precise architectural reproduction with the artistic freedom and systemic constraints of immersive media design. The result was a fully controllable 3D model of Narva Town Hall Square, full of structural integrity, cultural details, and responsive user design, ready for integration into the VRChat ecosystem.

3.4. VRChat Integration and Optimization

The integration and optimization phase of VRChat represented a transformative moment in which a static 3D model of Narva Town Hall Square was brought to life as an explorable, interactive virtual environment. While modeling and asset creation laid spatial and visual foundation, it was during this phase that these assets were configured, optimized, and programmed to support real - time interaction and social immersion. This phase was critical to translating architectural fidelity into functional virtual reality, ensuring aesthetic and spatial fidelity and technical compatibility, performance efficiency, and usability within the shared VRChat online ecosystem.

VRChat's platform - specific limitations and capabilities affected the decisions made during this phase. VRChat, which is built on the Unity game engine, requires all user-created worlds to be built using the Unity development environment and packaged with the VRChat SDK. Therefore, the first step in this phase involved exporting the Blender model to Unity using the FBX format, ensuring that scale, orientation, anchor points, and materials were conveyed correctly. This transfer process is not merely a technical formality - it is a critical step that determines whether the 3D models behave predictably once inside the game engine. Any inconsistencies introduced during export, such as incorrect scaling, flipped axes, misplaced pivot points, or broken material assignments, can cause significant problems later in the development workflow, including misaligned collisions, distorted lighting, navigation issues, and unnecessary rework. Using the FBX format is standard practice in VRChat and Unity-based pipelines because it reliably preserves mesh hierarchies, smoothing groups, embedded materials, and animation data, making it far more robust than alternative formats such as OBJ or DAE.

Blender’s export settings were carefully calibrated to Unity’s metric system (1 unit = 1 meter) to ensure that real-world architectural proportions measured during the data collection phase were preserved precisely in the interactive environment. Maintaining accurate scale is especially important for virtual architectural spaces, as even small deviations can negatively affect users’ sense of spatial authenticity and embodied presence. Test exports were conducted to verify that the model behaved consistently between the modeling software and the engine. These early validation steps helped identify and resolve issues related to origin placement, rotation conventions (such as Blender’s Z-up vs. Unity’s Y-up coordinate system), and material compatibility before the scene became more complex.

Figure 4. VRChat world in development.

Once imported into Unity, the digital version of Narva Town Hall Square was placed into a clean scene file prepared with the necessary components of the VRChat SDK. The SDK provided building blocks for user interaction, avatar spawn points, world settings, and scripted behavior via Udon, VRChat's node - based logic programming system.

From here, the scene was gradually assembled and optimized. Every significant element of the environment - the building, terrain, skybox, lighting systems, and navigation colliders - was refined and tuned. Effective use of box colliders for walls and floors helped reduce the performance overhead while maintaining physical realism. Lighting and atmosphere were critical components of the immersive experience and required extensive tuning. Unity's baked lighting system was used to create realistic, pre - computed lightmaps that simulate global illumination without the overhead of real - time rendering. Materials were tuned with baked ambient occlusion and normal maps to maximize visual depth while minimizing runtime overhead.

A significant part of the integration process was optimization, which ensured that the environment would meet VRChat performance guidelines and be accessible to users on a wide range of hardware. The project followed best practices from the VRChat World Creation documentation, including:

1. Texture Compression and Resolution Management: Textures were limited to lower quality unless high detail was needed.
2. Level of Detail Tuning: Important architectural assets were given multiple meshes that automatically changed based on the user's distance.

3. Culling and Occlusion: Unity's Occlusion Culling system was enabled to prevent unnecessary geometry rendering outside the user's field of view.

In addition to visual and performance optimizations, interactive functionality was introduced at this stage using Udon scripts. While it is not supposed to be a gaming environment, interactivity adds meaningful interaction to VR. Simple but effective additions were made, such as:

1. Teleporters between different floors or distant areas to accommodate users with limited physical mobility in VR.
2. Clickable information panels that provide context or historical data about specific buildings or features.
3. Ambient sound zones that enhanced the sense of place.

These interactions were programmed using Udon Graph, a node - based scripting interface.

A key part of this phase was the initial loading of the environment into VRChat, which involved compiling the Unity project into a world package and uploading it through the VRChat SDK dashboard. The world was initially set up as private, allowing entry and on-site functionality testing. These early testing sessions were invaluable for identifying bugs, navigation issues, scale inconsistencies, or visual inconsistencies that broke immersion. For example, the avatar's eye height inconsistencies revealed that the stair rises were too steep, and the light maps needed adjustments to avoid overly dark locations.

Finally, as the environment evolved, the VRChat world metadata was defined. This included the world name, description, tags, and preview images. Tags such as "educational," and "architecture," were chosen to position the space in the VRChat world search browser. The world release configuration was finalized: options such as enabling instance cloning, setting the maximum number of users, and defining trust levels for interactions were adapted to support guided academic exploration and casual public visits.

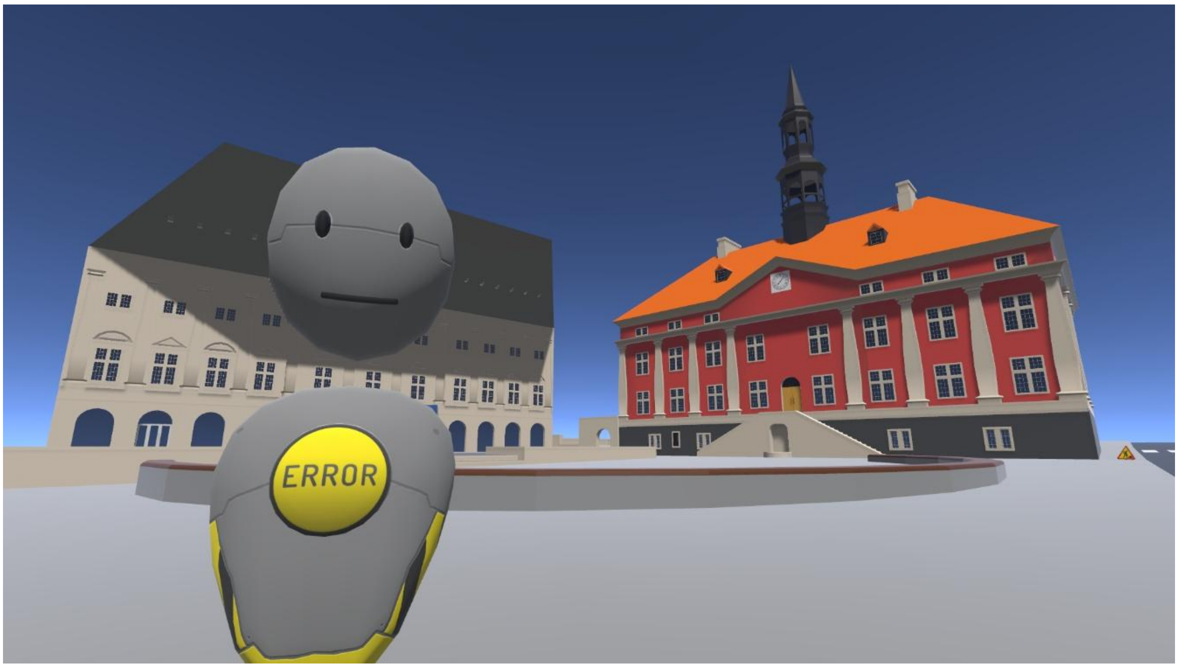

Figure 5. Release version of the VRChat world with player model in front of the camera.

By the end of this phase, Narva Town Hall Square had been completely reconstructed, embedded, and optimized within the VRChat ecosystem. The space functioned as a navigational 3D model and a performative, interactive environment capable of hosting events, educational tours, or simply enabling self - guided exploration. The environment's realism, performance efficiency, and interactivity demonstrated VRChat's ability to serve as a viable platform for immersive digital heritage projects.

The VRChat integration and optimization phase was technically rigorous and creatively satisfying. It required fluency in engine configuration, shader logic, interaction design, and performance engineering - all the while returning to the guiding vision of respecting and expanding the architectural and cultural identity of the city. This phase marked the completion of the transition from static representation to live virtual presence, opening the potential for real, embodied interaction with a place that might otherwise remain inaccessible to many.

3.5. Testing and Analysis

The Testing and Analysis phase of the project marked a turning point in the transition from development to critical evaluation. After successfully integrating the 3D model into VRChat and optimizing performance, this phase examined the environment's functionality, user experience, and educational value. It aimed to ensure that the digital replica functions as intended and meets the broader goals of cultural representation, accessibility, and immersive interaction.

Extensive internal testing was conducted to identify and resolve mechanical or performance - related issues. These sessions were conducted in both desktop mode and VR mode using devices like Oculus Quest 2 and PC.

The VRChat SDK Performance Assessment System served as a baseline metric, providing real - time feedback on draw calls, material complexity, texture usage, and total polygon count. In Unity, Profiler was used to monitor memory usage, frame timings, and CPU/GPU load during simulated runtime scenarios. Special attention was paid to maintaining a stable frame rate (>72 FPS for Quest) and ensuring that all interactive actions (teleporters, door animations, clickable panels) were triggered correctly with minimal lag.

Additionally, collision testing was performed by methodically walking through every hallway, doorway, stairwell, and corner to ensure no missing colliders, floating geometry, or dead ends in the traversal. Common VR - specific issues such as camera clipping, incorrect eye height, or scale inconsistencies were also checked.

The data collected during the testing and analysis phase provided validation and inspiration. It confirmed that the model achieved spatial authenticity while highlighting areas where the user experience could be improved. Notably, the feedback demonstrated that the digital environment resonates as a visual replica and a cultural artifact - a space that can engage users emotionally, cognitively, and socially.

The testing and analysis phase was a central process to the success of the virtual reconstruction of Narva Town Hall Square. It demonstrated the importance of testing real - world scenarios and verifying performance in immersive media projects. This phase ensured the final product would function technically.

4. EVALUATION CHAPTER

The evaluation framework is derived from the functional and non-functional requirements formulated during conceptual planning and from the theoretical discussions of digital heritage and virtual architecture presented in Theoretical Chapter. The core functional requirements specified that the environment should support free navigation at human scale, multi-user access for both desktop and VR users, and basic interactive elements that communicate architectural and historical information. Non-functional requirements emphasized performance, usability and authenticity, including stable frame rates on mid-range hardware, intuitive locomotion and readable in-world information, as well as recognizable building volumes and material impressions.

Finally, the evaluation considers the extent to which the VRChat world supports the educational and outreach goals formulated in the introduction. The virtual square is intended not only as a technical demonstration but also as an accessible cultural space that can be visited remotely, used in teaching contexts and serve as a starting point for discussions about Narva's architectural identity. The evaluation therefore examines how the environment supports spatial understanding, engagement and potential learning activities, while acknowledging that the assessment of concrete learning outcomes lies beyond the scope of this thesis.

Spatial authenticity is central to the value of the reconstruction as a digital twin of Narva Town Hall Square. The 3D models of Narva Town Hall, Narva College and the surrounding square were based on architectural drawings, archival and contemporary photographs and on-site observations. The resulting environment reproduces the main volumes, facade rhythms and spatial relationships between the buildings with a high degree of consistency. When explored in VR at human scale, the relative proportions of the square, the alignment of the buildings and the visibility corridors across the space correspond closely to the impressions documented during fieldwork. This supports the project's goal of offering an experience that approximates a visit to the physical square.

At the same time, visual fidelity is unavoidably shaped by the technical constraints of VRChat and the uneven availability of reference materials. Architectural details that would significantly increase polygon counts, such as very fine ornamentation or complex interior furnishings, were simplified. For Narva Town Hall, gaps and inconsistencies in historical documentation required interpretive decisions about certain facade details and interior configurations.

From the perspective of heritage theory, these trade-offs are acceptable if they remain intellectually transparent. The reconstruction does not claim to be a metrically exact survey; rather, it presents a plausible, evidence-informed interpretation of the square that is optimized for real-time social VR. The use of information panels and the documentation of sources and modelling decisions help to mitigate the risk of "hyperreal" misrepresentation and align the project with recommendations that digital reconstructions should disclose their evidential basis and interpretive choices. Overall, the evaluation suggests that the environment achieves a convincing level of spatial authenticity and visual coherence while openly acknowledging the limits of available data and platform capacity.

User experience in a social VR reconstruction depends not only on visual quality but also on how comfortably and meaningfully users can move through and inhabit the space. The internal testing described in Practical Chapter focused on identifying and correcting issues such as missing colliders, navigation dead ends, camera clipping, incorrect avatar eye height and inconsistent scale. Repeated walkthroughs in both desktop and VR modes helped ensure that users can traverse corridors, stairwells and open spaces without getting stuck or encountering invisible barriers, and that doors, teleporters and other interactive elements behave consistently.

These measures contribute directly to the sense of presence and embodied agency that are central to immersive experiences. When the avatar's height, movement and interaction range correspond to human expectations, and when collisions and spatial boundaries behave predictably, users can focus on exploring the architecture and the narrative content of the space rather than on compensating for technical irregularities. The final version of the world allows users to approach facades at close range, look out over the square from elevated positions and move between interior and exterior areas in a way that reflects plausible circulation patterns.

Nevertheless, the evaluation also indicates areas where user experience could be further improved. The environment currently assumes a basic level of familiarity with VRChat's locomotion and interaction conventions; first-time users may benefit from more explicit onboarding elements, such as a short tutorial panel at the spawn area or visual cues that highlight key interactive hotspots. In addition, while the lighting and atmosphere are tuned to create an appealing sense of place, certain viewpoints may produce high-contrast scenes or strongly saturated highlights that can be tiring during prolonged use, especially in VR headsets. Addressing these aspects would strengthen the environment's accessibility for diverse users, including those with limited prior VR experience.

Technical performance is a prerequisite for any meaningful user experience in VR. During development, the project followed VRChat's world-creation guidelines and used tools such as the VRChat SDK Performance Assessment System and the Unity Profiler to monitor draw calls, material complexity, texture usage, memory consumption and CPU/GPU load. Particular attention was paid to maintaining a frame rate suitable for VR usage on devices comparable to Meta Quest 2, as lower frame rates can cause discomfort and reduce the perceived smoothness of interaction.

The integration and optimization workflow included the use of baked lighting, occlusion culling, and texture compression. These measures reduced the runtime cost of rendering complex architectural geometry while preserving the visual qualities most important for recognizability. Testing shows that, under typical conditions, the environment runs stably on mid-range hardware, with responsive interaction for teleporters and clickable panels. The world therefore meets the basic performance-related requirements formulated at the outset of the project.

At the same time, the evaluation highlights that performance remains contingent on factors outside the direct control of the designer. The diversity of user hardware, network conditions and concurrent avatar presence in a VRChat instance means that performance can vary noticeably between sessions. Furthermore, the need to stay within VRChat's category thresholds for world size, polygon count and texture memory limits further expansion of the environment, for example by adding very detailed interiors for all buildings or large surrounding urban areas. From a digital heritage perspective, these constraints underline that the current reconstruction should be regarded as an optimized prototype rather than a definitive, fully exhaustive digital twin of Narva Town Hall Square.

One of the stated aims of the project is to explore how a VRChat reconstruction of Narva Town Hall Square can support educational use and broaden public access to the site. The evaluation of educational and heritage value therefore considers how the environment might function as a resource for teaching, self-guided exploration and cultural mediation, even though the thesis does not conduct a full-scale pedagogical intervention.

The environment offers several features that support educational use. Users can visit the square remotely, at their own pace, and experience the spatial relationships between Narva Town Hall, Narva College and the surrounding urban fabric. The ability to move freely, look around from different vantage points and revisit specific locations aligns with findings in immersive media research that embodied navigation can strengthen spatial understanding and memory compared with two-dimensional representations. Information panels and other contextual elements can be used to present historical and architectural explanations, timelines or thematic narratives that connect the built environment to broader questions of civic identity and regional development.

At the same time, the educational potential of the world depends on the design of concrete learning scenarios and facilitation strategies, which lie outside the scope of this project. The current version functions primarily as an explorable environment with embedded contextual information; structured learning activities, such as guided tours, collaborative tasks or assessment mechanisms, would need to be developed in cooperation with teachers and heritage organizations. Furthermore, access to the environment presupposes a VR-capable device or a sufficiently powerful desktop computer and a stable internet connection, which may limit its reach among certain user groups. Consequently, while the project demonstrates that VRChat can host a compelling and informative reconstruction of Narva Town Hall Square, its educational impact will ultimately depend on how institutions and communities choose to integrate it into their practices.

The evaluation also needs to address the main limitations of the project, both in terms of the reconstruction itself and the research design. A first limitation arises from the uneven availability and quality of reference materials for the different buildings. Narva College benefits from relatively complete and recent architectural documentation and photographic coverage, whereas Narva Town Hall has undergone multiple periods of damage and restoration, with some plans and images being incomplete or inconsistent. As a result, parts of the reconstruction, particularly for the Town Hall, are necessarily more interpretive and less tightly anchored in contemporary documentation than others.

A second limitation concerns the scope and nature of user evaluation. While internal testing in both desktop and VR modes was extensive, and qualitative feedback highlighted the environment's strengths and areas for improvement, the project does not include a large-scale, systematically sampled user study. The available evaluation material is therefore sufficient for identifying technical issues, assessing basic usability and drawing initial conclusions about presence and engagement, but it does not allow for detailed statistical analysis or for generalizing findings to specific user populations such as students, tourists or local residents.

Third, the reconstruction focuses primarily on the tangible architectural aspects of Narva Town Hall Square. Intangible heritage dimensions, such as everyday social practices, historical events, soundscapes or community narratives associated with the square, are only indirectly represented through the design of spaces and the limited textual information provided. Incorporating richer narrative layers, audio materials or interactive storytelling elements could help to connect the virtual architecture more explicitly to lived experiences and collective memory, as suggested in recent virtual heritage research.

Finally, the choice of VRChat as a platform, while justified by its technical openness and user base, introduces dependencies on a third-party infrastructure whose long-term evolution is beyond the control of the project. Changes in platform policies, SDK versions or hardware requirements could affect the accessibility and functioning of the world in the future. For long-term preservation, it may be necessary to export the core assets and consider parallel deployments on other platforms or in standalone applications.

These limitations point to several directions for further work. Future iterations of the project could focus on completing and refining the reconstruction of the square, integrating additional interactive layers and developing structured educational scenarios in collaboration with local schools or the University of Tartu. More systematic user studies could investigate how different groups experience and use the environment, including their learning outcomes, sense of presence and attitudes towards digital heritage. In parallel, exploring strategies for long-term preservation and cross-platform portability would help ensure that the virtual Narva Town Hall Square remains accessible as technologies and user practices evolve.

5. SUMMARY

The research problem was how to reconstruct a historically and architecturally significant urban space - Narva Town Hall Square with Narva Town Hall and Narva College - as an interactive, accessible and meaningful virtual reality environment. To address this, the thesis combined theoretical perspectives from digital heritage, immersive media and virtual architecture with a practice-based development workflow, in which the creation of a VRChat world functioned both as research method and main output.

The work proceeded through a systematic six-stage process: conceptual planning, data collection, 3D modelling and asset creation, integration and optimization in Unity and VRChat, testing, and evaluation and refinement. Architectural drawings, archival and contemporary photographs and on-site observations were used to model Narva Town Hall Square in Blender, after which the models were imported into Unity, configured with interactions and optimized according to VRChat's performance guidelines. Throughout, the project followed the ethical and methodological principles set out in the introduction, including careful source documentation, attention to authenticity and respect for the cultural significance of the site.

The evaluation of the finished VRChat world shows that the main functional and non-functional requirements were achieved. Spatially, the reconstruction provides a convincing and recognizable representation of Narva Town Hall Square at human scale, preserving key building volumes, facade rhythms and viewpoints while simplifying details where necessary for performance and safety. Usability tests in both desktop and VR modes indicate that users can navigate the environment fluently, with collisions, scale and locomotion behaving as expected. Technical profiling confirms that, under typical conditions, the environment performs stably on mid-range hardware. At the same time, the evaluation highlights that the environment's educational potential depends on how it is embedded in concrete learning scenarios and on users' access to suitable devices and network connections.

Taken together, the results allow the research questions formulated in the introduction to be answered. First, the comparative analysis of social VR platforms shows that VRChat currently offers the most appropriate combination of technical openness, world-building flexibility, VR and desktop support and active user base for a multi-user reconstruction of Narva Town Hall Square. Second, the development process demonstrates that reproducing real buildings for social VR requires continuous negotiation between spatial fidelity, performance and usability, supported by transparent documentation of modelling decisions and uncertainties. Third, the user testing and evaluation indicate that a VR version of the square can enhance spatial understanding, presence and accessibility compared to traditional two-dimensional media, especially for users who cannot easily visit Narva in person. Fourth, the study identifies key challenges and ethical considerations, including incomplete documentation for some parts of the site, the need to avoid misleading or speculative reconstructions and the long-term dependence on a commercial platform.

The main contribution of the thesis is therefore twofold. On the practical level, it delivers a functioning, documented VRChat reconstruction of Narva Town Hall Square that can be explored remotely and used as a basis for future educational or heritage activities. On the methodological level, it offers a concrete, practice-based example of how real-life architecture can be translated into a social VR workflow, from platform selection to optimization and evaluation.

Future work could address these limitations by refining and extending the reconstruction, adding richer interactive and narrative layers, and developing structured learning activities in cooperation with teachers and heritage institutions. More systematic user studies with diverse participant groups would make it possible to assess learning outcomes and user experience in greater detail. Finally, exploring options for cross-platform deployment and long-term preservation would help ensure that the virtual Narva Town Hall Square remains accessible as technologies and user practices continue to evolve.

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APPENDICES

Appendix 1. Comparison of selected social VR platforms by key characteristics

Table. Comparison of selected social VR platforms by key characteristics (1/2)

Feature / Platform	Horizon Worlds	Rec Room	Second Life	Vault Hill
Platform support	Native to Meta Quest headsets; expanding access via Horizon platform to mobile and desktop streaming as part of Meta's broader Horizon OS ecosystem.	Free-to-play; cross-plays on phones, game consoles, PC and VR headsets.	Primarily Windows and macOS desktop client (with some Linux support and mobile in development); VR access only via third-party viewers, not VR-first.	XR metaverse concept combining VR/AR/MR and blockchain; client ecosystem still emerging and more oriented to Web3 users than mainstream VR audiences.
Primary focus / target audience	Mass-market social and entertainment platform within the Meta ecosystem, emphasizing curated events, branded experiences and mainstream audiences.	Family-friendly "digital third place" where users play mini-games, socialize and explore user-made rooms; strong focus on teens and young adults.	General-purpose virtual world for adults with diverse social, educational and commercial communities; long history as a platform for remote meetings and events.	Human-centric metaverse built around themed virtual districts and virtual land ownership; target audience includes Web3 investors and brands.
Avatar and world creation	In-world world building tools and, more recently, Horizon Engine and Horizon Studio for higher-fidelity worlds and AI-assisted asset creation; tools are designed to be accessible to non-experts but are limited to Meta's ecosystem.	In-world Maker Pen and circuitry tools allow users to create rooms, games and interactive objects without external software; millions of rooms have been created this way.	Rich set of in-world building tools and scripting (LSL) for creating 3D objects, environments and interactive systems; most content in Second Life is user-generated.	Virtual districts and land parcels are designed using urban-planning principles; developers and users can build experiences on top of tokenized virtual land, though tooling is still less accessible than mainstream social VR editors.

Feature / Platform	Horizon Worlds	Rec Room	Second Life	Vault Hill
Monetization model	Free entry for users with Meta accounts; monetization focuses on platform-wide engagement, brand partnerships and integration with Meta's broader advertising and subscription ecosystem.	Free-to-play with in-game currency and cosmetic purchases; creators can monetize some of their content through platform-managed programs.	Long-standing virtual economy with Linden Dollars (L$) that can be exchanged for real-world currency; land ownership, rentals and in-world commerce are central to the platform.	Web3-style economy based on tokenized virtual land (VLAND) and other blockchain-based assets; value proposition centers on digital property and investment.
Unique selling point	Deep integration with Meta hardware and services, plus new AI-assisted world-building tools and large-scale branded events.	Accessible cross-platform "game-like" experience with strong onboarding, safety tools for younger users and built-in game creation.	Mature, persistent virtual world with a robust user-run economy and decades of accumulated user-generated content.	Combines XR with blockchain to position itself as a human-centric metaverse where owning virtual land is central to the experience.
Ownership / governance	Developed and governed by Meta Platforms, Inc.	Developed by independent company Rec Room Inc.	Developed and operated by Linden Lab.	Developed by Vault Hill, a blockchain-oriented company building Web3 products.

Table. Comparison of selected social VR platforms by key characteristics (2/2)

Feature / Platform	MootUp	BanterVR	VRChat
Platform support	Browser-based 3D platform accessible from smartphones, tablets, PCs and most modern VR/AR headsets, without installing a separate app.	PCVR via Steam with OpenXR support and 2D desktop mode; standalone versions for major headsets distributed via platforms such as SideQuest and other app stores.	Windows desktop client; VR support for major PC VR headsets and Android-based standalone headsets; mobile apps for Android and iOS (2D mode); cross-platform play.
Primary focus / target audience	Enterprise, education and event organizers who need branded virtual or hybrid events with analytics, sponsor booths and integrated communication tools.	Social VR sandbox for groups of friends and communities who enjoy physics-driven games, events and experimental spaces.	Open-ended social sandbox for a wide range of communities, from casual hangouts to niche subcultures and role-play groups.
Avatar and world creation	Event spaces are created by configuring and customizing pre-built 3D templates; booths, media walls, gamification elements and avatar options can be set up without coding, but full custom world building is limited.	Worlds can be created using external tools such as Unity and A-Frame, with support for importing custom assets (e.g. from Blender). Banter emphasizes physics-intensive spaces and plans to expand creator tools as part of its early-access roadmap.	Advanced avatars and worlds created externally in Unity using the VRChat SDK and Udon scripting; very high expressive power but also higher technical barrier.
Monetization model	SaaS model targeted at organizations; event organizers pay for access and features, while attendees typically participate for free within those spaces.	Free-to-play early-access title; developers emphasize that Banter will remain free, with future monetization likely to revolve around premium experiences or creator tools rather than mandatory fees.	Free to use; optional VRC+ subscription and an informal creator economy where avatars and assets are often sold via external marketplaces (e.g. Gumroad, Booth) rather than a fully integrated in-world currency.

Feature / Platform	MootUp	BanterVR	VRChat
Unique selling point	Turn-key browser-based solution for large-scale events with rich interaction features, analytics and hybrid event workflows.	Advanced physics-driven movement and interactions (FlexaPhysics), with a strong emphasis on physically engaging, experimental social spaces.	Extremely high degree of creative freedom in avatars and worlds, very active communities and large concurrent user numbers, making it one of the central hubs of contemporary social VR.
Ownership / governance	Developed and operated by MootUp / its parent company as a commercial SaaS platform.	Developed and published by SideQuest Ltd, it is best known for its alternative VR app distribution platform.	Owned and operated by independent company VRChat Inc.

Appendix 2. Comparison of alternative implementation approaches for a virtual reconstruction of Narva Town Hall Square

Table. Comparison of alternative implementation approaches for a virtual reconstruction of Narva Town Hall Square

Solution	**Advantages**	**Disadvantages / limitations (for this project)**	**Overall fit for this thesis**
3D scanning (photogrammetry)	High surface detail; convincing textures; can strengthen evidential basis	Heavy/inefficient geometry & materials; significant cleanup + optimization required for real-time social VR; does not remove authoring decisions	Medium (useful as support method, weaker as main pipeline)
360° photo/video tour	Very low access friction; fast to produce and distribute; broad reach	Mostly passive/ocular-centric; limited embodied navigation and interaction; weak support for shared co-presence and collaborative exploration	Low-Medium (good for presentation, not for interactive social experience)
Standalone application (Unity/Unreal)	Maximum technical control; fully custom features and visuals possible	Becomes product-level effort: distribution, accounts, networking/hosting, moderation, QA, maintenance; social affordances are costly to replicate	Medium (powerful but oversized for thesis scope)
VRChat world	VR + desktop participation; built-in multi-user presence and social interaction; established publishing/iteration workflow; discoverability via active user base; clear optimization guidance	Platform constraints (performance budgets, policies); dependence on a commercial ecosystem	High (best balance of access, social presence, feasibility, and reach)