Augmented reality as digital preservation and communication tool in Cultural Heritage domain.

Russia — Italy — Turkmenistan

Politecnico di Torino
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ABSTRACT

Cultural heritage is a rather broad concept that may refer to a specific place, a people, a country, or even be considered the legacy of the entire planet. Undoubtedly, the more significant and accessible a heritage site is to tourists and local communities, the more care it receives: “Local communities take pride in – and have a sense of responsibility and empowerment towards – the World Heritage properties, contributing to property conservation and the sustainable management of tourism” [1]. However, there are also other examples—places you may have walked by just yesterday, which no longer exist today. Many things decay and disappear before our eyes.
This contrast between well-preserved landmarks and overlooked, disappearing places raises an important question: how can we ensure broader visibility and preservation of cultural heritage, especially beyond official institutions? One possible answer lies in rethinking how communities engage with heritage and how new technologies can support that process. On the global stage, several initiatives aim at the digital preservation of cultural heritage, such as Global Digital Heritage, Google Arts & Culture’s Scan the World, and CyArk [2,3,4]. These platforms offer access to heritage in digital formats, introducing users to endangered languages, traditional crafts, sculptures, architecture, and other forms of expression.
Digitalization is becoming increasingly embedded in our lives. It is supported by international organizations such as UNESCO (Cultural and Digital Technologies) [5], and is part of governmental agendas—for example, Shaping Europe’s Digital Future [6]. As technologies evolve, the future begins to resemble the visions of science fiction and futurism: cybernetization, territorial expansion, digitalization, and life alongside AI. In an optimistic scenario, we could preserve our heritage—if not physically, then digitally—granting it a kind of digital immortality, anchored to its geographical location.
This thesis is dedicated to precisely this direction: experimenting with new, accessible technologies and devices aimed at enhancing the perception of cultural heritage objects. Special attention is given to the use of augmented reality (AR) technologies, which allow not only for the visualization of lost or difficult-to-access heritage objects within real-world environments but also for interactive engagement with them. These solutions enable viewers to explore objects in detail, examine their structures, listen to accompanying audio narratives, and move through digital reconstructions—fostering a deeper and more personalized cultural experience. This approach opens up new forms of access to heritage beyond the walls of museums—on the streets, in public spaces, or at the very sites of historical significance.

The aim of this thesis is to explore, in practice, how augmented reality technologies can function in the context of digital heritage preservation, as well as how they can engage people through interactive and game-based experiences.This thesis explores precisely this direction: experimenting with emerging, accessible technologies and devices aimed at enhancing the perception of cultural heritage objects.

Research Objectives and Scope:

The primary goal of this research is to broaden the understanding of digital heritage through the use of immersive augmented reality technologies. The work includes the development of a concept for an accessible AR application and examines its application in various environments. It also investigates the AR technology itself in different cultural and geographic contexts.
Work with augmented reality is structured around three case studies, each addressing distinct challenges:

- **House of Soviets — Kaliningrad, Russia (1970-2024).** A proposal for using augmented reality through a mobile application to work with currently lost cultural heritage sites.

- **Stupinigi — Turin, Italy.** Work with the interior section of a fragment of the Stupinigi complex using augmented reality simulation.

- **Nisa — Turkmenistan.** A conceptual proposal for an exhibition, based on archaeological research of the first Parthian capital (3rd century BC – 3rd century AD).

Each of these examples provides an opportunity to explore how technology can support a new way of experiencing and preserving cultural heritage—not as static museum exhibits, but as parts of a living landscape, relevant here and now.

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01| Cultural Heritage. Digitalization and preservation challenges.

1.1 Motivation.

During my childhood in the village of Baltiyskaya Kosa (Kaliningrad region, Russia), there stood an old German fortress directly on the seashore. Its corridors stretched far out into the Baltic Sea. What happened to it? Year after year, the fortress deteriorated and fell into disrepair: some people took its bricks to build sheds, others picnicked on its roof. Moreover, the condition in which I saw the fortress as a child was already quite different from what it was in my father's youth. In old photographs, it appeared almost new—surrounded by a water-filled moat where children used to jump from swings and swim. The last time I visited the fortress, I was 30. What had once been a grand structure had been reduced to a fragment of stone, on the verge of total collapse. The arms that once reached into the sea were completely destroyed, with only a few corridor remnants still visible in the water near the shore. So, what remains? From what was once a majestic place, all that is left are floating ruins in the sea, bricks reused for sheds, and the memory of its image in the minds of those who witnessed its slow decline.

Using Russia as an example, it is clear that this is not an isolated case. In addition to sites like the fortress on the Baltic Spit, there are also World Heritage sites that remain in good condition and receive proper care. However, there are examples such as the UNESCO-listed palace and park ensemble in Gostilitsy, Leningrad Region, Russia, which is, in fact, in the process of destruction and disappearance before our eyes [7]. After the damage inflicted during the Second World War, the estate continued to deteriorate in the postwar period, and today only the shell of the palace remains, now in an emergency state. The original park layout has almost completely disappeared: overgrown paths, dying alleys, ruined pavilions, and a degraded hydraulic system with filled-in channels have turned the historical territory into a wild landscape. The situation regarding the legal status of the area is particularly critical: part of the historic landscape, including the lower ponds, has fallen outside the protected zone, which has already led to private construction and the loss of key visual perspectives. Without systematic restoration and legal protection, the ensemble is at risk of being completely lost, despite its high historical, cultural, and artistic value [8]. There are also many traces of human presence on the palace grounds—litter, and even campfire sites from barbecues.

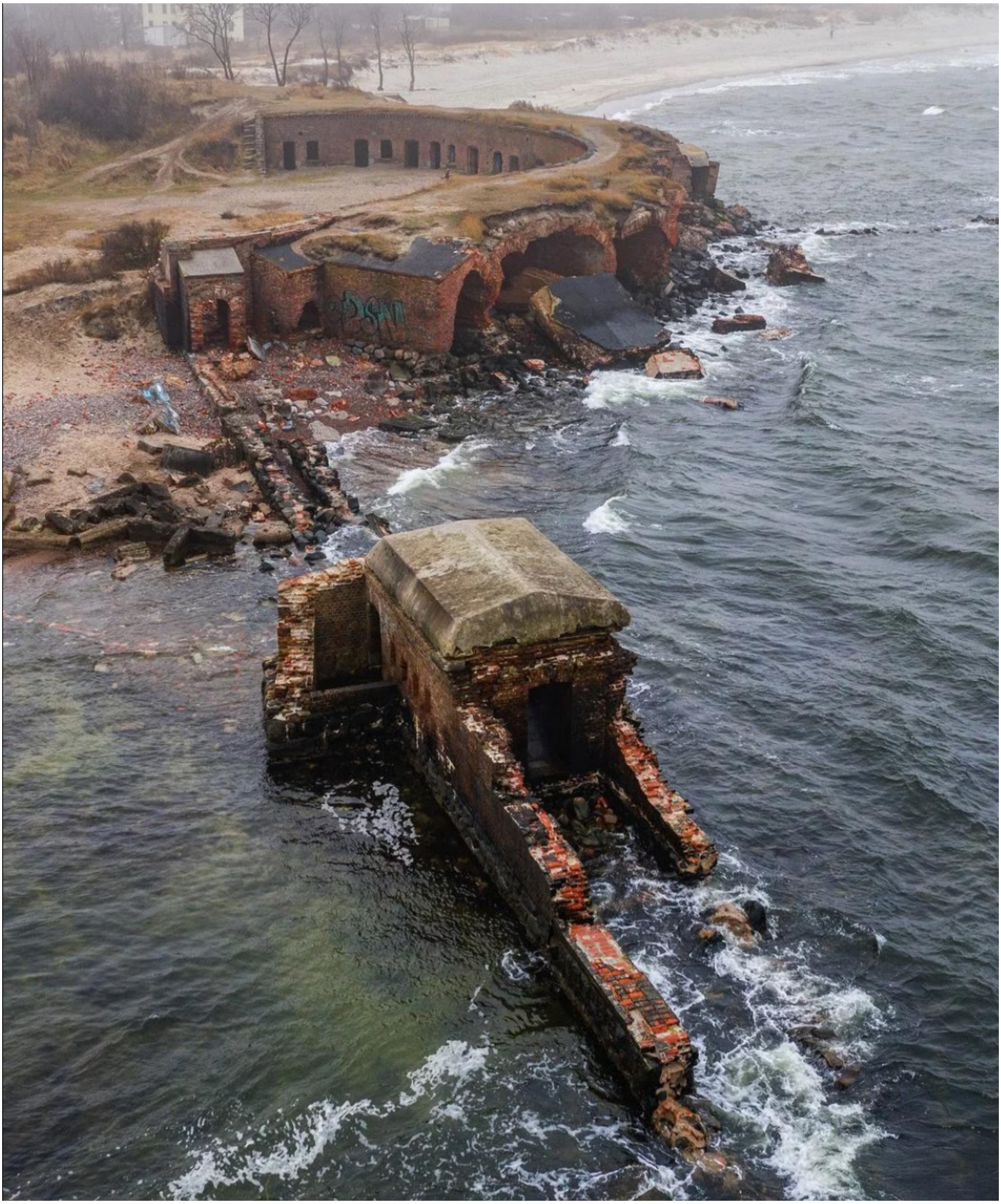

Figure 1. The fortress located on the territory of the Baltic Spit. Source: Sukharev Instagram, n.d.

Figure 2. The palace and park ensemble in Gostilitsy: campfire sites and litter on the grounds of the complex. Source: Ivan Karnitckii 2025.

Visiting such places makes me reflect on how these sites might be preserved through individual efforts, and serves as a motivation for writing this thesis.

1.2 The Concept of cultural heritage and differences in criteria.

The concept of cultural heritage encompasses a broad spectrum of tangible and intangible cultural expressions. According to UNESCO [9] :"Cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artefacts, sites or monuments. The definition excludes ICH related to other cultural domains such as festivals, celebration etc. It covers industrial heritage and cave paintings".
The criteria for inclusion in the UNESCO World Heritage List are outlined in the Operational Guidelines for the Implementation of the World Heritage Convention [10] and include, among others: the uniqueness of the site, its connection to cultural traditions or extinct civilizations, outstanding architectural or artistic value, and associations with important historical events.
The Russian Federation has its own set of criteria defined in Federal Law No. 73-FL "On Cultural Heritage Objects (Monuments of History and Culture) of the Peoples of the Russian Federation" [11]. An object must demonstrate historical, artistic, architectural, memorial, scientific, or technical value, be authentic, and sufficiently preserved for identification.
Cultural heritage status imposes restrictions on the types of interventions allowed. Failure to comply can result in the loss of heritage status. One example is the Bagrati Cathedral and Gelati Monastery in Georgia. In 1994, the cathedral was inscribed on the World Heritage List as part of the combined property. However, in 2010, UNESCO expressed concerns about extensive reconstruction efforts, which were seen as compromising the integrity and authenticity of the site. As a result, in 2017,introduced a major reduction in the boundaries. The new boundaries exclude Bagrati Cathedral, which has undergone major reconstruction detrimental to its integrity and authenticity. The decision retains the Monastery of Gelati's World Heritage standing as a site of outstanding universal value [12].

Figure 3. Gelati Monastry. Source: UNESCO WHC News, 2017

1.3 Unrecognized heritage sites and critique of existing approaches.

Despite existing criteria, a significant number of heritage-worthy objects remain unrecognized. In Russian practice, the term “identified cultural heritage site” refers to objects that are protected and registered in the state heritage register [11]. However, there exists an unofficial counterpart—unrdefined cultural heritage—referring to objects whose significance is apparent to local communities but remains formally unacknowledged.

Architect Kuba Snopek, in his book "Belyayevo Forever", addresses the issue of modernist residential districts in Moscow, which do not meet UNESCO criteria but possess important socio-cultural value. He emphasizes that existing classifications fail to account for the hybrid nature of heritage—both tangible and intangible. Snopek proposes modernizing the classification system: "We currently lack the tools to work with mixed, tangible-intangible forms of heritage, so introducing a new criterion or creating an entirely new protection program for such heritage seems inevitable." [13]
This perspective is supported by Professor Laurajane Smith, who argues that heritage is not an object but a process that occurs at specific sites [14]. Smith's vision aligns with the concept of heritagization, a term denoting the social process by which certain objects, places, traditions, or practices acquire the status of cultural heritage. Unlike the view of heritage as something inherently existing, heritagization emphasizes that heritage is a construct shaped by society in response to needs of identity, memory, tourism, politics, or economy. [15]
Thus, the heritage discourse must acknowledge the existence of unrecognized objects that hold cultural value for specific communities.

1.4 Digitalization as a preservation tool.

Rapid technological development allows us to explore any corner of the world without leaving home, monitor sites in remote locations, and manage them over long distances. Technologies are no longer just auxiliary—they actively support the goal of cultural heritage preservation through non-invasive methods [15]. The ability to immerse oneself in 3D environments and interact with spaces, objects, or information creates a new immersive context for experiencing heritage. Users can virtually visit historical simulations and engage with diverse cultures and phenomena. Tools enabling this interaction include smartphones, computers, VR headsets, and augmented reality devices [16].
Notable examples of projects that provide access to digitized cultural heritage include:

- **Scan the World (Google Arts & Culture):** the world's largest open-access platform for digitizing cultural objects, launched in 2014. It features over 16,000 items created with input from more than 50 cultural institutions. Based on accessibility and participation, the platform allows users worldwide to contribute to heritage preservation by 3D scanning artifacts using photogrammetry and everyday devices:smartphones,tabs,cameras.
All digitized objects are freely available via MyMiniFactory under a Creative Commons license. This example illustrates how digital technologies and community engagement can dramatically expand access to and participation in cultural heritage conservation. [2]

- **Global Digital Heritage (GDH):**is a not-for-profit, private research and education organization dedicated to documenting, monitoring, and preserving our global cultural and natural heritage. We use digital visualization, 3D virtualization, geospatial informatics, and open access solutions to provide digital data and 3D models to governments, regional institutions, museums, local scholars, and the public." A key element of our mission is the democratization of science-we make all data freely available to the world in support of cultural heritage, heritage management, education, public access, scientific research, and to enhance the digital humanities". [3]

Digital heritage is increasingly shaped by community involvement. Contemporary approaches emphasize the importance of including local participants not as passive observers but as co-creators. The concept of "public heritage" suggests that those affected by heritage decisions and those who value the site must be involved in the process [15].

1.5 Key challenges of digitalization.

According to the study Digitalizing Cultural Heritage through Metaverse Applications [16], despite the many advantages of digital technologies, several key challenges remain:

- **Authenticity and Interpretation:** Digital models may oversimplify or distort original forms, leading to misinterpretations of historical context.

- **Digital Divide:** High hardware and internet requirements, along with low digital literacy among vulnerable groups such as the elderly, as well as language and cultural barriers, limit access to digital heritage.

- **Cultural Sensitivity:** Without community involvement, there is a risk of cultural appropriation, misuse of symbols, or violation of privacy in sacred sites.

- **Technological Dependence:** Risks include data loss, outdated formats, cyber threats, and legal gaps in protecting digital repositories.

- **Environmental Impact:** High energy consumption by data centers and electronic waste pose environmental concerns.

- **Limitations of the Digital Experience:** The absence of smell, touch, and atmosphere may lead to digital substitutes lacking the depth of physical interaction.

Thus, digital heritage preservation requires a balance between technological innovation and cultural responsibility, as well as thoughtful policies for engagement and inclusion. At the same time, digital immersion offers experiences that are otherwise inaccessible due to the restrictions imposed on physical heritage sites.

02| Case study 1. House of Soviets.

2.1 Digitalization in Russia.

Russia, as a member of UNESCO and ICOMOS, has a legal system in the field of cultural heritage protection that was largely formed under the influence of these organizations, as well as international legal documents such as the 1972 UNESCO Convention, the 1964 Venice Charter, the Nara Document of Authenticity (1994), and other acts [17,18,19].
In her article on the connection between international law and Russia's cultural heritage, Marta Polyakova directly states that these documents underlie concepts such as "authenticity," "conservation," "cultural landscape," and "intangible heritage," which have become part of Russian restoration and conservation practice. The Federal Law "On Objects of Cultural Heritage (Historical and Cultural Monuments) of the Peoples of the Russian Federation," adopted in 2002, consolidated a number of concepts and approaches derived from international experience: a systemic approach to protection, taking into account the natural and cultural context, and working with historic settlements rather than just individual monuments. Thus, heritage protection began to focus not on individual restorations but on an integrative approach that considers the interrelationship between architecture, landscape, and the socio-cultural environment [20,11].
At the same time, both Marta Polyakova and Kuba Snopek draw attention to the fact that international criteria, including UNESCO's, can be overly universal and require adaptation to local specifics. This is especially relevant in the recognition of intangible and "unidentified" heritage, the significance of which is formed primarily through local communities and social memory [20,13].
A significant aspect in the Russian cultural sphere is the issue of digitalization: the government is taking steps to support digital culture, which is being implemented according to the "Strategic Direction for Digital Transformation of the Culture Sector up to 2030," approved by the Government of the Russian Federation in 2023 [21]. This document sets out priorities for digital development, including raising the digital maturity of cultural institutions, implementing modern technologies such as artificial intelligence, big data, VR, and augmented reality, as well as ensuring public access to digital services.
Within the framework of this strategy, three key projects are being implemented: "Digital Cultural Profile"—a system of personalized recommendations and tracking of citizens' cultural activity; "Digital

Environment for Culture Sector Management"—a unified infrastructure for managing cultural institutions based on data; and "Library of the Future"—modernization of the library network with a focus on digital services, cloud solutions, and integration with state platforms.
The Kultura.rf domain has also been launched—a public educational project dedicated to Russian culture. It covers significant events and figures in the history of literature, architecture, music, cinema, theater, as well as folk traditions and monuments of nature, in the form of educational articles, notes, interviews, tests, news, and in all modern internet formats [22].
By 2030, it is planned to connect 90% of institutions to the digital environment, create centralized sector databases, and ensure broad access to cultural content in digital format [21].
Russian cultural institutions also participate in international projects for the digitalization of heritage. For example, museums such as The State Hermitage Museum, The State Tretyakov Gallery, The State Russian Museum, and others collaborate with the Google Arts & Culture platform, providing digital access to their collections. This promotes the integration of Russian cultural heritage into the global information space and broadens the audience familiarizing itself with Russian culture [23].
At the same time, it is precisely at the regional level, in cities with multilayered history and complex identity, that digitalization opens up new opportunities for rethinking and preserving memory. Kaliningrad serves as a vivid example of such a space, where the intersection of cultural and historical layers requires the search for contemporary approaches to working with heritage.

2.2 Kaliningrad.

IAfter the end of World War II, part of German territory became part of the USSR. According to the decision of the Berlin (Potsdam) Conference in 1945, Königsberg was transferred to the USSR in 1946 and in the same year was renamed Kaliningrad [24]. In 1991, as Lithuania gained independence, left the USSR, and the Soviet Union collapsed, Kaliningrad became an exclave of the Russian Federation [25,26].
The central core of Königsberg—including the Royal Castle, the Cathedral, and the surrounding quarters—was almost completely destroyed after World War II. These areas turned into a zone of ruins, where Soviet urban planning projects were later implemented. According to the materials from the City Council session in 1967, the plan for the former center included the creation of a new architectural ensemble with administrative and cultural buildings "on the territory bounded by the Lower Pond, the Pregolya embankment, and the ruins of the former Royal Castle." This area became the Central Square, where the construction of the House of Soviets began in the 1970s [27].
A key event that marked the final abandonment of the idea of restoring the historical center was the demolition of the ruins of the Royal Castle in the late 1960s. Although during the Thaw the demolition of the castle was suspended thanks to public resistance, in the era of "stagnation" the opinion of the townspeople was ignored. As the press wrote: "Military equipment arrived at the cordoned-off site. And the castle collapsed, crushing the paper resolutions for its salvation" [28].
This act triggered a lively discussion in the local press. A series of publications titled "Battle After Victory" criticized the actions of the authorities, who, according to the authors, continued the "combat actions" against cultural monuments even after the war had ended. The loss of "the most famous" building of Königsberg was perceived as the symbolic erasure of the German layer of memory from the space of the new Soviet city [28].

Figure 4. Ruins of the Royal Castle, photo 1951. Source: Kropotkin Andrei, n.d.

Thus, the Soviet approach to transforming the center of Kaliningrad combined an architectural taboo on the past with a functional redefinition of space. Instead of restoring the historical center, a "renewal from scratch" was carried out, in which the House of Soviets replaced the Royal Castle, standing on its ruins and becoming the architectural dominant, symbolizing the new identity of the city.

The House of Soviets in Kaliningrad is a striking example of an architectural object that did not receive protected heritage status, yet possessed important symbolic and cultural significance. Its construction began in 1970 under the direction of architect Yulian Shvartsbreim [29], at the site of the Royal Castle demolished in the late 1960s. The building was intended to become the new Soviet dominant of the city center. Despite the ambitious project, the building was never completed and remained unfinished for decades [28].**The House of Soviets was a 21-story building project that served as an architectural landmark against the backdrop of predominantly mid-rise development.**

The House of Soviets became the subject of public debate, especially in the 1990s and 2000s. It was called "a monument to architectural failure"; a German journalist described it as "funny" and at the same time "a gloomy, grey double bunker," adding, "If the sky had eyes, nothing but tears would fall from them at the sight of all this." Despite the negative criticism, it became a recognizable symbol of Kaliningrad.

Figure 5. Construction of the House of Soviets on the Central Square of Kaliningrad, 1980.
Source: Novy Kaliningrad, 2024

The building became notable not only for local residents and citizens of Russia, but also for the international audience, thanks to the publication of French photographer Frédéric Chaubin in his photo collection "Cosmic Communist Constructions." Various competitions were held to rethink the building, such as "Heart of the City," but in the end, attempts to reconstruct or adapt the building for new functions (hotel, university, cultural center) were not realized. In 2023, the building was finally demolished, which caused a wave of discussion in professional circles and the media [28,29,,30,31].
From the heritage perspective, the House of Soviets represents an "unidentified" object with socio-cultural significance that was never included in the unified register of cultural heritage sites [32]. Its fate demonstrates how the absence of official status and a timely decision for reinterpretation can lead to the loss of an important element of urban identity. This case underlines the need to develop tools for documenting and rethinking objects whose value is determined not so much by historical age or style, but by their meaning for the community.
Digital technologies, and augmented reality in particular, offer the possibility to return to such places in a new format—not as lost architecture, but as virtually revived memory.

Figure 6. The demolition process of the House of Soviets on the Central Square of Kaliningrad, which lasted from March 2023 to June 2024. Source: Novy Kaliningrad, 2024

Within the framework of this work, it is proposed to consider and test the functions of an AR application concept, which allows the user to interact with digital reconstructions of disappeared or unidentified objects of cultural value, as well as to consider the use of AR for digital reconstruction and museography, with the involvement of user communities and the possibility of attracting interest through gamification and user-generated content.
Moving on to the next stage, a number of questions arise: How can modern digital platforms contribute to the preservation of such objects? What approaches and tools are most effective for engaging users and recording "unidentified" heritage in the digital environment? These are precisely the issues that form the basis for further analysis—from the AR app concept to technical experiments with modern augmented reality technologies.

2.3 Use of AR.

The effectiveness of digital platforms in the field of cultural heritage directly depends on the level of user engagement. According to self-determination theory, the digital experience becomes especially meaningful when the interface satisfies basic psychological needs: autonomy, competence, and relatedness. This, in turn, enhances the user's intrinsic motivation and encourages repeat interaction with the platform: "Users are motivated by activities perceived as satisfying, interesting, or enjoyable. Therefore, the casual browsing of DCH websites highly depends on intrinsic motivation. Intrinsic motivation is promoted by the fulfillment of basic psychological needs: autonomy (sense of willingness or volition), competence (sense of capability and efficiency), and relatedness (sense of belonging). Interfaces designed to support these needs should yield a better experience" [33]. Another important factor is the sense of discovery and the ability to see something unexpected. Social engagement elements—such as the ability to create collections, receive likes, and share content—are somewhat controversial, but they do enhance the perceived value of interaction [33].
According to A Systematic Literature Review of Gamification in/for Cultural Heritage [34], based on a sample of 77 publications from 2017–2021, it is emphasized that successful gamification practices in the field of cultural heritage are primarily focused not on external rewards, but on intrinsic moti-

vation, creativity, and the emotional involvement of users. The study states that elements such as immersion, completeness, autonomy, social relatedness, and challenge are encountered much more often than purely external incentives (such as points or prizes). The study highlights the role of AR/VR: the publication reviews 12 AR and 10 VR applications. As an example, it describes a quest-game concept in which an interactive tourist route in Malta combines geolocation, augmented reality, and game mechanics to make the study of cultural heritage more engaging, especially for younger audiences [35].

Particular attention is paid to the following categories of gamification [34-32]:

- **Completeness and Mastery:** mechanics that give users a sense of progress through task completion and achievements;

- **Autonomy and Creativity:** the opportunity to freely choose actions and express oneself within the platform;

- **Immersion:** the use of narrative, visual environments, and atmosphere to enhance engagement;

- **Ownership and Rewards:** increasing user motivation through real and virtual rewards;

- **Feedback:** informing users about their progress and about new available tasks.

2.4 Concept and research approach(method).

Using augmented reality, principles of psychological engagement, and user interaction, the question arises:

- **How can the House of Soviets be preserved in digital format, and how can this experience be used as an approach for working with other unidentified heritage objects?**
- **What could a potential application look like, and where should the process start?**

To begin with, it is important to understand how potential interaction can be implemented and to define the approach I will be using. The goal of this case study is to create a concept of AR preservation with a direct demonstration of how AR works — in other words, to build a prototype. I will explore the problems that arise during the development process and how they can be addressed.
In this approach, I do not start from general theory and move to practice, but rather the other way around — from hands-on development, as the main objective is to create a functional prototype. The creation of this prototype depends on the context — in this case, the urban environment — and on the tools and engine I can use to produce a working model.

In this case study, I will primarily refer to devices and software I personally tested, explaining why certain tools did or did not work in the process of reaching a final, functional result. I aim to investigate practical problems at different stages of application development and to reflect on their theoretical solutions, drawing on relevant articles and research — but most importantly, I will describe the approach that I can implement myself to achieve a stable and functional result.
This case study documents the steps I followed to create a potential mass-market AR application. The general structure of my approach is twofold:

- **a reference project:** the application I chose as the conceptual foundation;

- **path of potential realization:** how to implement it in th real life?

Why do I say **potential?** Because some steps were only described, not implemented — but they do not affect the final demonstration of AR content.
As a reference for the concept of interaction with heritage objects, it is helpful to look at the treasure hunt game Pokémon GO. Developed by Niantic and released in 2016, Pokémon GO is a mobile AR application where players move around a digital map and catch fictional creatures — Pokémon. These Pokémon vary in rarity and appearance, each with distinct characteristics.
For example, a player might open the app at Turin's central train station and see on the map that a rare Pokémon — one not yet in their collection — is located one kilometer away. Will they be able to catch it? Upon arriving at the location, the user sees the Pokémon through the phone's camera in AR mode and follows on-screen instructions to catch it [36,37].

Two simple but powerful principles follow from this example:

- **Digital maps**

- **AR objects tied to specific locations**

In other words, it is necessary to use digital GIS data for navigation, determining with its help the exact place where the required object is located. Another important aspect is the possibility for users to add objects themselves—as implemented in Scan the World and Global Digital Heritage. Based on the model of open digital heritage by Google and Digital Heritage, as well as on geolocational AR as realized in Pokémon GO, **three key steps can be distinguished for testing and potential implementation: upload, placing, use** [2,3,36,37].

Figure 7. The process of playing Pokémon GO, left to right: 1. a global map with points of interest; 2. upon approaching, you can see that there is a Pokémon to catch at the location; 3. with the camera and AR mode enabled, the Pokémon appears in the real world. Source: ResearchGate, 2017]

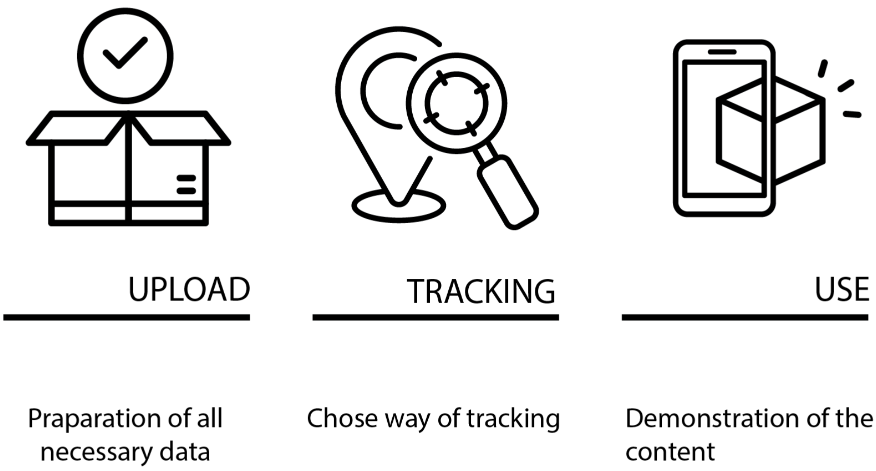

Figure 8. Three key steps can be distinguished for testing and potential implementation: upload, placing, use. Source: Ivan Karnitckii 2025.

2.5 Platform.

Another key aspect in this experiment is the choice of platform with which the AR functions will be tested. For this, it is necessary to analyze which engines and AR technologies are available, as augmented reality is created through a combination of hardware sensors and software tools known as SDKs (Software Development Kits). These SDKs provide environment tracking, placement of virtual content, and 3D graphics visualization.
Depending on the platform and use-case scenario, developers can use native SDKs, such as ARKit (for iOS), ARCore (for Android), or cross-platform solutions like Vuforia, Wikitude [38-41]. For browser-based AR (WebAR), frameworks like ZapWorks, 8thWall, MindAR.js, AR.js are used, which work via WebGL and JavaScript [42-46].
For visualization and interaction with content, real-time 3D engines are used, such as Unreal Engine, Unity, and web tools like A-Frame. These engines support shaders, animation, physics, and scene management, often supplemented with AR plugins or modules [47-49].

The main platforms include:

- **ARKit** — Apple Inc.'s SDK for iOS, designed for creating AR applications. Supports motion tracking, plane detection, facial and object recognition, as well as LiDAR scanning on newer devices [38].

- **ARCore** — Google's SDK for Android, providing similar features to ARKit: visual tracking, plane detection, depth understanding, and camera integration [39].

- **OpenXR** — an open API standard by Khronos Group that provides unified access to XR devices. Used for creating cross-platform virtual and augmented reality applications [50].

- **WebXR** — an API for running AR/VR applications directly in the browser, developed by W3C and partners (Mozilla, Google, etc.). Supports scene rendering, camera access, and device sensors. Used for simple, accessible AR experiences [51].

After initially considering platforms that offer browser-based solutions (such as 8thWall and ZapWorks), the decision was made to focus on mobile AR, since browser-based augmented reality (WebAR), although convenient for users (no app installation required), has a number of technical limitations compared to mobile AR. These limitations mainly relate to performance, tracking quality, and access to device hardware. Unlike mobile AR based on ARKit and ARCore, WebAR does not have full access to features like LiDAR scanning (Light Detection and Ranging), high-precision spatial anchoring, depth tracking, or stable SLAM (Simultaneous Localization and Mapping). Moreover, WebAR runs in the browser, which restricts the use of graphic shaders, complex animations, and heavy 3D models. This makes WebAR better suited for simple, quick-to-launch experiences (such as AR marketing or interactive print), while mobile AR is used in more resource-intensive and technologically rich projects [38,39,42,43].

To find a suitable tool, cross-platform solutions that work with both Android and iOS were considered. The main criteria for selection were accessibility, free or low cost, visual quality, and ease of use (simple programming). I examined Unity + AR Foundation, Unreal Engine, Meta Spark Studio SDK (Spark AR), and Lens Studio SDK (Snap AR). This analysis is based on my empirical experience with these programs and an analysis of their documentation [47,49,52-54].

1. Unity + AR Foundation
A cross-platform game engine, widely used for AR application development. AR Foundation is Unity's official framework, enabling the creation of ARKit (iOS) and ARCore (Android) apps via a unified API. Supports surface tracking, image and face tracking, and allows rapid creation of interactive AR scenes for mobile devices [48,52].

2. Unreal Engine
A professional game engine from Epic Games, known for photorealistic graphics and powerful 3D content tools. Supports AR app creation via plugins for ARKit, ARCore, and other platforms. Used for more complex, visually rich AR projects [47].

3. Meta Spark Studio SDK (Spark AR)
A tool and SDK for creating AR effects and masks for Instagram and Facebook. Allows creation of interactive masks, filters, and visual effects without deep programming knowledge, suitable for creative projects, and easily published on Meta platforms [53].

4. Lens Studio SDK (Snap AR)
The official platform from Snap Inc. for creating AR lenses and filters for Snapchat. Offers ready-made templates and tools for face, hand, and object recognition, as well as the creation of interactive and animated effects. Designed for fast creation and publication of AR content for a wide audience [54].

Out of all the cross-platform solutions considered, I chose Snap AR because it offers the most convenient and fastest process for developing and testing AR scenes, fully demonstrating the capabilities of augmented reality. Using the Lens Studio editor, you can instantly launch prototypes and test them in the Snapchat mobile app, which significantly speeds up iterations during the design process and is a clear advantage over Unreal Engine and Unity. Snap AR and Spark AR are analogous solutions, but as of January 14, 2025, Spark is no longer supported by Meta [47,48,52-54].
Moreover, Snap AR is highly optimized for mobile devices: lenses can be viewed starting from Android Galaxy S6 and iPhone 6, which were released in 2014–2015, meaning even a decade after their release [55,56-53,54]. Lenses load quickly, work efficiently on a wide range of smartphones, and support such features as face, body, hand, and plane tracking. Optimization was a decisive factor, since Snap AR developers set engine constraints directly in their guidelines [57], allowing you to focus on testing—in contrast to Unreal and Unity, where optimization is a resource-intensive process. Even though Snap AR is primarily integrated into the Snapchat ecosystem, its architecture allows you to achieve quality results without the need for complex software builds or deep coding expertise. Snap AR uses a visual programming language and JavaScript, and also provides an API, which makes it possible to integrate it into third-party mobile applications [47,48,52-54].
Having worked with all four environments, I can make a subjective conclusion: for VR and AR development, Unity is best suited, as it offers the most flexible interactions and optimization opportunities for

a potential application. However, to create an app you need to know C#, while Unreal's visual scripting is quite flexible but still doesn't provide such deep interaction without direct programming in C++. Thus, Snap AR was chosen as a platform providing a balance between accessibility, visual quality, and development speed, especially at the early stages of designing a user AR experience.

	Unity + AR Foundation	Unreal Engine	Spark AR	Snap AR
CASUALITY	++ Need C# undersanding	+++ Visual programming-Blueprint; C++	++++ Convenient 3D - ar editor, visual programming, JavaScript	++++ Convenient 3D - ar editor, visual programming, JavaScript,good optimisation
FIEXIBILITY	++++ Final product requires good optimisation	++++ Final product requires good optimisation	++ limited by the concept of use - Instagram, Facebook Doesn't support by Meta anymore	+++ limited by the concept of use - Snap Chat, have API
VISUAL	+++	++++	++	+++ Good shaders out of the box

Figure 9. Comparison of engines by parameters: casuality, flexibility, visual. Source: Ivan Karnitckii 2025.

Before starting testing, it is also important to specify which devices I use:

- **Smartphone:** Redmi Note 12 Pro

- **Laptop:** Lenovo Legion 5 16ARX8

Thus, the choice of platform and technical solutions was determined not only by functionality but also by actual limitations regarding accessibility, optimization, and development speed, which is especially important at the prototyping stage of user experience in the field of digital heritage.
Next, in practice, it is important to consider how the 3D model of the object is prepared, optimized, and integrated into the augmented reality environment using the chosen toolset. The next stage is a description of the steps for creating the AR scene and initial tests, as well as analysis of the problems that arise and finding possible solutions based on real experience working with the House of Soviets model.

2.6 Upload and optimization - Step 1.

The first step is obtaining the model. In this case, the approach to acquiring the 3D model is the same as in Scan the World and GDH—photogrammetry [2,3]. Within the concept of accessible and free user collaboration, you can use free photogrammetric services such as Meshroom, CoolMap, or conditionally free/paid services like Agisoft Metashape, Reality Capture [58-61]. For this project, I used a model of the House of Soviets downloaded from Sketchfab, authored by Mikhail Volkov [62].
The original model has quite high visual and volumetric quality and a fairly dense geometry mesh—200,000 polygons. According to the Lens Studio guidelines, the number of polygons in a published lens should not exceed 100,000, and the lens size should not be more than 8.5 MB. That's the final file size that must be aimed for, otherwise the AR demonstration just won't work [57].

Figure 10. The original model of the House of Soviets with 200,000 polygons. Area 1 and Area 2 show mesh density and texture quality. Source: Ivan Karnitckii 2025.

Despite its high level of detail, it cannot be said that the quality of the obtained scan fully corresponds to architectural scale. It's a good model for demonstrating the overall appearance, volume, and structure of the building. However, for a 1:1 scale, the model of the House of Soviets doesn't offer the highest quality in terms of textures and small-scale geometry — such as facade articulation and wall thickness. The space between the two towers also lacks geometric accuracy.

The model does not meet the RMSE (root mean square error) geomatic standards used in the Geomatics Lab for Cultural Heritage, where I'm doing my thesis, and where 3D scans and photogrammetry are actively used and produced for building analysis. For example, the error for detailed survey is around 1–2 cm, or the image resolution is expected to be close to 1–2 mm. The 3D model of the House of Soviets is limited in its level of detail. This is primarily due to the scale and dimensions of the building itself: since the structure is massive, the photographs had to be taken from relatively distant positions. As a result, the images used for photogrammetry were of a small scale, which directly affected the accuracy of the reconstruction. Consequently, the model cannot reproduce fine architectural details with high precision. This makes the model unsuitable for precise analysis, but it still communicates its visual qualities and general dimensions — which makes it suitable for AR demonstrations and interactions [63].

It should also be noted that, since I did not create this model myself, I don't place much focus on photogrammetry as the process of obtaining the model. Nevertheless, for the purposes of AR demonstration, this model serves as an excellent base that can be optimized and used to build additional models on top of it.

With the 3D modeling software Blender [64], the mesh can be optimized using the Decimate tool. Decimate is a relatively quick way to reduce the polygon count but not the best quality-wise: when reducing the number of polygons, the UV map of the texture can start to distort. Nevertheless, in my case, after applying Decimate, the number of polygons was reduced from 200,000 to 89,000 without significant loss of quality. In the Figure 11, you can see how the mesh changed and that in some places the textures became slightly distorted.

Figure 11. The House of Soviets model with 89,000 polygons after applying Decimate. Area 1 and Area 2—mesh density and texture quality. Source: Ivan Karnitckii 2025.
.

more accurate results, it is better to use texture reprojection in the environment where the scan was obtained, for example, in Agisoft Metashape. This approach allows you to project the texture onto geometry: you can create a high-poly model, then use Blender or Instant Meshes to reduce the polygon count, turning the model into a low-poly mesh, and project the texture onto the new low-poly mesh [60,64,65]. This is analogous to LOD (level of detail) in games, where the polygon count depends on the distance between the user and the model [66]. An example is models from the Megascans 3D scan library [67]: in Figure 12, you see two stones—on the left, a high poly with 1,000,000 polygons; on the right, LOD 1 with 7,000 polygons. Megascans models do not have baked shadows, so to see the difference between the models, I set up lighting: in the first, the geometry is more detailed, even though the textures are the same. If you add a normal map to LOD 1, the visual difference almost disappears, while the model size and performance impact are dramatically different [68].
a potential application. However, to create an app you need to know C#, while Unreal's visual scripting is quite flexible but still doesn't provide such deep interaction without direct programming in C++.

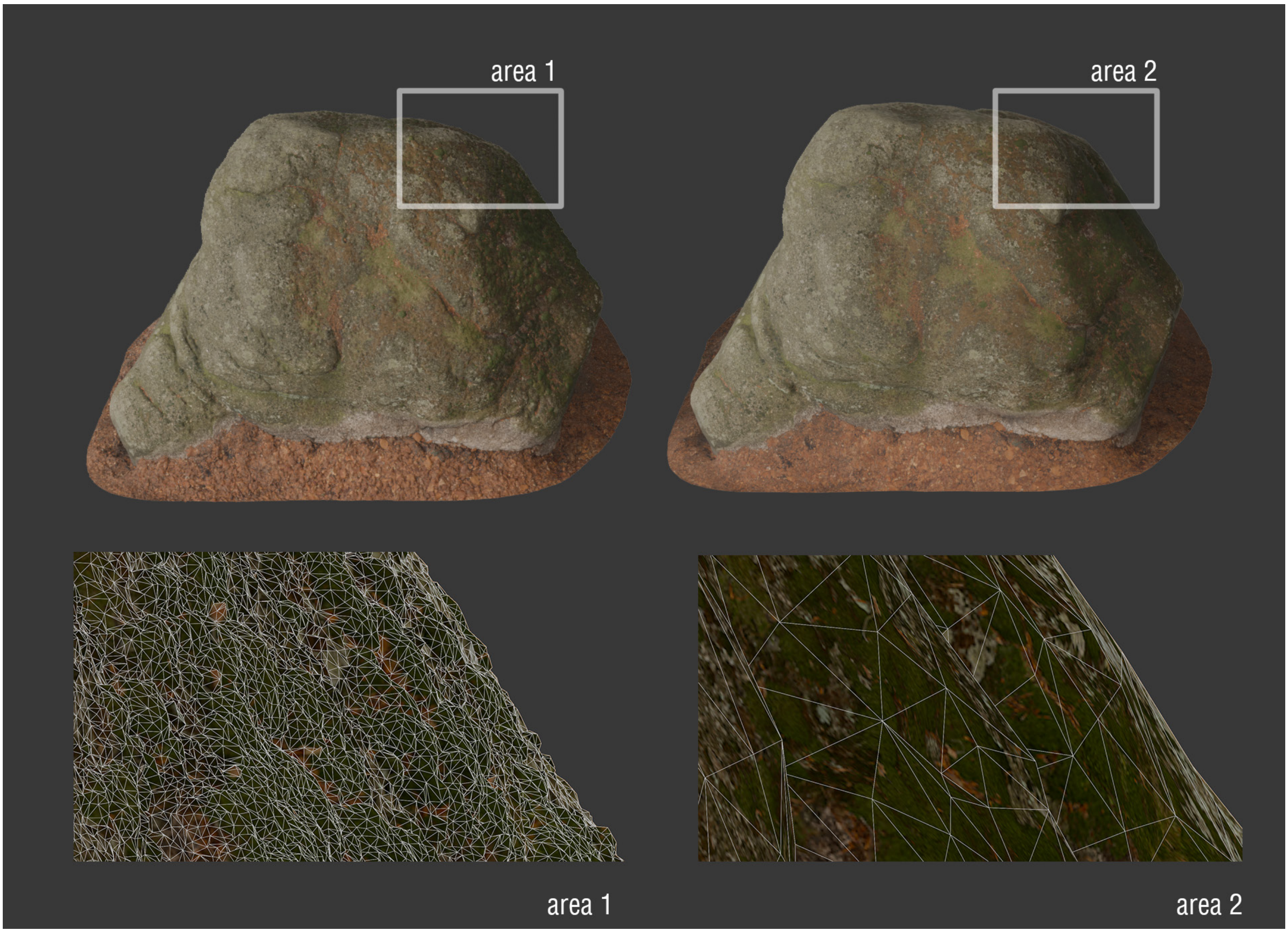

Figure 12. Model from Megascans: left—high poly (1,000,000), right—LOD 1 (7,000). Source: Ivan Karnitckii 2025.

Based on work with the House of Soviets photogrammetric model, the following conclusions can be drawn:

-The quality of the scan directly affects the geometry quality and how closely the final model matches the original: in some places, the geometry is not orthogonal and looks more like a cloud than orthogonal objects.

-The textures obtained for the House of Soviets contain shadows that are not always possible to remove: for example, Agisoft Metashape offers Texture De-Lighter [66], but in this case, the tool did not produce the desired result (it was not possible to achieve the quality found in Megascans) [67].

Based on the photogrammetric model, I also made a new model in Blender, recreating the shell of the House of Soviets [64]. This model has a regular mesh with 80,000 polygons; windows and columns details are worked out, the walls and facade have thickness (if you remove it, the polygon count can be further reduced - around 40 000 polygons).This replica model was created to allow for testing, manipulation of the House of Soviets, and creative exploration. It is difficult to work with and edit a model that lacks clear structure and UV mapping, and an important issue was that it was not possible to remove the shadows from the facade.The key difference between this and the photogrammetric model

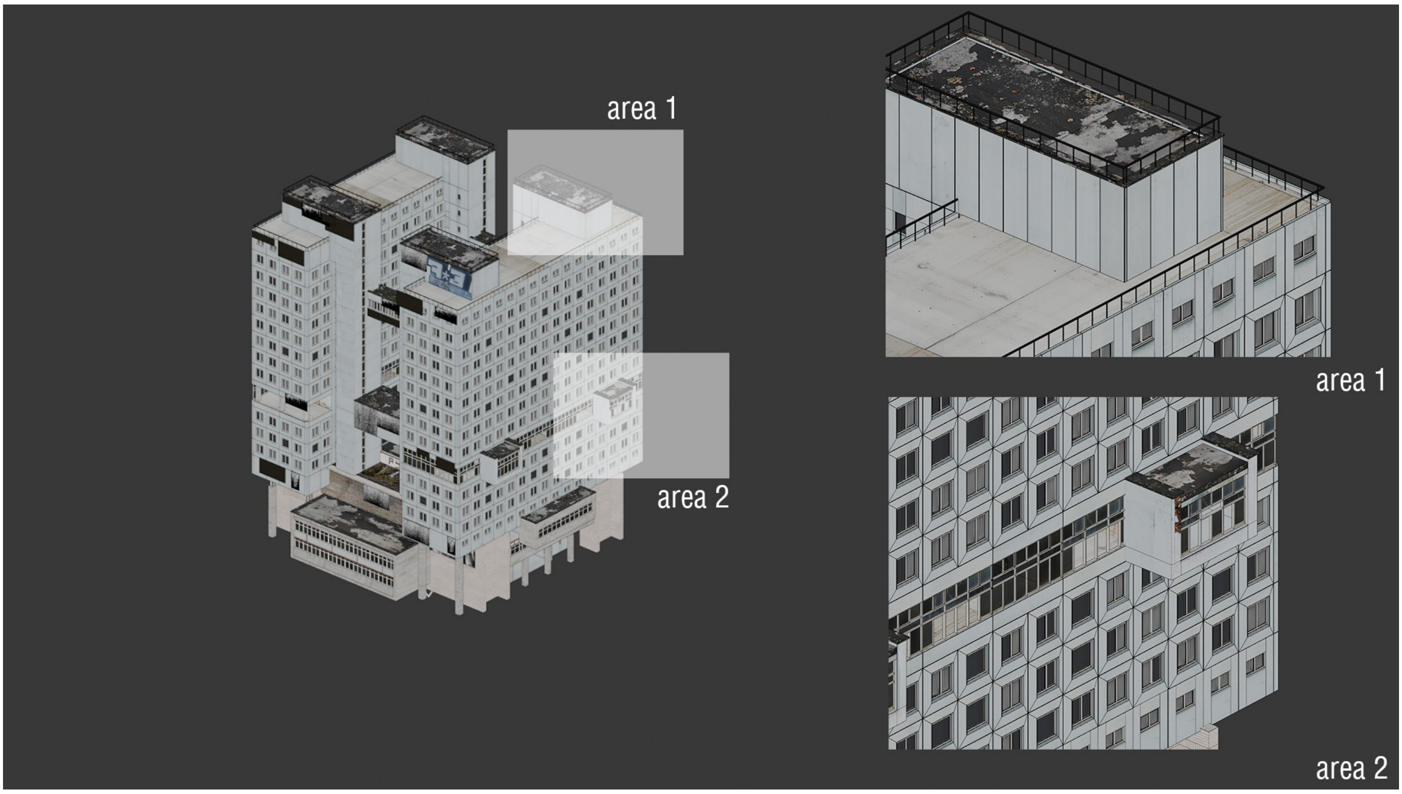

Figure 13. The House of Soviets model with 80,000 polygons, created based on photogrammetry. Area 1 and Area 2—mesh density and texture quality. Source: Ivan Karnitckii 2025.

For transfer from Blender to Lens Studio, the file was saved in .fbx format and added to the Lens Studio asset browser by dragging it from the working folder. The model has 6 UVs for textures; for each

UV map, a basic Unlit material was created that displays only the texture in flat mode—that is, the model will not have additional shadows and reflections, as, for example, with physically based materials (PBR). To add the model to the scene, you need to drag it from the asset browser to the scene hierarchy [54,64,71].
At this stage, it is worth noting that lighting and shaders are one of the main challenges of augmented reality. The article "Challenges of Visually Realistic Augmented Reality"[72] points out that it is difficult to achieve realistic rendering of shadows, reflections, and global illumination. When using global illumination, it is impossible to accurately simulate shadows, color temperature, and reflections, especially with dynamic changes in lighting. Without data on surface properties, it is impossible to accurately reproduce visual effects related to materials [72]. That is why I try to avoid PBR shaders and use elements of visual stylization.

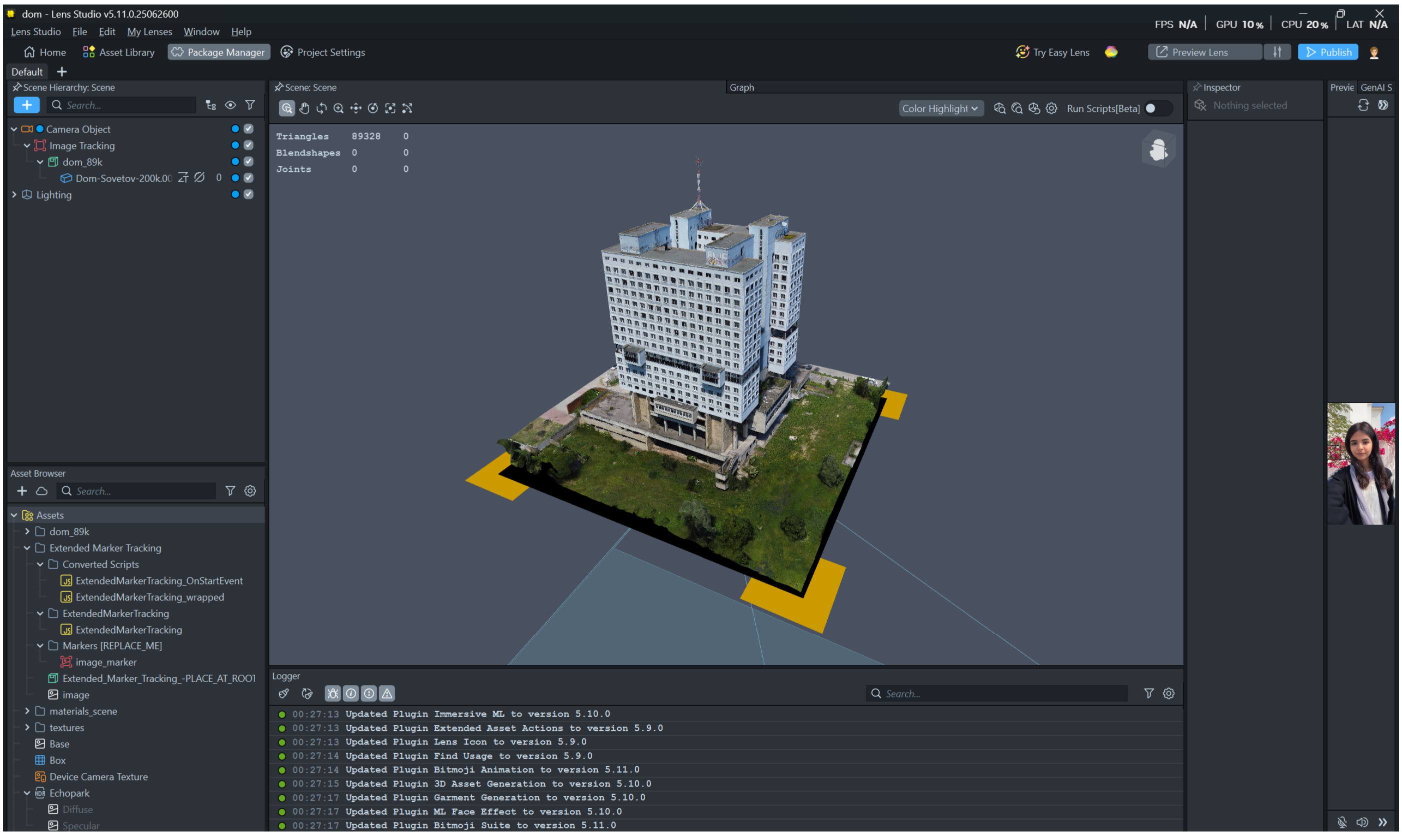

Figure 14. The House of Soviets model in Lens Studio. Top left—scene hierarchy, bottom left—asset browser. Source: Ivan Karnitckii 2025.

2.6.1 Tracking and initial tests - Step 2.

After transferring the model into the Lens Studio environment, the first thing to determine is what the model will be anchored to in the real world—in other words, which tracking method to use. Snap AR provides several types of tracking for creating augmented reality experiences [73]:

- **Face Tracking** — tracks the user's face, including expressions and movements.

- **Body Tracking** — detects body pose and movements.

- **Hand Tracking** — tracks hands and gestures.

- **Marker Tracking** — uses images or markers to anchor virtual content.

- **World Tracking** — determines the device's position in space for placing objects on surfaces.

- **Landmarks Tracking** — allows the use of objects as anchors for virtual content.

In the current context of the war between Russia and Ukraine, the issue of GPS usage has come to light. GPS is a system that can be jammed, and when that happens, the signal becomes unreliable, which makes it impossible to accurately position AR content. If GPS can be jammed in Russia, then why couldn't it be jammed anywhere else? Moreover, some countries have their own alternatives to the GPS navigation system — such as GLONASS (Russia), Galileo (Europe), and BeiDou (China) [74,75].

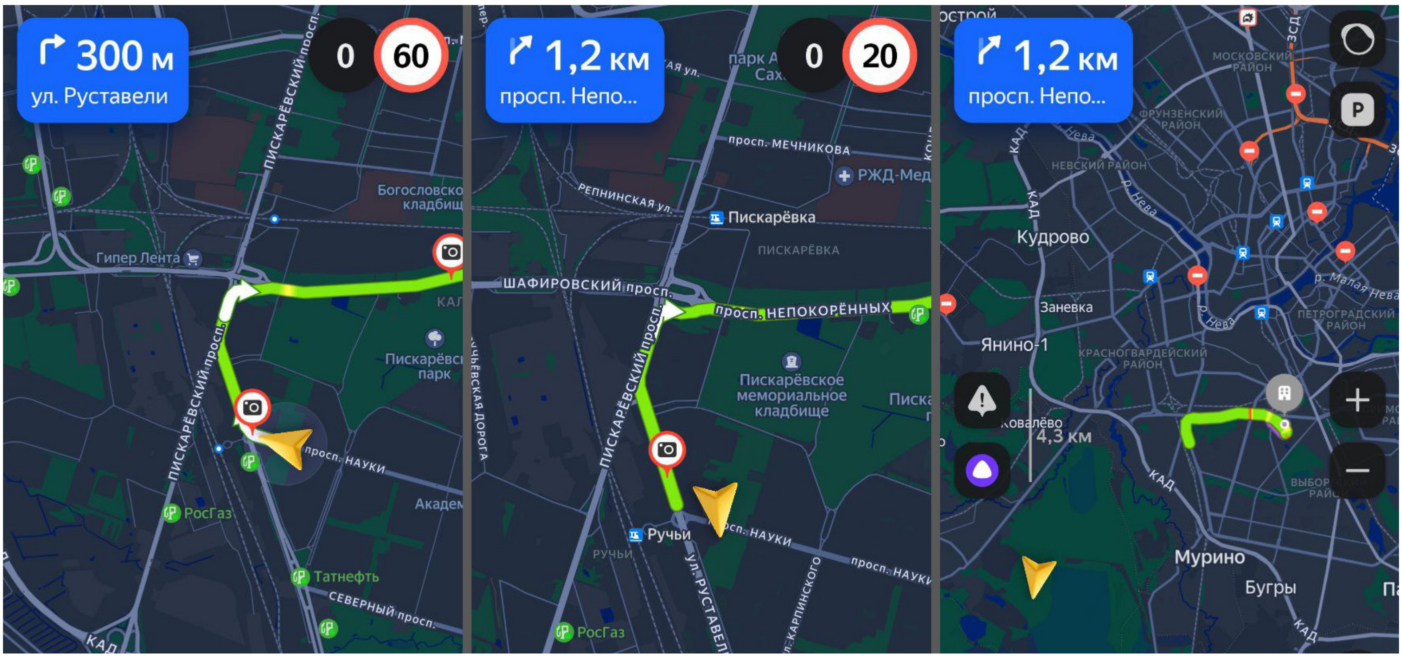

Figure 15. Navigation in map applications in real time becomes inaccurate, as the actual location is incorrectly determined. Source: Ivan Karnitckii based on Yandex Maps application,2025

However, Snap AR does not support full geo-tracking (GPS) for anchoring content to geographic coordinates. For such features, other platforms or SDKs are required, for example, ARKit with ARGeoAnchor or ARCore Geospatial API [76,77]. At present, GPS tracking also faces issues with positional accuracy: you can place an object on a map, but in real life it will be offset by 5–6 meters [78], which for a building the size of the House of Soviets is not critical, but at a smaller scale can seriously disrupt the immersive experience. Another problem for geo-tracking objects of this scale is occlusion: the object may be overlapped by the surrounding environment and display incorrectly.

Conclusion:

In this case study, I used basic Marker Tracking, which allows you to anchor the object to a marker and works on a wide range of mobile devices. To anchor the model to a marker in Lens Studio, the following steps should be performed (see Figure 16):

- Create an Image Tracking object in the scene hierarchy and attach it as a child to the camera object.

- Move the model as a child to the image tracker in the scene hierarchy.

- Place the model above the marker in the viewport and scale it.

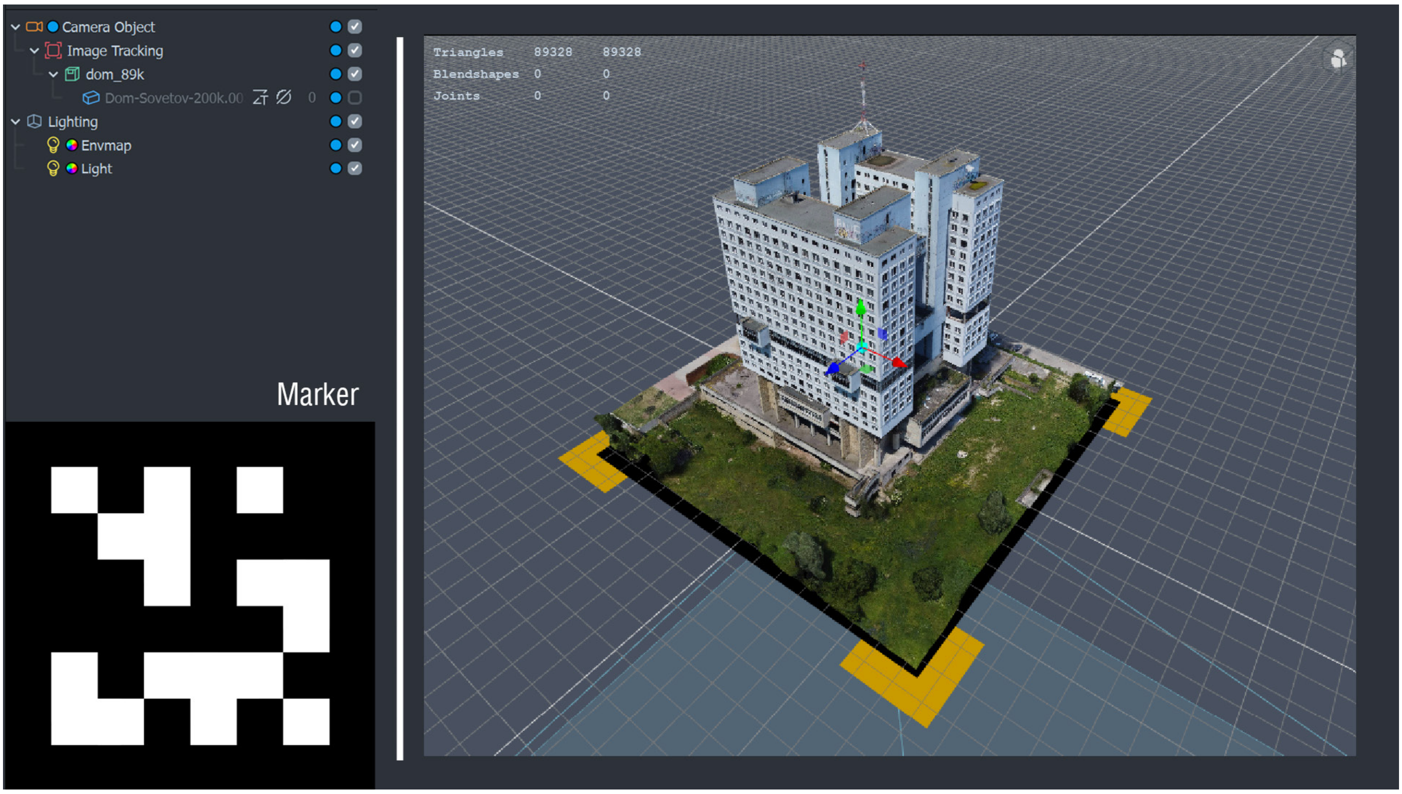

Figure 16. The House of Soviets model in Lens Studio, attached to a marker. Bottom left—the marker texture used for anchoring. Source: Ivan Karnitckii 2025.

Using the pairing function—send to all devices—you can run the first marker test. You can see how the 3D model is anchored to the marker, but several problems arise during interaction:

- The object shakes relative to the marker. The marker is sufficiently high-contrast, but probably due to the high frequency of position updates, the phone checks the tracker's position every n frames.

- Occlusion occurs when a hand is placed in front of the camera—as shown in Figure 17.

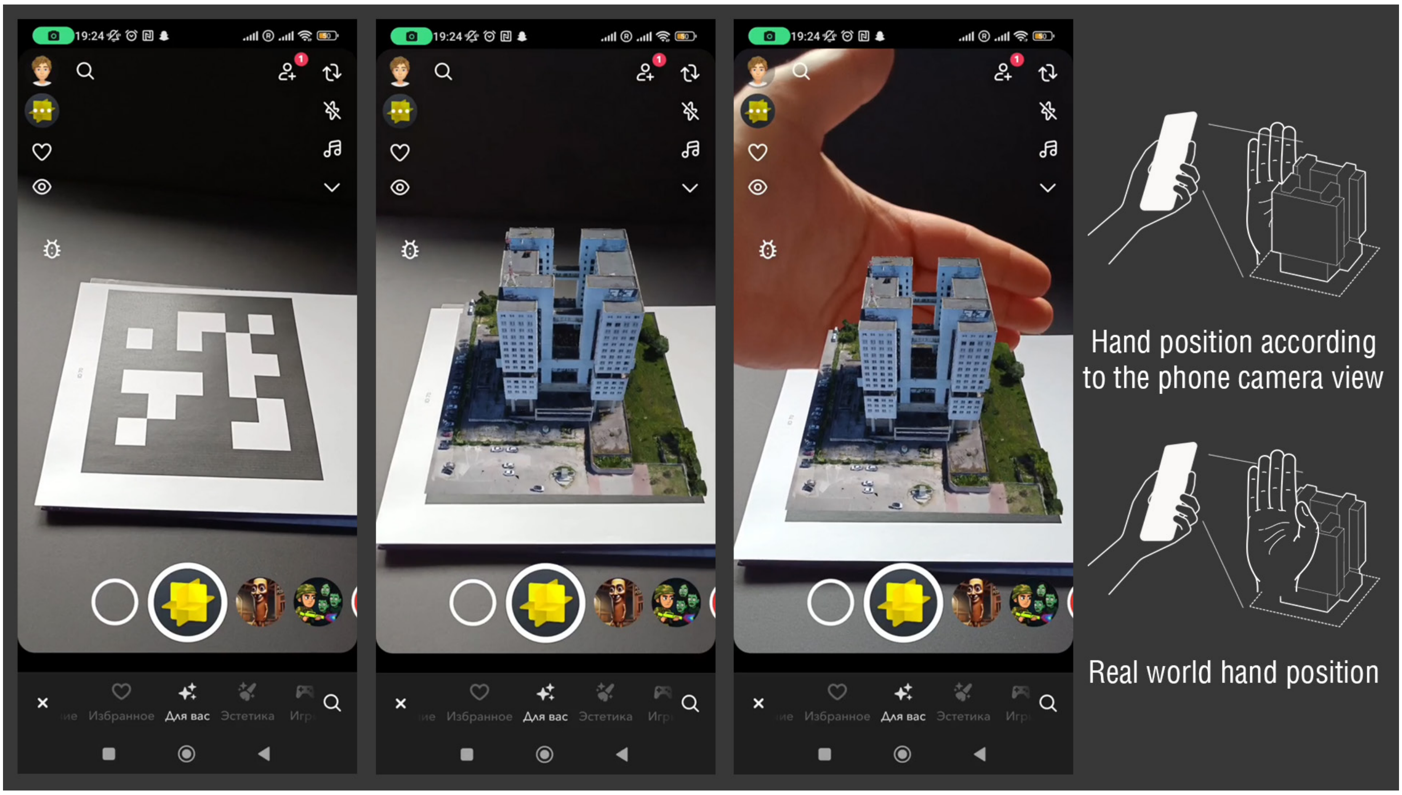

Figure 17. AR test: placement of the House of Soviets on a marker. Left to right: 1. scanning the marker; 2. placing the model on the marker; 3. occlusion occurs when the hand is in front of the camera; 4. the actual position of the hand during occlusion. Source: Ivan Karnitckii 2025.

It is worth examining occlusion in more detail.

Occlusion is a phenomenon in which one object partially or completely covers another in the field of view. In AR, this means that virtual objects should be positioned correctly relative to real objects, so as to create a sense of coexistence in the same space:
"When building AR scenes, the purpose of occlusion is to maintain the laws of the line of sight. That is, any virtual item that is placed behind a real object should be occluded or hidden behind the actual object to provide the viewer with a realistic experience and improve the viewer's depth perception" [79].
Occlusion arises when there is no accurate information about the depth of the scene. If the AR system does not understand where the real object is in relation to the virtual one, it will not be able to "place" the virtual object behind the real one [79,80].

One of the key factors affecting the accuracy of occlusion in AR scenes is the distance to the object and the context of its placement. Indoor environments are more favorable: limited distances, controlled lighting, and a minimal number of moving elements make it possible to use depth sensors—Time-Of-Flight (ToF) or LiDAR—with high reliability. Outdoor environments present additional challenges: strong sunlight, dynamic objects, and the need to visualize scenes at large distances. ToF and LiDAR have limited range—“Depth accuracy tends to degrade significantly with increasing distance from the sensor, especially in outdoor environments” [80]. These features must be taken into account when designing AR scenes aimed at accurate and realistic placement of objects in the urban environment.

According to the articles Occlusion Screening Using 3D City Models [79] and Innovative Approaches to Real-Time Occlusion Handling [80], potential methods for solving occlusion include:

- **Use of CityGML**—a structured model of the urban environment, which allows you to predefine which objects should be visible and which should be occluded. Combined with depth maps from the camera (LiDAR or ToF), this provides a more accurate spatial model, even when depth sensors perform unstably.

- **Semantic segmentation combined with SLAM (Simultaneous Localization and Mapping):** When a precise 3D map is not available, semantic image segmentation is used to determine which objects should occlude virtual elements (cars, buildings, trees). This is then combined with SLAM to understand the spatial position of the camera and objects in real time.

- **Temporal smoothing and adaptive occlusion modes:** Temporal smoothing stabilizes depth maps, helping to avoid flickering and sudden changes when occlusion occurs. Adaptive modes allow customization of which scene objects are used to create the depth map and calculate occlusion.

Despite the proposed theoretical methods for solving occlusion described in the articles, in practice they are not available to me when working with Lens AR. In this context, we’ll have to look for alternatives and workarounds.
In the context of the House of Soviets at real scale, occlusion problems will almost certainly arise due to rendering distance and the lack of ToF/LiDAR sensors on most devices. Nevertheless, the model can be used for demonstration at a reduced scale (for example, as a 1:100 model), or another display method can be attempted.

What actions can be taken to eliminate or mitigate problems after the first test?

2.6.2 Experimental approaches to solving tracking and occlusion problems.

To solve the identified problems, I decided to test several different approaches and tools. This made it possible not only to reveal the technical limitations of the platform but also to try different strategies for optimizing the user experience—from scripting to visual tricks with an AR portal. Below is a brief analysis of each method and their impact on the final result.

1. Scripting
The first option was to use a script that regulates how frequently the model's position is updated relative to the marker.

The parameters were used for the script manipulation:

- `smoothingFactor` (from 0.05 to 0.2) — how smooth object follows to the tracker

- `updateInterval` (2–4; the higher the value, the less frequently the position is updated) — how often the marker position is updated

The script smooths the following of the object after the tracker. Overall, this provided good results in reducing "shaking" but another problem appeared: when the tracker disappears from the phone's viewfinder, the model freezes for a while until the tracker appears again. The position stops updating, and the model "sticks" in an unnatural position—especially noticeable at the edges of the screen or in poor lighting conditions. I tried to solve this via scripting by hiding the model when the tracker disappears from the frame, but this didn't help. So, I decided to move on to the next option.

```
//@input SceneObject tracker
//@input SceneObject model
//@input float smoothingFactor = 0.1
//@input int updateInterval = 2

var lastPosition, lastRotation, initialized = false;
var frameCounter = 0;

script.createEvent("UpdateEvent").bind(function () {
    if (!script.tracker || !script.model) return;

    frameCounter++;
    if (frameCounter % script.updateInterval !== 0) return;

    var trackerTransform = script.tracker.getTransform();
    var modelTransform = script.model.getTransform();

    var currentPosition = trackerTransform.getWorldPosition();
    var currentRotation = trackerTransform.getWorldRotation();

    if (!initialized) {
        lastPosition = currentPosition;
        lastRotation = currentRotation;
        initialized = true;
    }

    lastPosition = vec3.lerp(lastPosition, currentPosition, script.smoothingFactor);
    modelTransform.setWorldPosition(lastPosition);

    lastRotation = quat.slerp(lastRotation, currentRotation, script.smoothingFactor);
    modelTransform.setWorldRotation(lastRotation);
});
```

Figure 18. Script regulating the model's behavior relative to the marker. Source: Ivan Karnitckii 2025.

2. Extended Marker Tracking (Decoupling the Model and Switching to World Tracking)
The second approach was to use the Extended Marker Tracking preset from the Lens Studio asset library. In theory, it allows you to position the object correctly upon the first marker capture and then leave it in world space without being anchored to the marker. This removes the need to keep the marker in the camera frame all the time.
However, on my phone, using this asset resulted in the camera losing focus—the marker was not always detected or was detected incorrectly. In the end, the model would anchor with a strong offset, or sometimes would not load at all (especially during tests with the House of Soviets model—I had to switch to a basic cube, and the phone could take up to a minute to recognize the marker). I was working with Lens Studio Version 5.8.1—I believe this is a bug, since the function doesn't work as claimed; perhaps it will be fixed in the future. Nonetheless, if the asset works reliably, it offers wide possibilities: you can anchor the object in space once and then no longer depend on the marker.

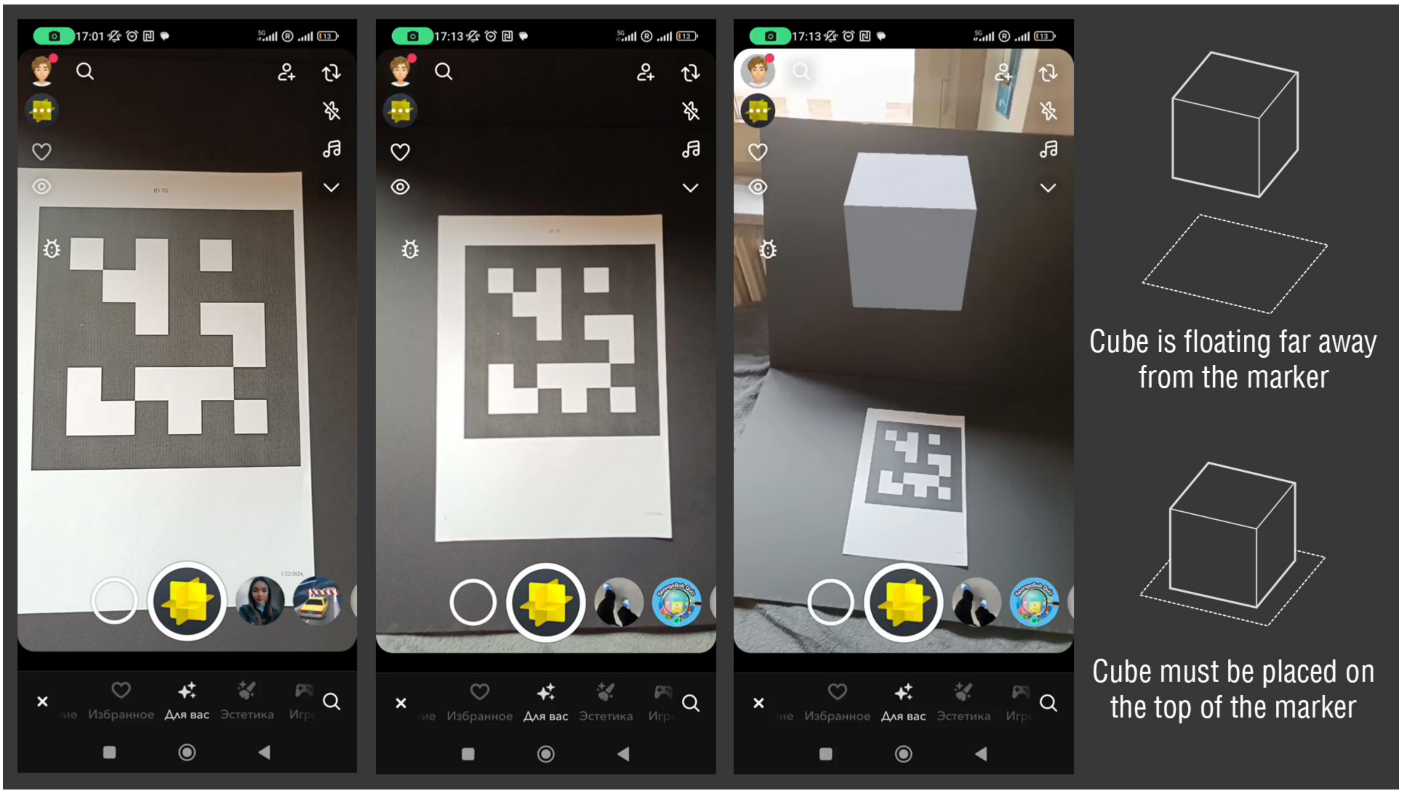

Figure 19. AR test — Extended Marker Tracking. Left to right: 1. scanning the marker without Extended Marker Tracking—the marker image is clear; 2. scanning with Extended Marker Tracking—the marker image is blurry, the camera does not focus; 3. the model appears not on the marker but in space; 4. explanation of where the model should have appeared and where it actually appeared. Source: Ivan Karnitckii 2025.

3. AR Portal (Visual Bypass for Occlusion and Jitter Problems)
After testing the first two methods, I decided to try a different approach—the AR portal. The idea: the user, using their phone, looks through a “window” (the marker) into a 3D scene. This method helps hide the effect of occlusion and model jitter relative to the tracker (which is almost unnoticeable to the user) and is also efficient in terms of performance. The concept is simple: a marker is placed, and after it’s detected, it becomes a “window” into the 3D scene. I assembled the scene based on the parallax principle [81]. All content is placed inside an occluder—a visual element used to mask protruding geometry [71].

To create this, I first prepared the scene in Blender: I took a Google Street View photo, used Krita to cut it into separate layers with alpha channels, and saved them as .png images [82]. After preparing the textures, the scene was built so that in the foreground there are images creating the environment, behind them is the model of the building and a sky texture.

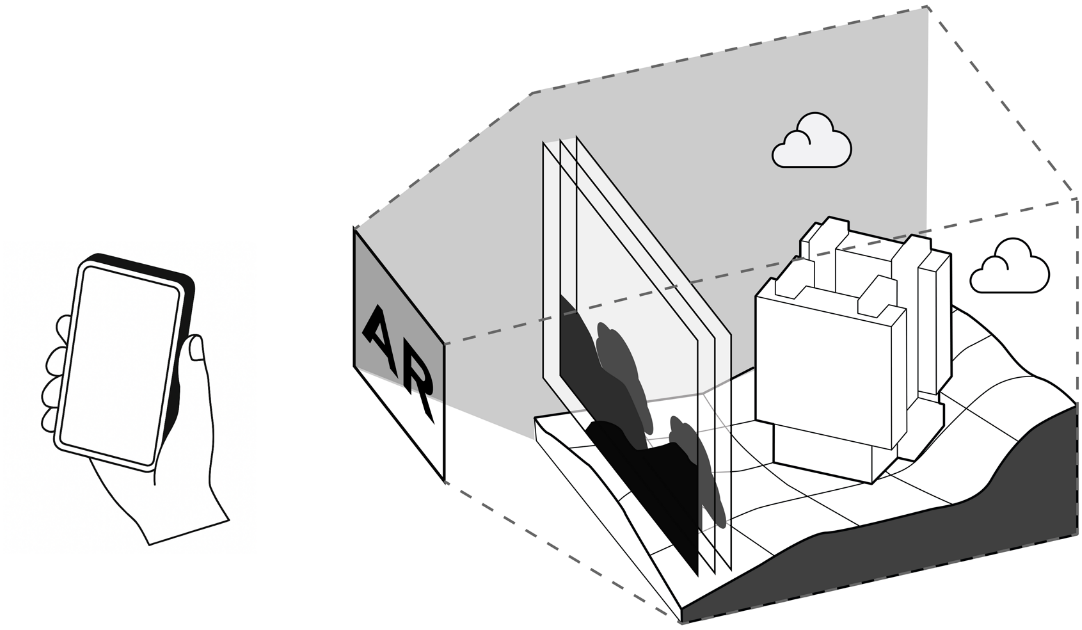

Figure 20. Illustration of the AR portal. Source: Ivan Karnitckii 2025.

2.6.3 AR portal in use.

To create AR portal, I prepared the scene in Blender: I took a Google Street View photo, used Krita to cut it into separate layers with alpha channels, and saved them as .png images [82]. After preparing the textures, the scene was built so that in the foreground there are images creating the environment, behind them is the model of the building and a sky texture.

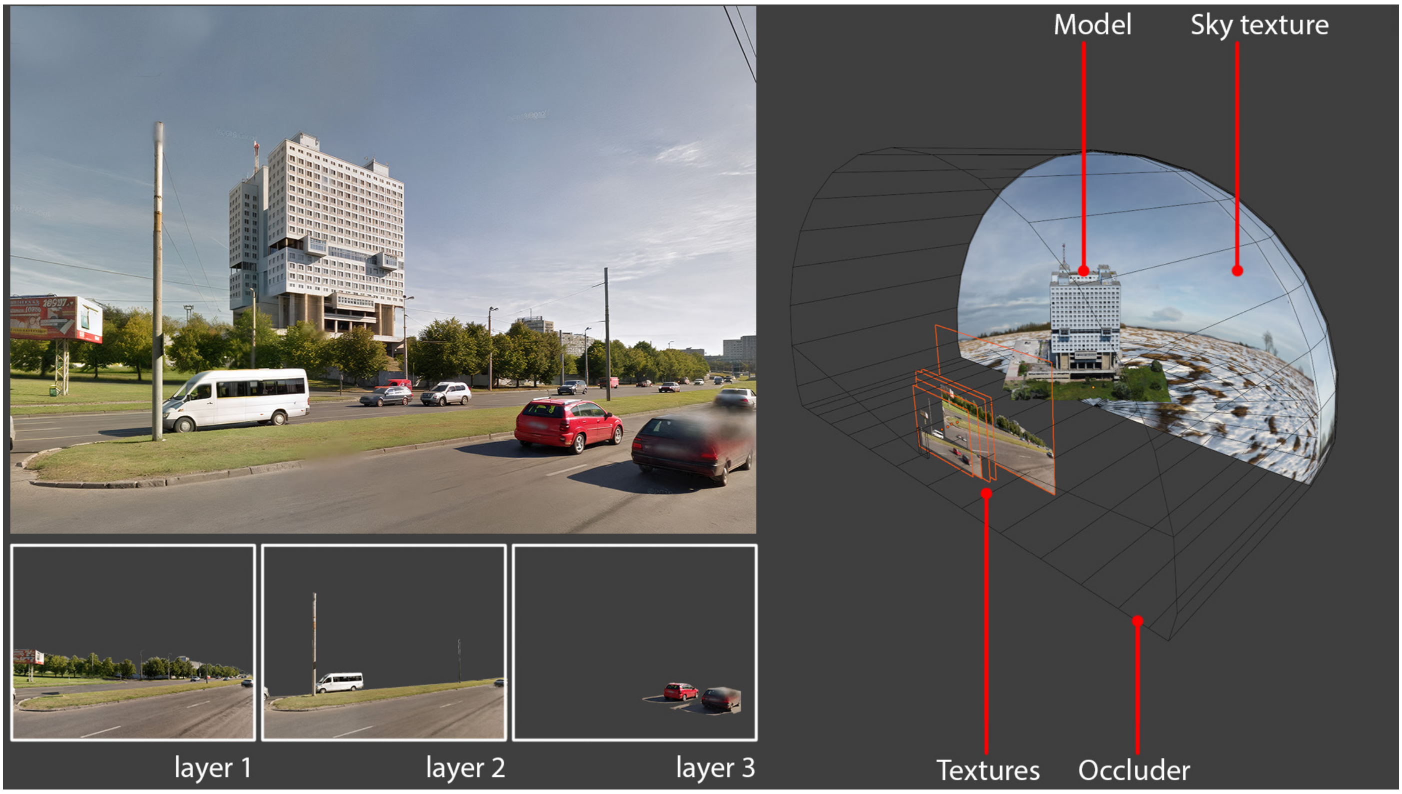

Figure 21. AR portal preparation. Left to right: 1. Google Street View image and its breakdown into layers; 2. Scene assembled in Blender. Source: Ivan Karnitckii 2025.

For export to Lens Studio, I used .fbx. Materials for the geometry and backgrounds were Unlit with alpha enabled, for the occluder—a material of the Occluder type, and the marker received the appropriate texture. The marker is placed behind the “window” in the occluder and scaled to fit the window size. Importantly, Lens Studio has no true 3D snapping, and scaling the marker is only possible by entering numerical values, which makes exact alignment difficult. During AR demonstration, this can create a gap between the marker image and the portal. Also, the marker must be square(see Figure 21).
After assigning materials, the scene can be published. You must check for compliance: the final lens size should not exceed 8 MB (mine was 19.05 MB). There are 14 materials in the scene, 12 of which have textures (the House of Soviets is 4096×4096 pixels). I reduced the texture resolution to 1024×1024, and the remaining images were decreased by 25% in Photoshop. The final lens size was 7.48 MB(see Figure 22).
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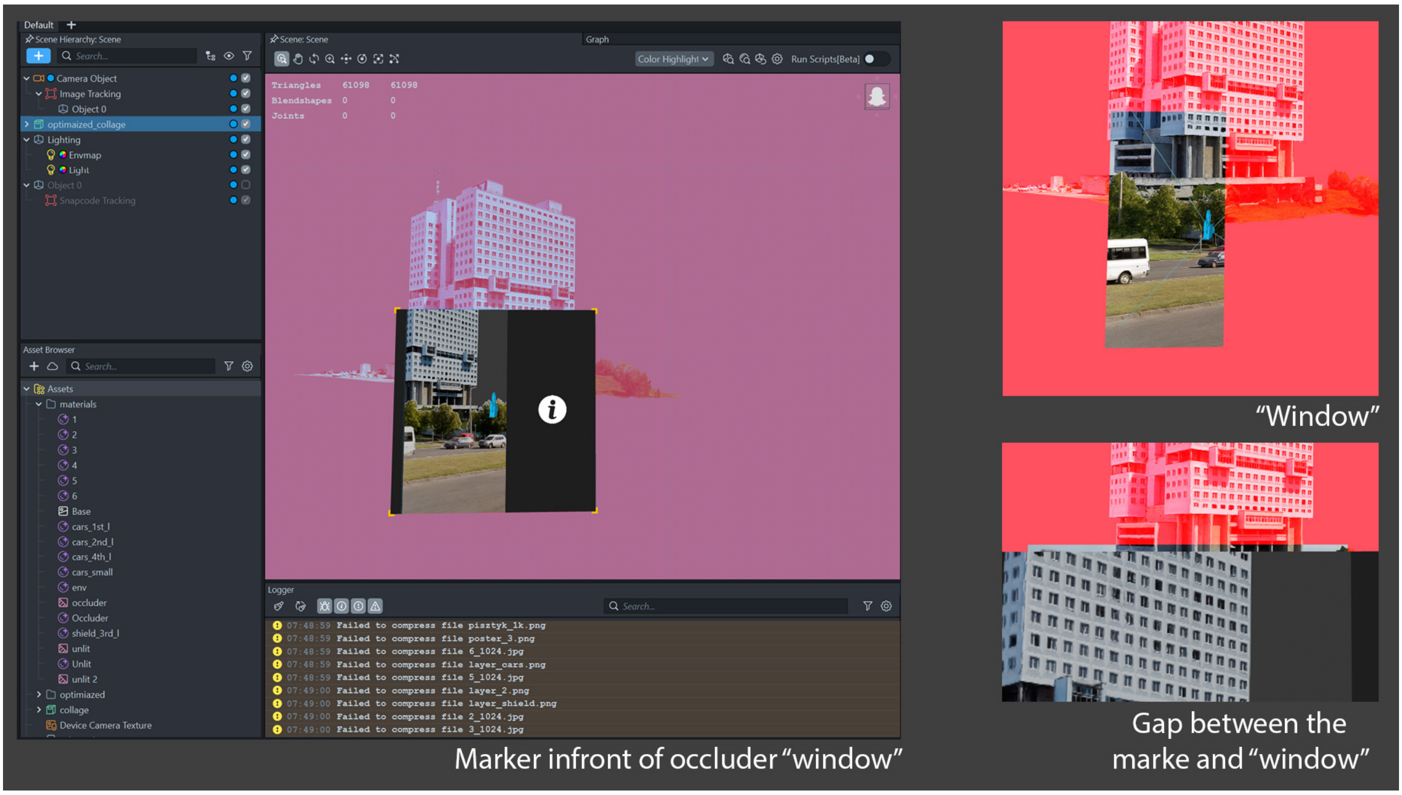

Figure 22. Importing the AR portal into Lens Studio. Left to right: 1. Marker in front of the occluder; 2. Window in the occluder; 3. Gap between the window and the marker. Source: Ivan Karnitckii 2025.

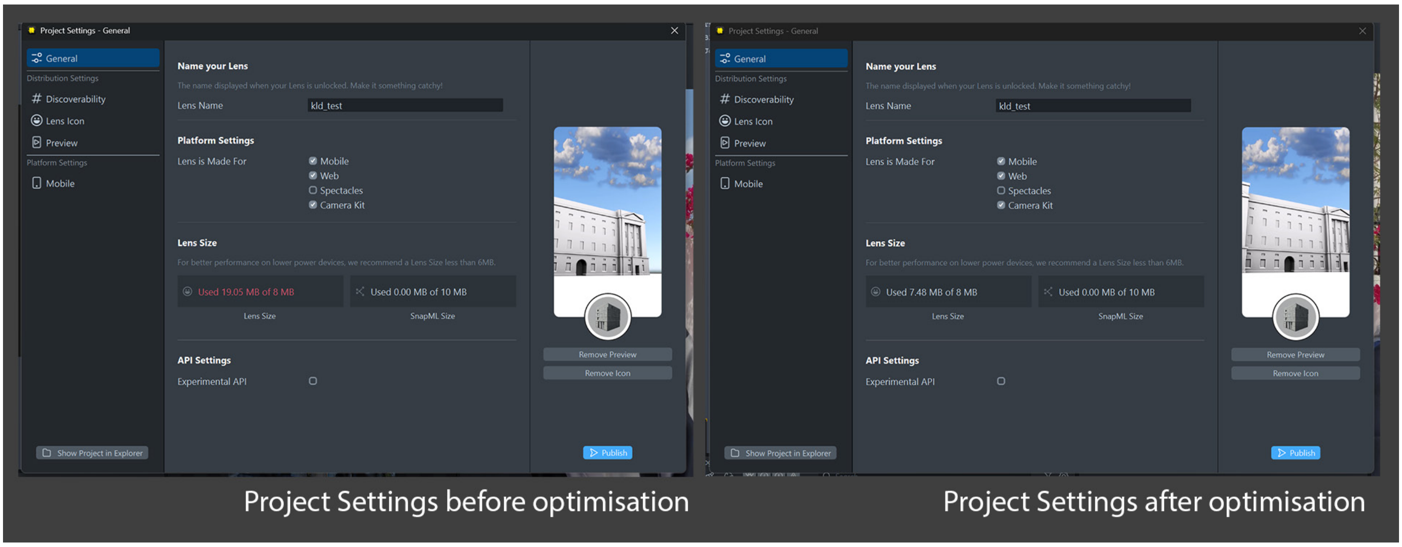

Figure 23. Optimization for publishing. Source: Ivan Karnitckii 2025.

After publishing, Snapchat generated a snapcode—an internal QR code which, when scanned, allows you to see the effect. The lens includes an “information” icon—added as a location for info on tap(see Figure 23).

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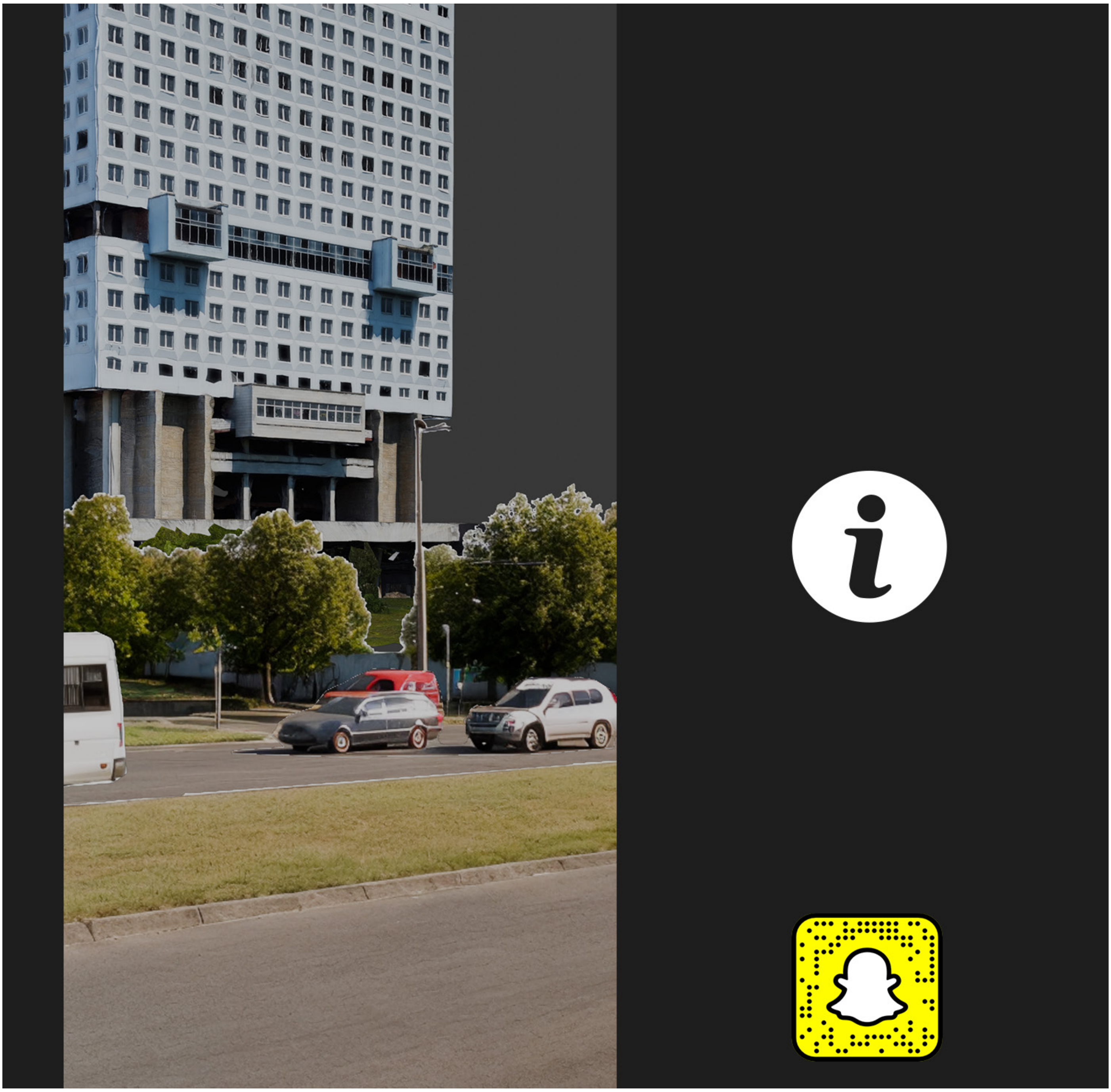


Figure 24. Example of the final lens. To view: open Snapchat and scan the snapcode.
Source: Ivan Karnitckii 2025.

In addition to the static portal, another variant was created—an animated lens. In this case, a model created based on the 3D scan was used: it was animated in Blender, and in the scene, the House of Soviets "transforms" into a robot, stands up, and leaves its place, symbolizing the demolition of the building. When exporting, experience with lens size was considered, so the House of Soviets animation was saved not as a 3D model but as a separate .mp4 layer. The movement of city layers relative to each other was also animated in Blender and exported as .fbx.

When importing into Lens Studio, it turned out that .fbx with animated layers does not retain the correct position, scale, and orientation. The cause could not be determined, so I tried exporting the animation as .glb, which transferred the information from Blender to Lens Studio correctly. The video with the building was prepared in two versions: a color (diffuse texture) and a black-and-white mask (alpha channel). When assigning materials, it turned out that the video and mask were out of sync by frames, causing the background not to be cut out correctly—this is a Lens Studio quirk (alpha mask on video works unstably, and there is no direct way to fix this in the program). The solution: render the video with the building on a bright green background and create a custom chroma key shader.

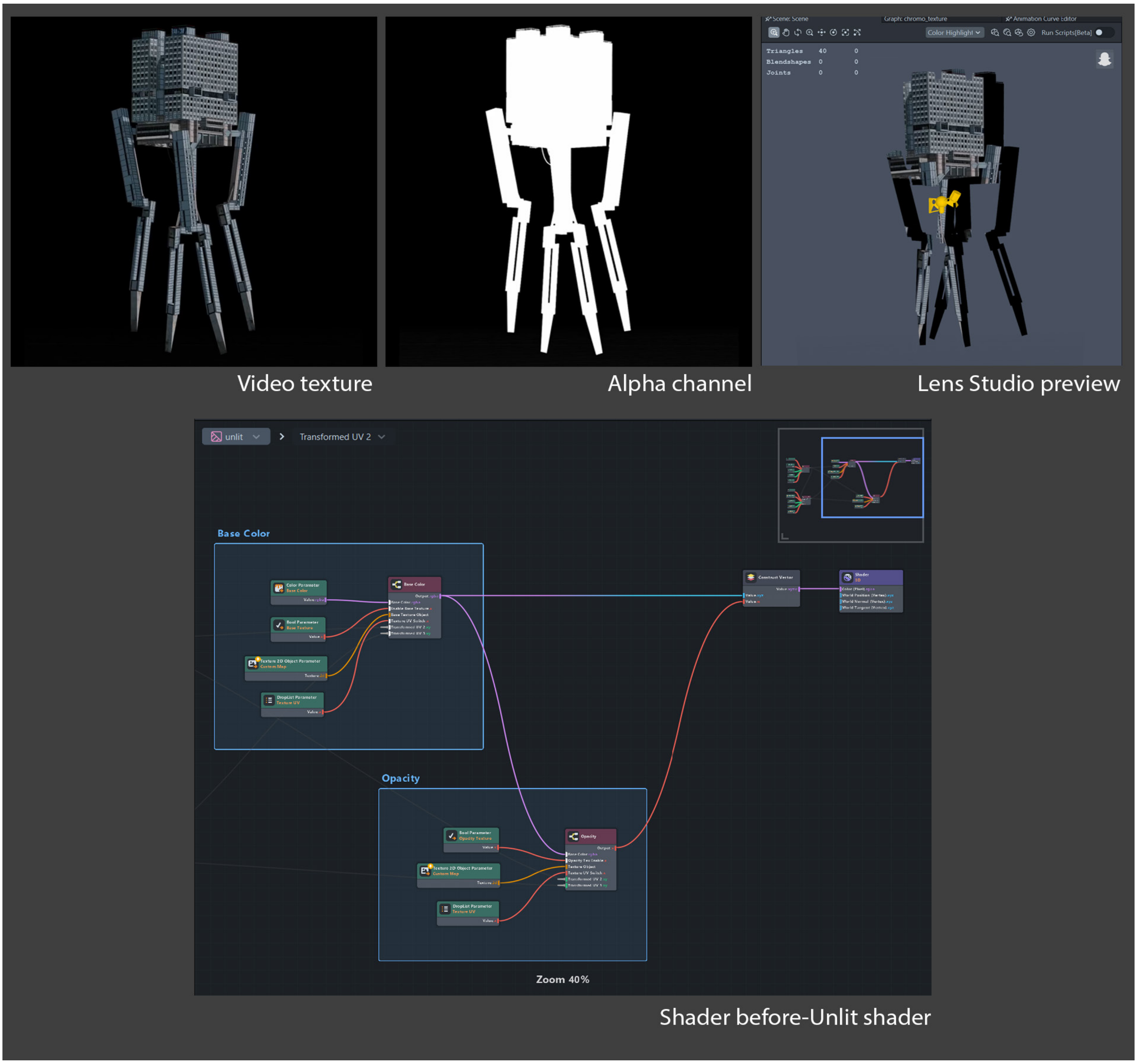


Figure 25. Setting up the texture via Unlit shader. Top right in Lens Studio preview: mismatch of diffuse texture and alpha channel. Source: Ivan Karnitckii 2025.

To create a custom shader, I used a flat shader (basically analogous to unlit, not critical here). A chroma mask node is created, connected to the base color; in the chroma mask, the capture color (green #00fb1d) is selected, then the chroma mask and base color are mixed, and the original opacity node is disabled. The result is a cleanly cut-out background from the video texture.

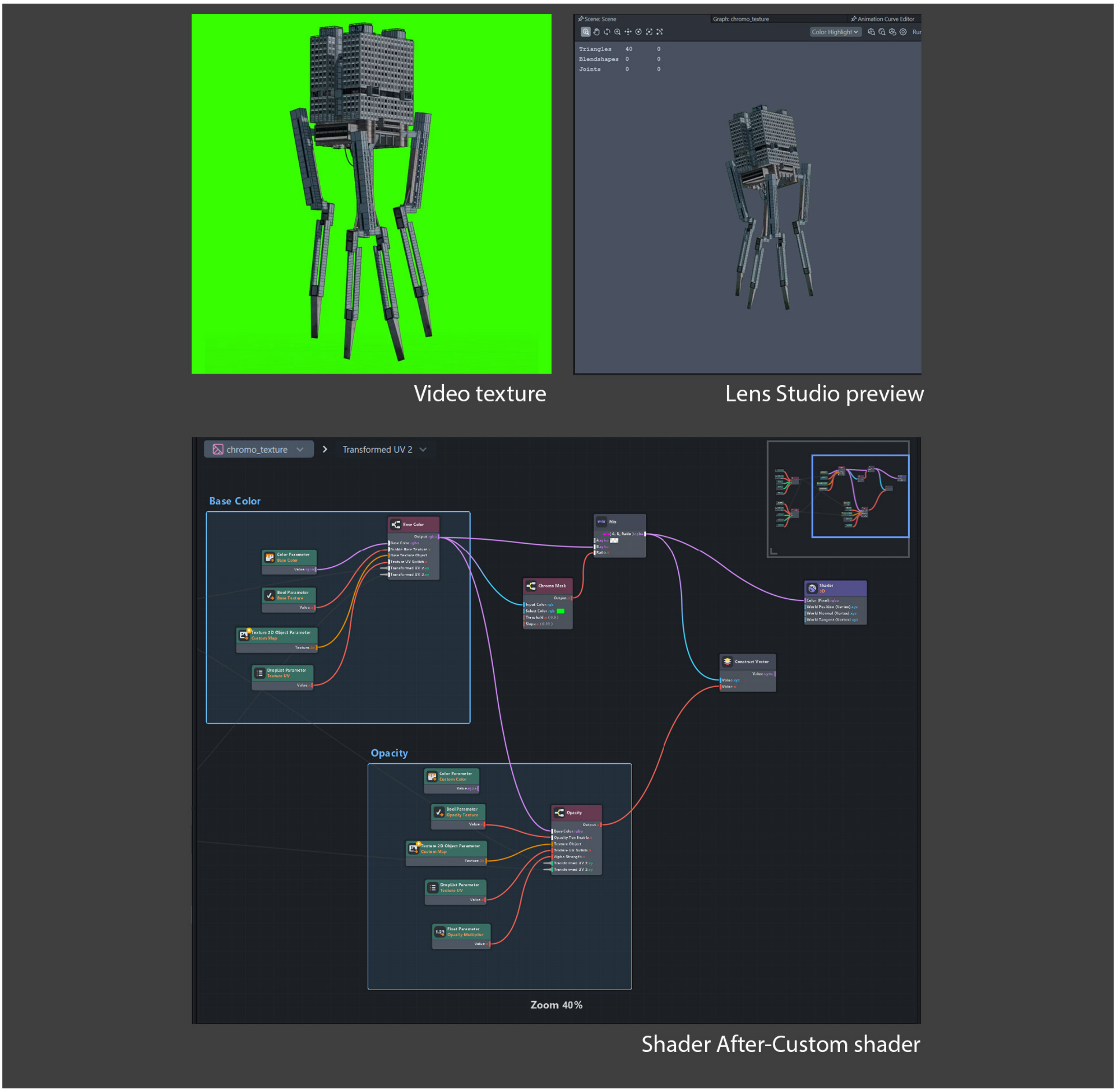
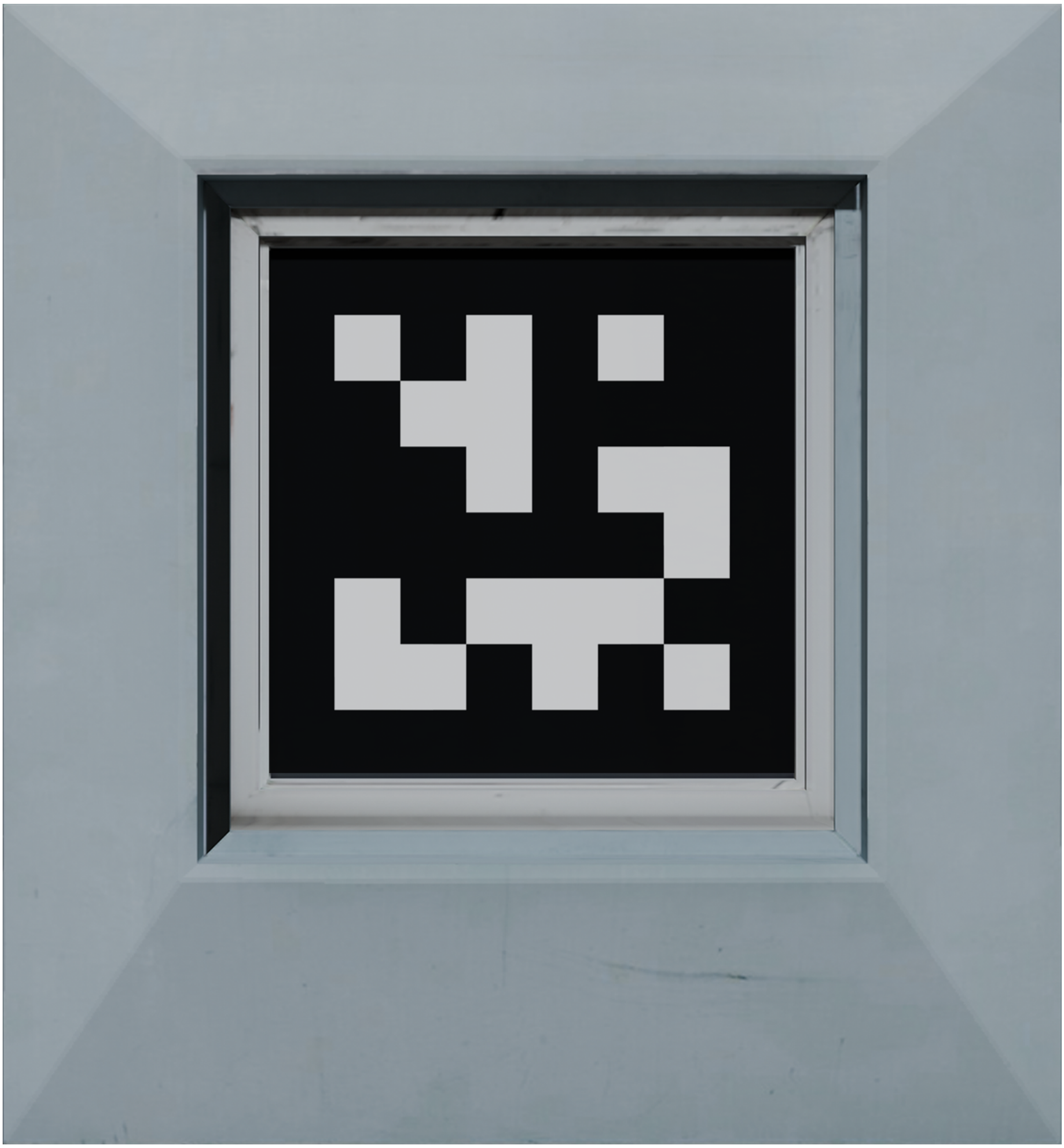


Figure 26. Setting up the texture with a custom shader. Top right: correct cut-out of the background from the diffuse texture. Source: Ivan Karnitckii 2025.



SCAN ME IN SNAPCHAT/
ОТСКАНИРУЙ МЕНЯ В SNAPCHAT

ПОМНИМ/ЛЮБИМ

Figure 27. Example of the final lens. To view: open Snapchat and scan the snapcode.
Source: Ivan Karnitckii 2025.

As a result, assembling a scene by the same portal principle, I got an animated lens—a local product fully corresponding to the principles of psychological engagement (Autonomy and Creativity) and the principle of non-invasive cultural heritage preservation [15,34]. For me, as someone who grew up in Kaliningrad, the House of Soviets evokes the image of a robot for whom the time has come to get up and leave (see Figure 27).
The choice of marker has a significant impact on how and what type of content can be placed in the scene. In our case, we had to look for workarounds, because an object of this scale cannot be correctly anchored in Snap, and due to technical limitations (occlusion, GPS tracking, and the fact that some Lens Studio functions do not work in a “marker + world tracking” setup), there are no universal solutions yet. Nevertheless, technologies are evolving, and in the future it should become possible to place objects of different scales with minimal constraints related to tracking, collisions, optimization, or shader realism. For now, these technical limitations set the boundaries that we need—and should try—to overcome with creative approaches.

2.6.4 Use: interactive map and user-generated content - Step 3.

Snap offers Camera Kit—a cross-platform SDK that allows you to integrate AR features into mobile applications [83]. This tool opens up the possibility of using a Pokémon GO–style approach, but instead of Pokémon, the user sees points where AR lenses are located: you can approach these points, scan them, and access digital content. This can partially solve the issue of precisely linking different types of content, and also enables digital map scenarios in the urban environment.
In this way, you can create an interactive map where the content consists of urban integrations dedicated to architecture, history, and cultural layers. Each of these points can have a unique AR lens attached via Camera Kit. In this format, users themselves choose what type of content they want to upload: this could be a 3D model of a building, a creative animation, a 3D portrait, or even alternative formats—giving much more freedom and creativity when working with digital heritage (see Figure 28). Moreover, such a creative map can also include objects from the field of museography; an application of AR in museography will be discussed in case study 3.Additionally, social mechanics can be introduced: the ability to leave comments, reviews, and messages directly at points of interaction, as implemented in the Souls series of games [84]—players leave local markers, accessible only to those who physically reach the location. Such a game-based approach, corresponding to the treasure hunt concept, can motivate users to explore and collect new “marks”—each point becomes unique, and the number of users interacting with it can even serve as an indicator of its value and appeal.

2.7 Key takeaway.

In general, despite technical limitations—problems of tracking, occlusion, optimization, and platform imperfections—modern AR tools open up new opportunities for preserving, rethinking, and collectively comprehending urban heritage. The case of the House of Soviets shows: the quality of the user digital experience ultimately depends less on the technology itself and more on the creativity and thoughtfulness of the approach to content creation.
Building a platform where anyone can add their own interpretation, memory, or digital reconstruction of a lost object becomes not only a technological, but also a cultural gesture. Such a platform can serve as a meeting point for different layers of urban memory, and the involvement of users through gamification mechanics and social functions can give the project genuine, living dynamics.

In this sense, augmented reality becomes not only a way to "revive" a lost building, but also a tool for collective preservation of memory about a place—in digital, visual, and, most importantly, human form.

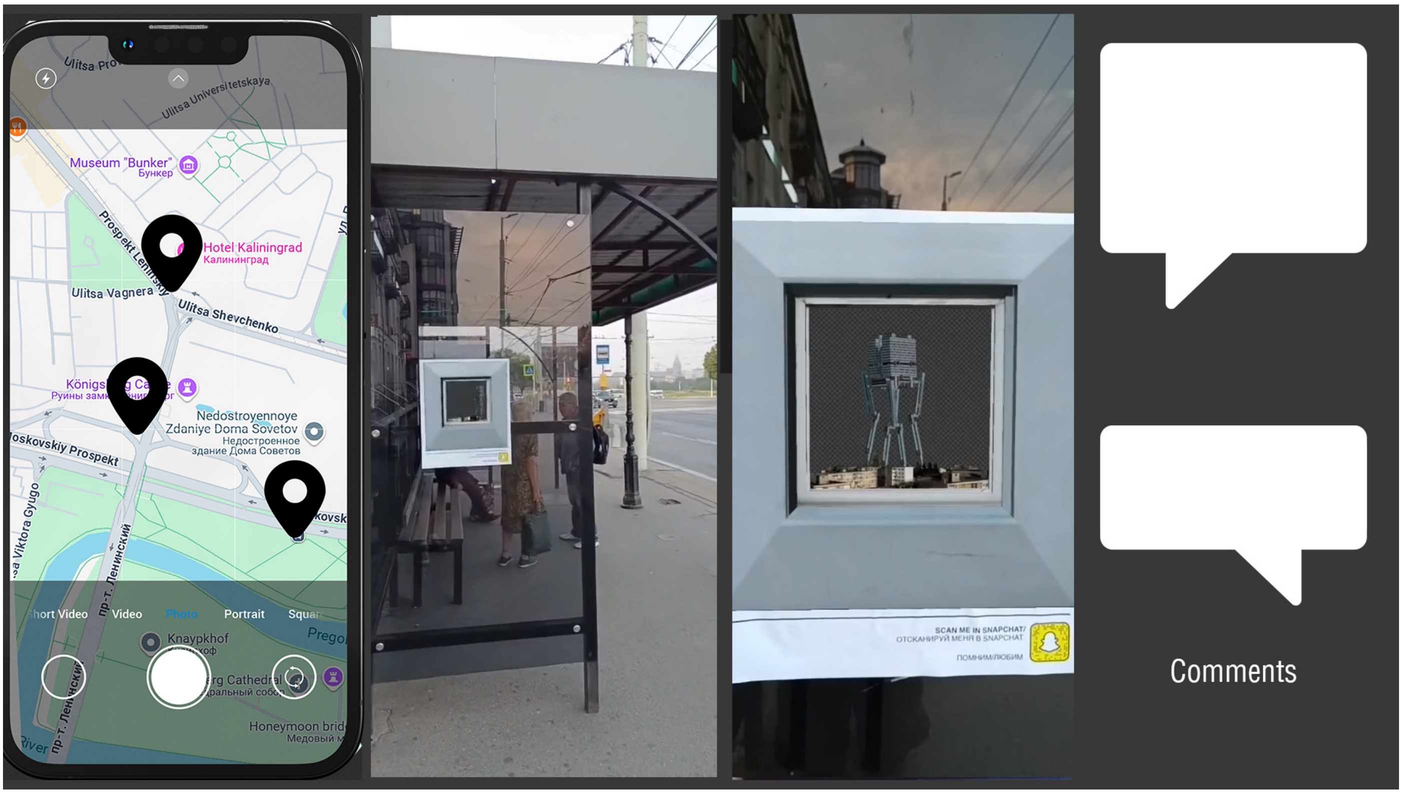


Figure 28. Example of a map with points: the user finds a point on the map, approaches the object, scans a snapcode, receives AR content, leaves comments, and highlights the location. In this case, the poster with the snapcode and the attached content is placed at a bus stop opposite the demolition site of the House of Soviets. Source: Ivan Karnitckii 2025.

03| Case study 2. The Stupinigi complex.

3.1 Introduction.

In this work, the case studies are not just examples but ways of looking at augmented reality (AR) from different angles. Each of them follows its own approach and opens a different line of reflection. In Case Study 1, I examined how AR can currently be used for preserving digital heritage, and what technical challenges are associated with it. However, it is equally important to think about the future of AR:

- **What would the experience be like if current technological limitations were lifted?**
- **What could augmented reality look like if we used the full potential of modern computer graphics?**

This is the question I set out to explore in Case Study 2. The main goal is to simulate a scenario where AR is realized as realistically as possible, using the resources of a personal computer. Today, the active development of 3D graphics already makes it possible to visualize, with a PC, what AR could look like in the coming years.
Since the late 1990s, the computer graphics industry has evolved from simple three-dimensional scenes with limited geometry to dynamically lit, highly detailed, and visually plausible worlds. In recent years, the most significant achievement has been the implementation of real-time ray tracing, which has transformed the approach to lighting and reflections in games and interactive applications. Although full photorealism is not yet achievable, modern technologies such as PBR (Physically Based Rendering), HDR, and ray tracing already allow the creation of scenes that are visually very close to "ground truth"—the level of realism perceived as reality [85].
In this case study, using an example from Italy's cultural heritage, I aim to achieve a high level of visualization and demonstrate the potential of modern technologies for augmented reality.

3.2 Europe's digital future strategy: key directions and cultural dimension.

Moving from technological capabilities to institutional strategies, it is important to consider how digital transformation is conceptualized at the policy and societal levels. In Europe, this process receives special attention at all levels.
The European Commission's program Shaping Europe's Digital Future [6] formulates a comprehensive strategy for digital transformation, focused on developing technologies that serve human interests, support a fair economy, and help build an open democratic society. The priority areas include artificial intelligence, supercomputers, cybersecurity, 5G/6G networks, and a massive increase in digital literacy across society. Special attention is given to digital identity, protection of personal data, fair competition, and sustainable development.
The cultural dimension is manifested in a number of initiatives aimed at supporting media pluralism, cultural diversity, and the digital transformation of the audiovisual sector. In particular, the Media and Audiovisual Action Plan [6] aims to increase access to high-quality content, strengthen citizens' trust in the digital environment, and support the position of European cultural industries. In the European agenda, the digitalization of culture is closely connected to the protection of democratic values, inclusivity, and sustainable development, where cultural heritage becomes part of a unified digital ecosystem.
Within this context, individual EU member states develop their own national strategies, adapting common principles to their cultural and institutional specifics. Italy is one of the countries most actively engaged in the digital transformation of culture. The national plan for the digitization of cultural heritage, Piano Nazionale di Digitalizzazione del Patrimonio Culturale [86], demonstrates not only a commitment to technical modernization but also to profound institutional reform, in which digital heritage is considered an independent cultural asset and a foundation for sustainable development.

3.3 Digital transformation of cultural heritage in Italy.

In Italy, the digitalization of cultural heritage is seen as a systemic transformation, aimed not only at preserving objects but also at rethinking the role of cultural institutions in the digital age. According to the Piano Nazionale di Digitalizzazione del Patrimonio Culturale [86], digital heritage is recognized as a distinct form of culture, capable of establishing new relationships between objects, contexts, and users. One of the key goals of this plan is to expand access to cultural assets by creating inclusive, multisensory, and personalized digital services. Platforms based on user-centered design and universal design principles are intended to overcome physical, cognitive, and social barriers.
As part of the 2022–2026 strategy, the creation of a national cloud infrastructure for data, the introduction of a digital certification system for cultural objects, and the development of co-creation and crowdsourcing tools are all planned. Special attention is given to integration with pan-European initiatives—especially the European Collaborative Cloud for Cultural Heritage [87], which offers a cloud-based model for sharing and combining digital heritage data. These measures support the achievement of the UN 2030 Agenda for Sustainable Development Goals [88] (such as quality education, infrastructure, industrialization and innovation, peace, justice, and strong institutions, etc.). Thus, digitalization is seen not only as a means of preservation but as a way to actively rethink cultural heritage, where users themselves play a key role as co-creators of meaning.
Of particular interest are approaches based on new digital tools. For example, the article Sustainable

Restoration of Cultural Heritage in the Digital Era discusses H-BIM (Heritage Building Information Modelling) and Digital Twin concepts:

> "The introduction of digital technologies such as H-BIM and DTs manifests as cutting-edge advancement, proposing optimised methodologies for recovery and maintaining cultural heritage, and representing a new horizon for those kinds of building processes" [89].

H-BIM is used to create an information-rich 3D model that integrates data on geometry, materials, and the history of the object, while the Digital Twin concept allows for real-time monitoring of a building's condition using sensors and simulations, including the assessment of resilience to disasters (such as earthquakes in L'Aquila and Amatrice).
Building on these ideas of digitalization and the diversity of Italian approaches, I will next discuss the concept of digital restoration using a case study focused on a fragment of the Stupinigi complex in Turin. We studied this site in detail as part of a restoration course(Restoration and integrated conservation B) at Polito under the supervision of Carla Bartolozzi

3.4 The Stupinigi complex.

The Stupinigi Hunting Residence (Palazzina di Caccia di Stupinigi) is a unique example of late Baroque and Rococo architecture in Italy, built in the first half of the 18th century for the House of Savoy. The building is located about 10 kilometers southwest of Turin, in the village of the same name. The name "Stupinigi" comes from an ancient local toponym, probably of Latin or Celtic origin, and is historically closely linked to the region's hunting traditions [90].
Construction began in 1729 by order of Victor Amadeus II and continued under his successors Charles Emmanuel III and Victor Amadeus III. The main architect was Filippo Juvarra, one of the leading masters of architecture of his time. He proposed a completely original layout, inspired by European country residences (such as Versailles and Fontainebleau), but at the same time deeply rooted in the Italian architectural tradition. The project involved the creation of a complex with a central pavilion intended to accommodate the court during hunting trips, combined with a rural settlement serving the residence. Subsequently, other architects contributed to the project, including Giovanni Tommaso Prunotto, Benedetto Alfieri, Ignazio Birago di Borgaro, Ludovico Bo, and Ignazio Bertola [90,91].

Figure 29. General view of the main front with the courtyard and gardens. Source: La Venaria Reale , n.d.

The architecture of the complex is impressive in both scale and originality: the central core has an

elliptical shape, from which four wings radiate in the form of a skewed cross. Two of them frame a hexagonal courtyard, while the other two extend into the landscape. This solution makes the building not only a dominant feature, but also the center of the visual and functional composition. The spaces between the wings are also built up, forming additional volumes and symmetrical transitions. The central hall is a two-story oval space topped with a dome, adorned with elegant stucco work and clover-shaped balconies [90,91].
Particular attention was paid to integrating architecture and nature. In 1740, a garden was designed inside the large transportation ring, with French landscape architect Michel Bernard responsible for the project. He combined elements of the French formal garden (axial symmetry, flowerbeds, lawns) with the Italian style (enclosure, decorative elements, fountain groups). The territory was bordered by a wall that repeated the contours of the buildings, creating a sense of a single ensemble. Today, the park is partly included in the Parco Naturale di Stupinigi nature reserve. There was also a complex of farms — San Luigi Farm, which includes eleven farms built from the 1840s along the road to the hunting lodge, according to Juvarra's original design. On March 27, 1747, the contract for the construction of the San Luigi Farm was signed by entrepreneurs Allino and Bertone with architect Tommaso Prunotto. Materials from a dismantled farm, lime from the Superga dome, and gravel from Sangone were used in construction [90,91].
Although originally conceived as a hunting residence, the complex is closer in typology and scale to a country palace. Since 1992, it has been open to the public as a museum, hosting temporary exhibitions, theatre performances, concerts, and educational programs. In 1997, Stupinigi was included in the UNESCO World Heritage List as part of the Residenze Sabaude complex [90].
It is important to note that Stupinigi is the subject of research at the Polito Geomatics Lab for cultural Heritage, in which I took an active part. In the context of collaboration with Polito, the residence is considered one of the priority sites for the national plan for the digitization of cultural heritage (PND 2022–2023) [86]. Here, H-BIM (Heritage Building Information Modelling) and Digital Twin [89] technologies are actively used, enabling not only documentation of the current state of the building but also the creation of digital models for future restoration, monitoring, and virtual access. In addition, the project is linked to the European Collaborative Cloud for Cultural Heritage initiative, which opens up opportunities for transnational cooperation, digital conservation, and engaging a wide audience in the study of Savoy dynasty heritage.
Stupinigi is thus not only an architectural masterpiece of the 18th century, but also a modern cultural center that today has the potential to become part of the digital age.

3.5 Use of AR.

As part of this restoration workshop in Polito(Restoration and integrated conservation B), the main object of study was the Stupinigi complex—a hunting residence located in the commune of Nichelino. The team I worked with focused on the western semi-rotunda (semiesedra di ponente - see Figure 29), and the project proposal, to which my AR simulation would be linked, is directly connected with a fragment of the stables. To implement a digital simulation of an architectural object—especially when it comes to heritage sites—it is essential to obtain an accurate, comprehensive 3D model with textures and correct geometry. As in Case Study 1, I break down the workflow into several stages: defining the environment in which the simulation will take place (Chapter:2.5), obtaining the model (Chapter:2.6.1), and developing the project concept and its implementation (Chapters: 2.4,2.6.3,2.6.4).

Overall, the process can be divided into three main stages::

- choosing the environment for the simulation,

- obtaining the 3D model,

- developing the concept and creating the simulation project.

3.5.1 Choosing the environment for the simulation.

In Case Study 1, I used SnapAR due to its multiplatform nature and accessibility on mobile devices. Now, since the goal is not to create a mobile product but rather to go beyond AR limitations and use the power of the computer, I chose another game engine—Unreal Engine. My aim is to demonstrate what augmented reality might look like in the future if current technical restrictions are removed. Unity could also be considered an alternative for this kind of task, but when comparing the two engines, my main criteria were the high level of realism, Unreal's lighting quality, as well as the presence of the visual coding language Blueprint, which allows me to set up game mechanics without having to learn C++ or C#[add ref unity and ureal].
I was particularly impressed by the Aximmetry[92] plugin for Unreal Engine, which can be used as an alternative for desktop simulation. I got an Aximmetry license to test this technology.
Aximmetry is a professional platform for virtual production and augmented reality, widely used in television studios and live events(see Figure 30). Integration with Unreal Engine makes it possible to create a realistic AR scene in which 3D objects are precisely matched to real space, including proper lighting and perspective. In simple terms, Aximmetry lets you experience augmented reality through a phone, but with the computing power of a PC—making photorealistic graphics possible, which is not achievable with a regular smartphone setup without Aximmetry. To build the AR scene, you need a tracking camera (in my test, an iPhone 14 Pro with LiDAR), a computer with Aximmetry DE installed, a green screen, a wired connection between the computer and phone to the modem, and external cooling for the phone[92].
However, despite the wide possibilities, there were certain challenges in building the AR scene. One of the main technical issues was the abundance of cables: to transmit the video signal, synchronize tracking, and connect Unreal Engine over the network, many connections were required, which greatly complicated the mobility of the setup. In particular, working via modem turned out to be problematic: signal instability, delays, and limited bandwidth during my test runs led to desynchronization between AR objects and the camera, which is critical for the immersive effect. The device also overheated significantly.

As a result, I decided to focus on building the simulation entirely on the computer using Unreal Engine, without Aximmetry and the phone, since that process turned out to be unstable and impractical for real tasks.

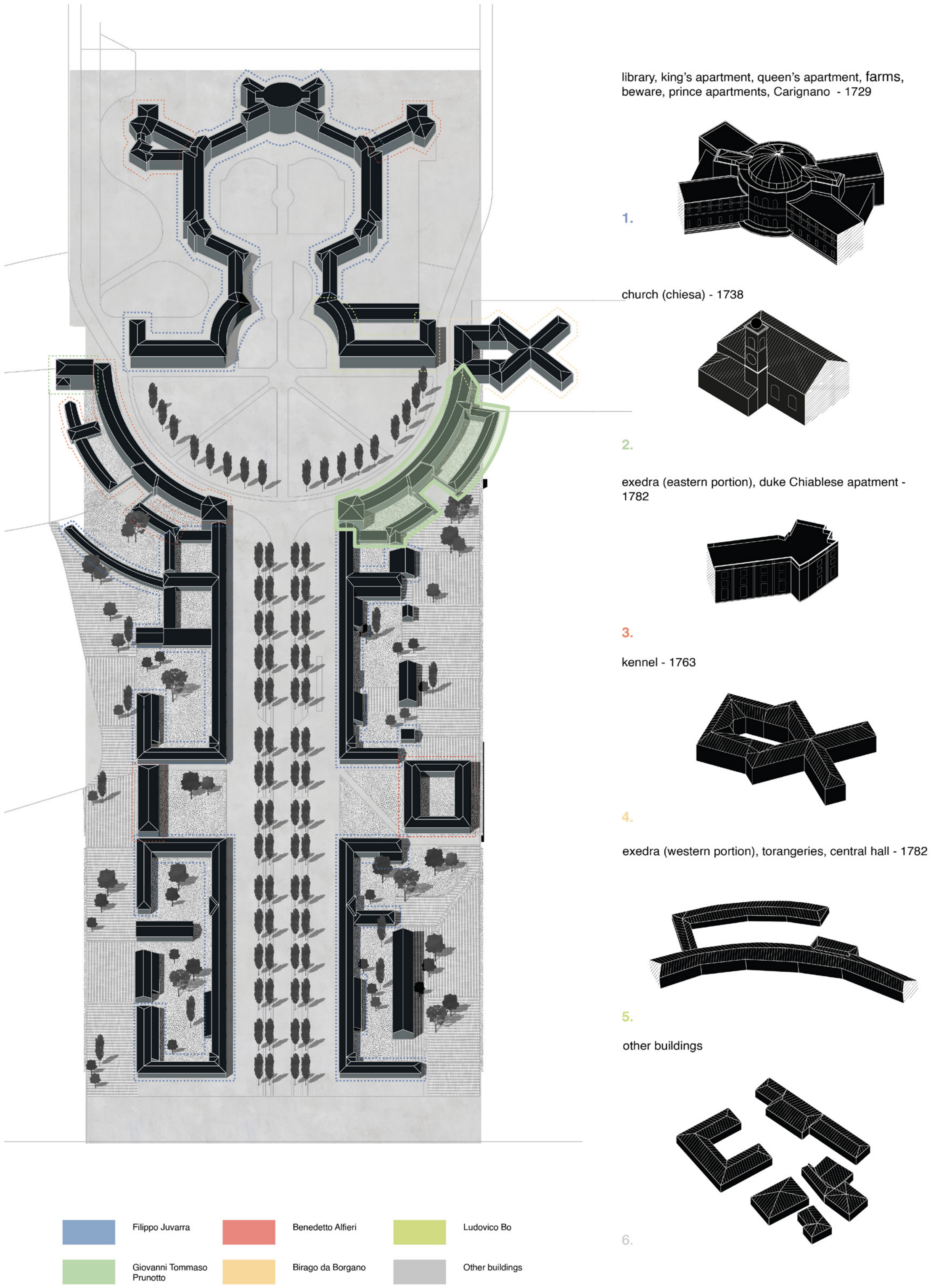


Figure 30. Diagram of the Stupinigi complex with the highlighted research zone choosen for the course of “Restoration and integrated conservation B” by Polito. Source: Ivan Karnitckii, Restoration and integrated conservation B, 2024.

Figure 31. Example of Aximmetry in use: in the image, the TV presenter is composited with a 3D scene in real time. Source: Aximmetry JP, n.d.

3.5.2 Model generation.

The next stage was the creation of an accurate digital model of the object under study. At the initial phase, the team visited the complex to collect the necessary data using various instruments: a laser scanner and a total station to obtain geo-referenced point clouds of the facades and interiors, as well as a camera for photogrammetric capture of facade orthophotos.
The entire survey procedure was organized by professor Giulia Sammartano from Geomatics Lab for cultural Heritage according to modern geomatics methods and included several steps: planning, data collection, processing, and the creation of digital projections. At the beginning, the coordinate system and reference points—so-called GCPs (Ground Control Points)—were established; these were then used to calibrate the point clouds and align the data sets. These points were physically placed on the facades and measured using the total station, ensuring high-precision georeferencing.
The basis for the digital recording was provided by data collected through laser scanning. For the external facades, a stationary laser scanner was used on a tripod; for the interior spaces, a mobile device with SLAM technology (Simultaneous Localization and Mapping) was employed. As a result, a highly detailed point cloud was obtained—a set of spatial coordinates forming a digital copy of the object.
These data were then processed in specialized software: initial alignment and noise removal were performed in SCENE[93], after which the data were exported in *.e57 format and loaded into

.

CloudCompare[94-11] for merging and further optimization. Special attention was paid to compatibility between different sources: static and mobile scanners, as well as photogrammetric materials.

Figure 32. The process of obtaining the 3D model. Source: van Karnitckii, Restoration and integrated conservation B, 2024.

At the next stage, the PointCab[95] software was used to place sections and extract plans. Using specified parameters—intervals, slice thickness, and resolution—horizontal and vertical projections were created. In parallel, facade photogrammetry was carried out with a digital camera, capturing the building from various angles. Based on the photos, orthophotoplans were constructed in Metashape, after which the images and geometry were imported into AutoCAD[96]. At this final stage, the reconstruction of drawings, redesign of facades, large-scale drafting, and refinement of structural elements necessary for the simulation took place.
Thus, the entire digital survey process resulted in an accurate three-dimensional model of the object—both in terms of geometry and visual appearance. This model not only reflects the current state of the complex but also becomes the basis for analytical calculations, reconstruction proposals, and virtual simulations.
I especially want to mention the quality of the material obtained through photogrammetric data collection, as it is an important part of the simulation. The texture quality and geometry produced by photogrammetry convey the 1:50 scale very well, especially compared to the House of Soviets from case study number 1, where the textures and geometry were not as detailed and were sometimes inaccurate. In this case, the model follows the RMSE (root mean square error) standards used in the

Geomatics Lab for Cultural Heritage. In case of stables for the scale 1:50, the RMSE is required 1-2cm [63].

Figure 33. Comparison of photogrammetry results: House of Soviets (left) and Stupinigi Stables (right). Source: Ivan Karnitckii, Restoration and integrated conservation B, 2024.

The final result of the survey carried out during the restoration course was the production of high-quality photogrammetry of the courtyard, including the facade of the stables, as well as the preparation of drawings: plans, sections, and elevations. Later, when constructing the 3D scene, I will rely on these drawings and photogrammetric models.

3.5.3 AR concept.

As a result of restoration course analyzing the current state of the stables, it was concluded that the building is suitable for continued use and is not in an emergency condition. During the course, we

analyzed the current condition of the stables' facades, which can be considered satisfactory, as well as the condition of the roof structures, which bear the marks of time and age but are still in working condition. The use of augmented reality makes it possible to implement unconventional approaches to working with space: in this case, I decided to try the option of full "preservation," that is, to keep the stables as they exist today, preserving as much as possible the current cultural layer.
Functionally, the renovated stables will serve as a cafe-showroom. Structurally, a special box is inserted into the existing space—a furniture insert on which markers for virtual reality tracking are placed.

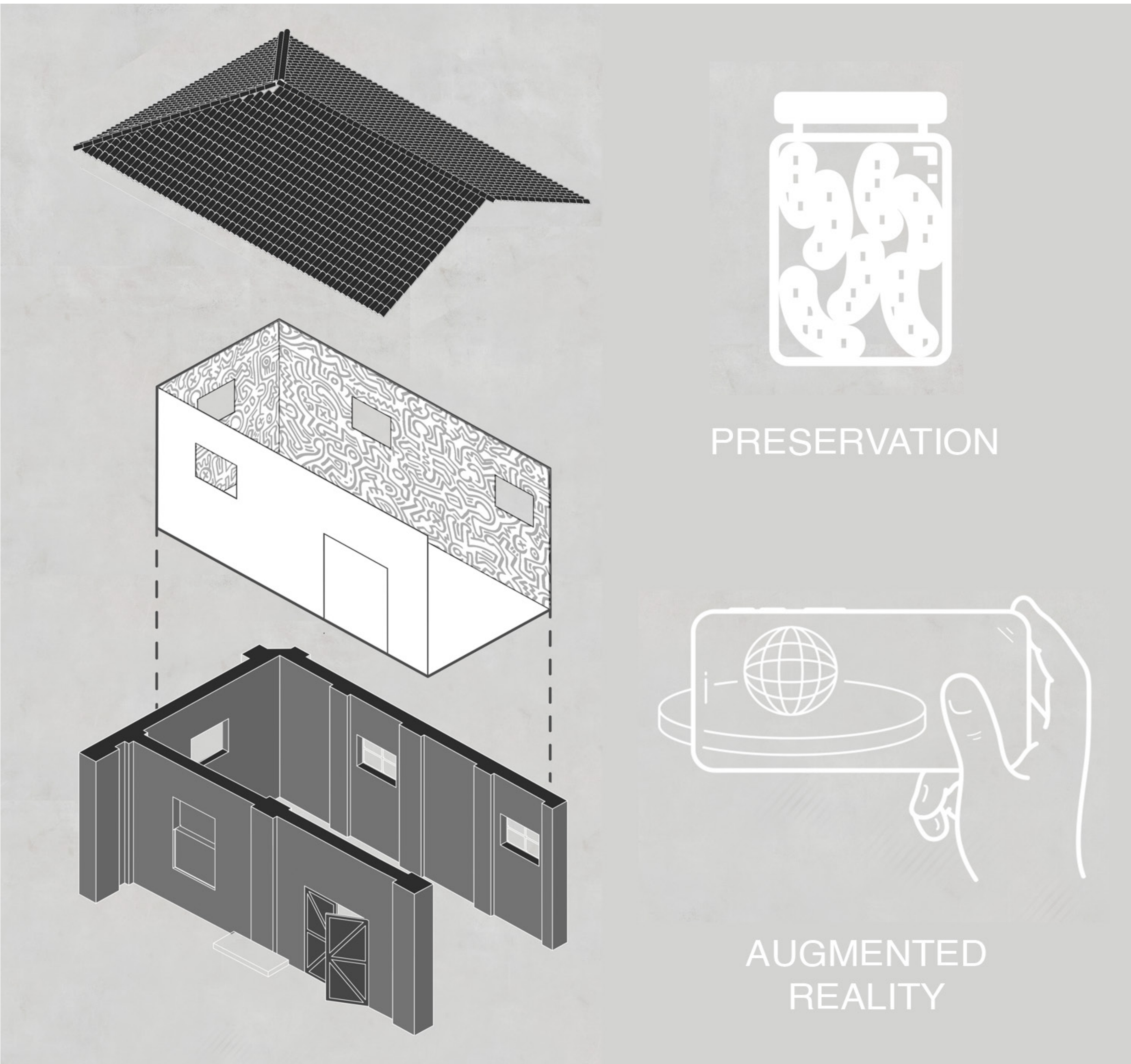


Figure 34. Concept diagram of the intervention, placing the box with markers inside the stables. Source: Ivan Karnitckii, Restoration and integrated conservation B, 2024

Unreal Engine allows you to simulate AR within a computer application: you launch a “game” prototype on the PC, where your character holds a smartphone and the project proposal in hand. Moving around the digital twin scene, you can see an additional layer of reality through the virtual phone. Another option is to use a VR headset for deeper immersion: in this case, instead of a controller, you hold a virtual phone, and while walking through the scene in VR, you get an experience of AR interaction that is as close to reality as possible, but without today’s technical limitations

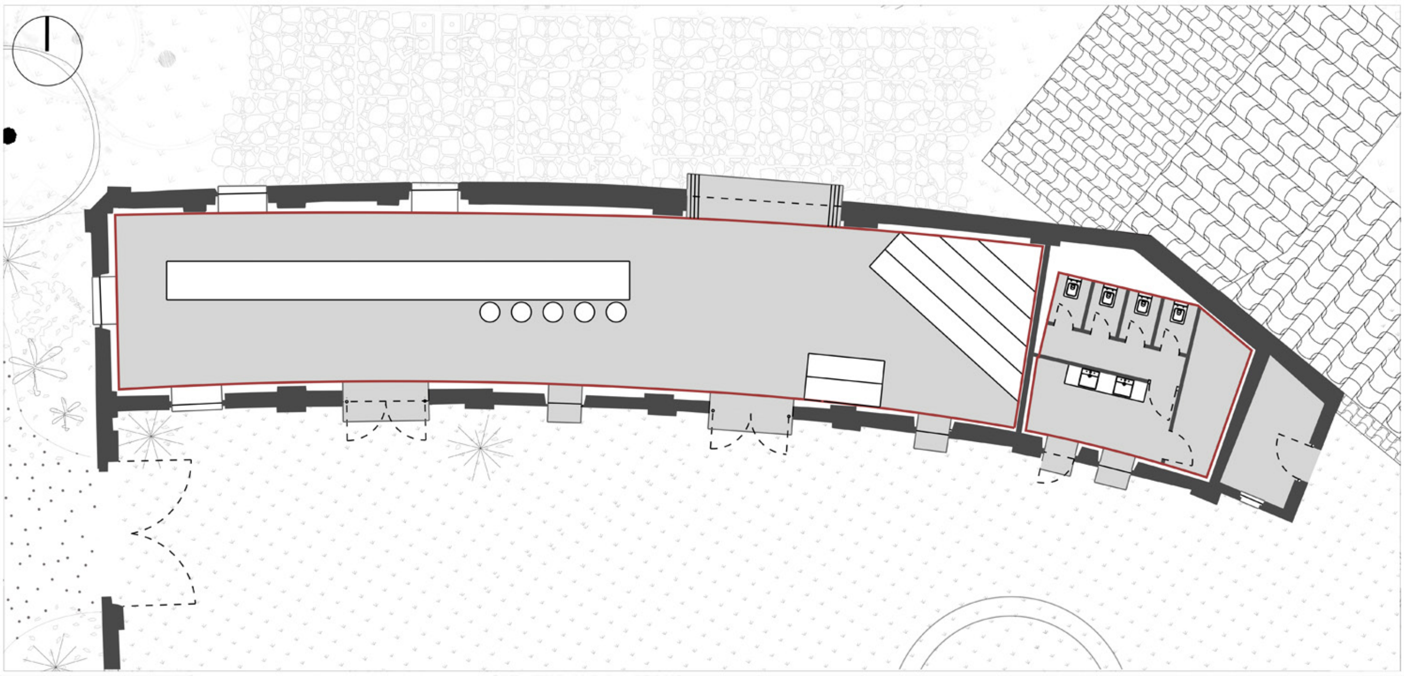


Figure 35. Plan of the stables’ reconstruction. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

All new elements in the layout are designed as furniture inserts so as not to load the historical walls and structures. Only the windows and doors are replaced, and an additional internal block with a bathroom is introduced.

3.6 Preservation of original structures.

Preservation of Original Structures
Since the work was conducted in two different environments, namely Blender and Unreal Engine, the process of creating the AR simulation was divided into two main stages:

- **3.6.1 Creation and transfer of the model;**

- **3.6.2 Application setup.**

3.6.1 Creation and Transfer of the Scene.

The 3D scene was modeled in Blender. For this project, I did not focus on polygon count optimization: the total polygon count amounted to 1,420,000. The scene consists of two sets of models: the first is the base layer with the project proposal and box with markers, the second includes objects that are visible only in augmented reality mode.
All space in 3D is modeled as a set design: the stables building was recreated based on the results of the 3D survey, the roof structure—according to the drawings by Ludovico Bo (see Figure 36), the inner courtyard was made by photogrammetry, while the environment outside the courtyard was created as stage scenery.

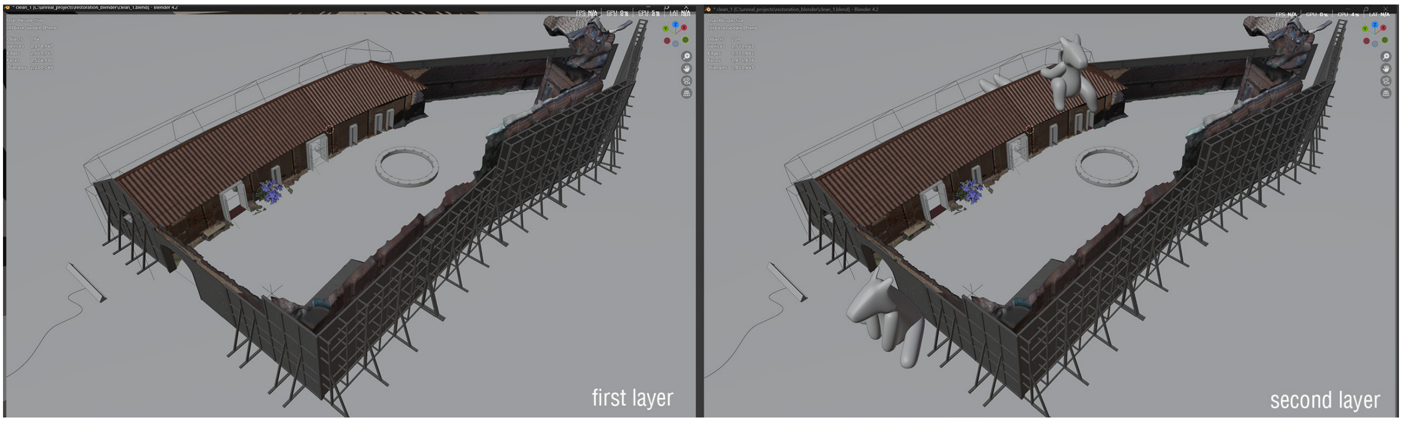


Figure 36. Scene in Blender, left to right: 1. base layer, 2. augmented reality layer. On the augmented reality layer, large sculptures of metallic dogs have been added. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

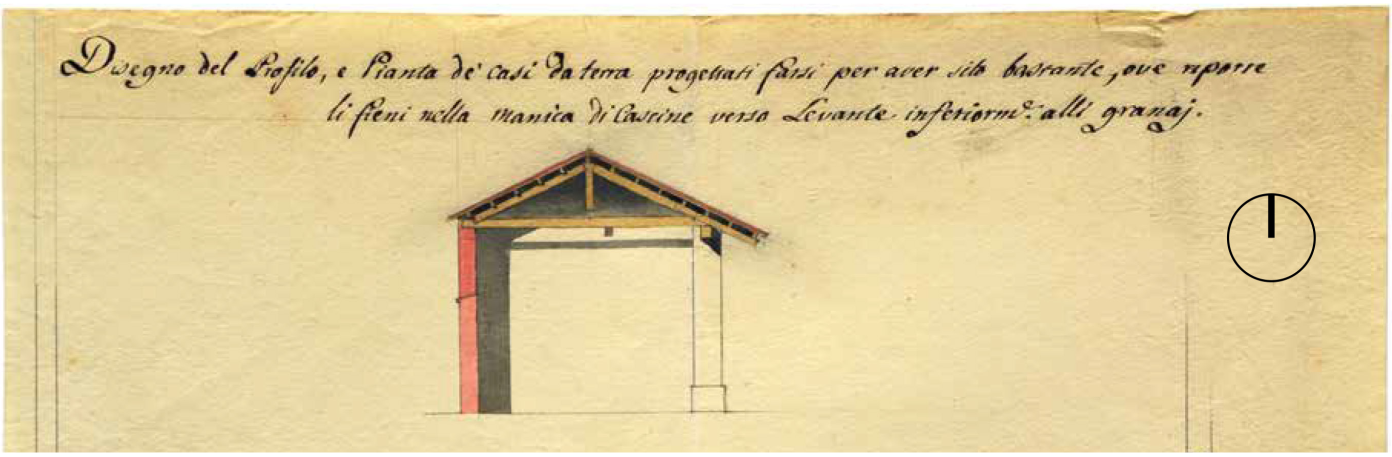


Figure 37. Stables, Ludovico Bo, n.d. Source: Bartolozzi, Roggero & Sabia, 2022–2023

When creating the models, basic PBR shaders were used, including a diffuse texture and, when necessary, reflections. The texture for the photogrammetry-based courtyard contains baked shadows, so a flat material is used for it (a material that only displays the diffuse texture).

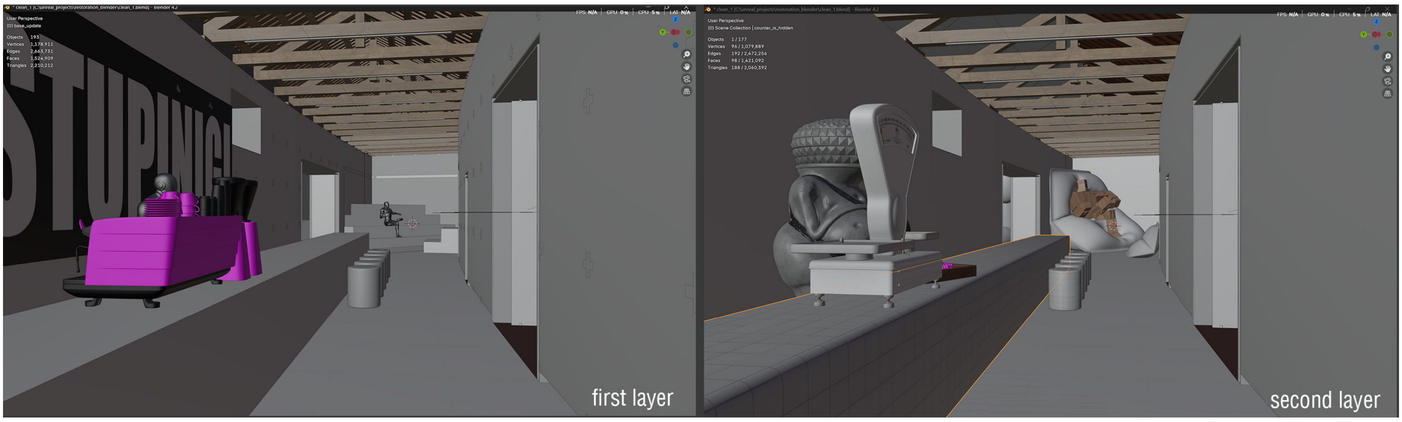


Figure 38. Scene in Blender, left to right: 1. base layer, 2. augmented reality layer. On the augmented reality layer, the Venus of Willendorf has been added in place of the cashier. The seats at the end of the room have been replaced with a giant metallic cushion, and the person sitting on the steps appears with a robot skin. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

Export from Blender was carried out in Universal Scene Description (.usd) format, which supports scenes with a large number of objects, hierarchies, assemblies, and links, and also preserves basic PBR shaders—this is especially important for architectural and game projects[97].

3.6.2 Application setup.

The simulation is designed as a first-person walk: the character controlled by the user holds a cup and a phone. By pressing the E key, the camera mode is activated, allowing the user to see the hidden AR layer of objects. Zoom is available by right-clicking in this mode. Controls are implemented via WASD keys, or with controllers if using a VR headset.

▼ Figure 39. Scene in Unreal Engine, left to right: 1. base layer, 2. augmented reality layer. On the augmented reality layer, large sculptures of metallic dogs have been added. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

▲ Figure 40. Scene in Unreal Engine. Dynamic lighting and grass created with foliage tools. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

▼ Figure 41. Scene in Unreal Engine, left to right: 1. base layer, 2. augmented reality layer. On the augmented reality layer, the Venus of Willendorf has been added in place of the cashier. The seats at the end of the room have been replaced with a giant metallic cushion, and the person sitting on the steps appears with a robot skin. Under the ceiling, a portal with an astronaut has been added as a demonstration of an AR portal variation. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

After exporting the scene to .usd format, my first steps were to set up the lighting, shaders, and grass. The scene uses dynamic light (real-time active lighting): this approach provides high-quality visuals but requires more computing resources. In my case, the scene is relatively small, so real-time light is used. For optimization in VR, however, it is better to bake the lighting, increasing FPS(frame per second).
The facades of the stables and the inner courtyard use textures with baked light; they do not participate in global illumination (do not cast shadows) and have a flat shader applied. The scene contains Sky Light with HDRI for reflections and soft ambient light, which only affects the roof geometry and hidden objects. The environment and large decorative elements are excluded from this lighting.
Decorative grass was added to the scene to create the impression of a natural AR environment. This was implemented using foliage or instanced static meshes. For optimization, the grass appears within a certain radius as the camera moves—thus the computer does not render the entire grass array at once, reducing performance load. I also experimented with Nanite (a technology in Unreal Engine for handling huge numbers of models without a performance hit), but for grass, it did not improve performance and at times even decreased scene stability [98,99].
The core interaction logic was implemented using the Blueprint system. The key element is `Toggle Visibility`—an individual actor, `VisibilityManagerActor`, which contains arrays of objects to show and hide (for example `Managed Actors, ArrayToHide`). Array management is handled via a `ForEachLoop` and the `Set Actor Hidden` in Game node. For the player character, a mechanism for hiding hands and attached objects (the cup or phone) was implemented via `FirstPersonMesh` control.

Figure 42. Toggle Visibility. Blueprint script in Unreal Engine. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

The virtual phone interface is implemented as a widget, called up by pressing key E (Add to Viewport) and hidden with another press (Remove from `Parent`). The state of the widget is tracked by the variable `bIsWidgetActive`, which also restricts other functions, such as camera zoom.
Zoom is implemented via FOV (field of view) control using a `Timeline` and `Lerp` function (values from 90 to 135 degrees). Zoom is only active when the widget is enabled, thanks to the `bIsWidgetActive` check. A full-screen launch mode is provided, as well as the ability to hide certain objects when the "phone screen" is active, to prevent geometry overlap. To change the zoom, you need to press the right mouse button while the widget is active (when looking at the "phone screen").

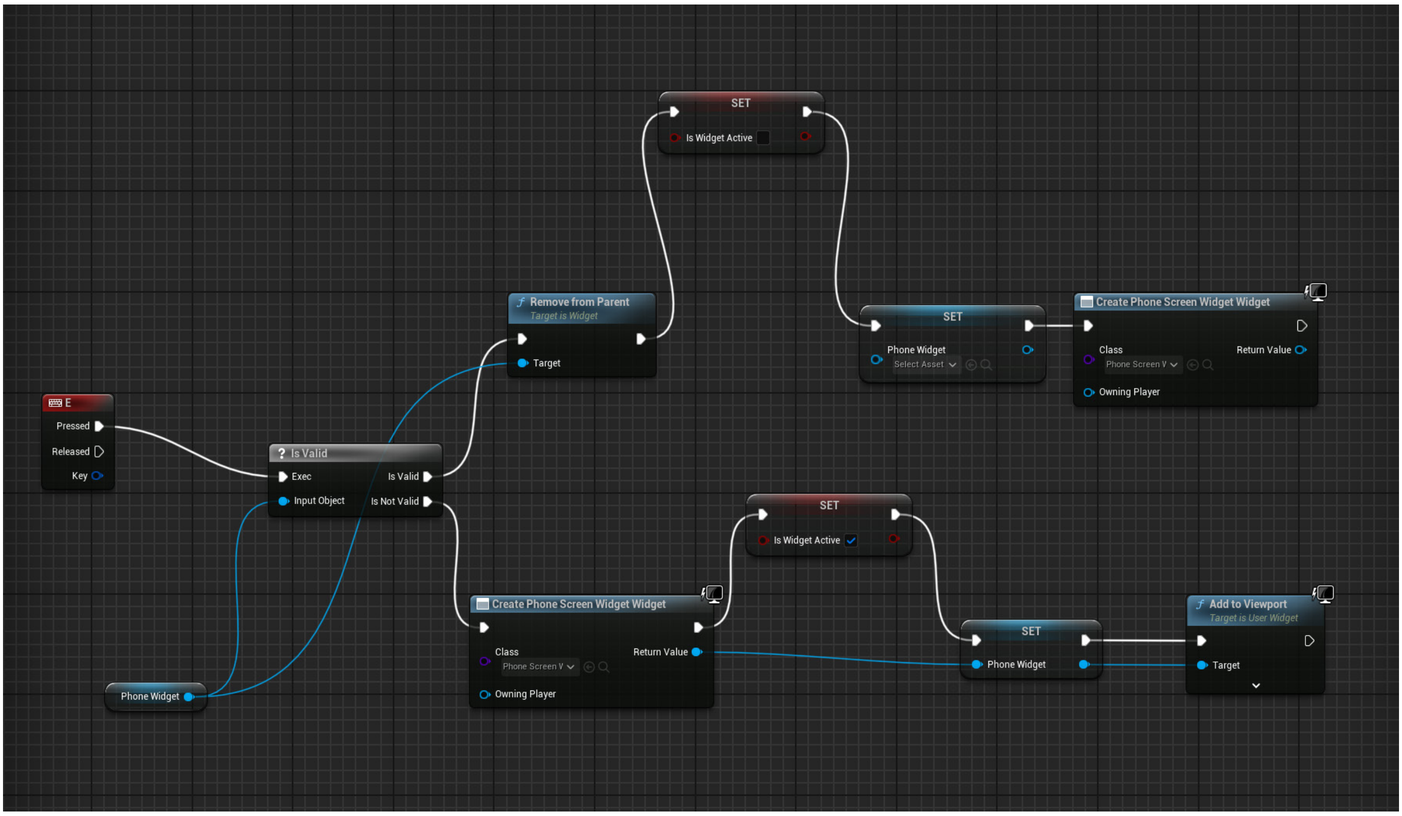


Figure 43. Key E-phone screen activation key. Blueprint script in Unreal Engine. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

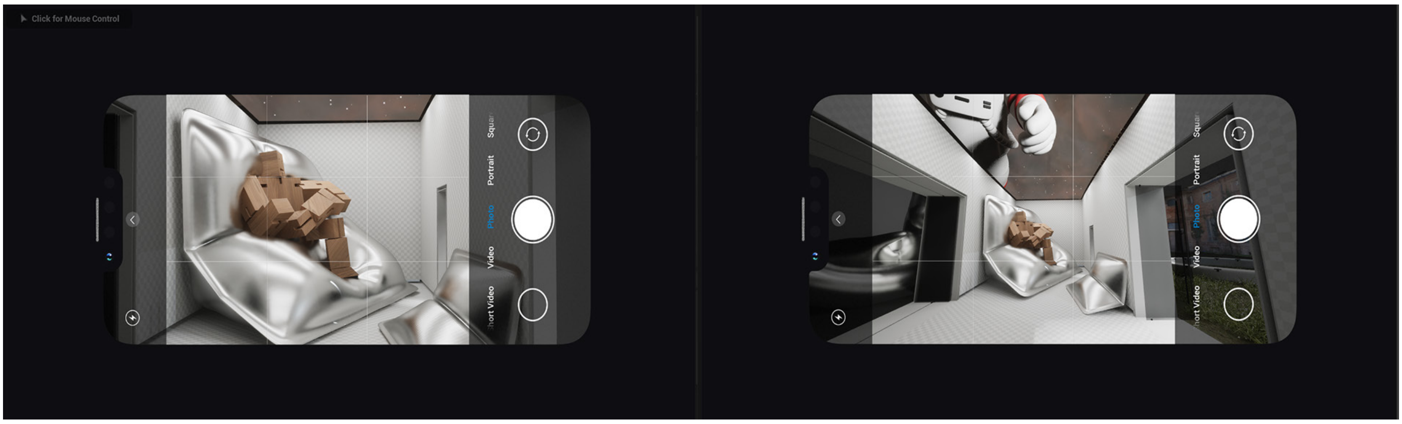


Figure 44. Scene in Unreal Engine, left to right: 1. FOV 90, 2. FOV 135. To activate the phone screen press key E, to change the zoom, you need to press the right mouse button. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

Additional animation of hands and objects (for example, reloading), with synchronized sound and visibility control during animation, was set up. In some cases, nodes with numerical and color parameters (`Constant`, `Vector3`) and texture tests were used—for example, checker patterns and attempts to implement `Box Projection`.

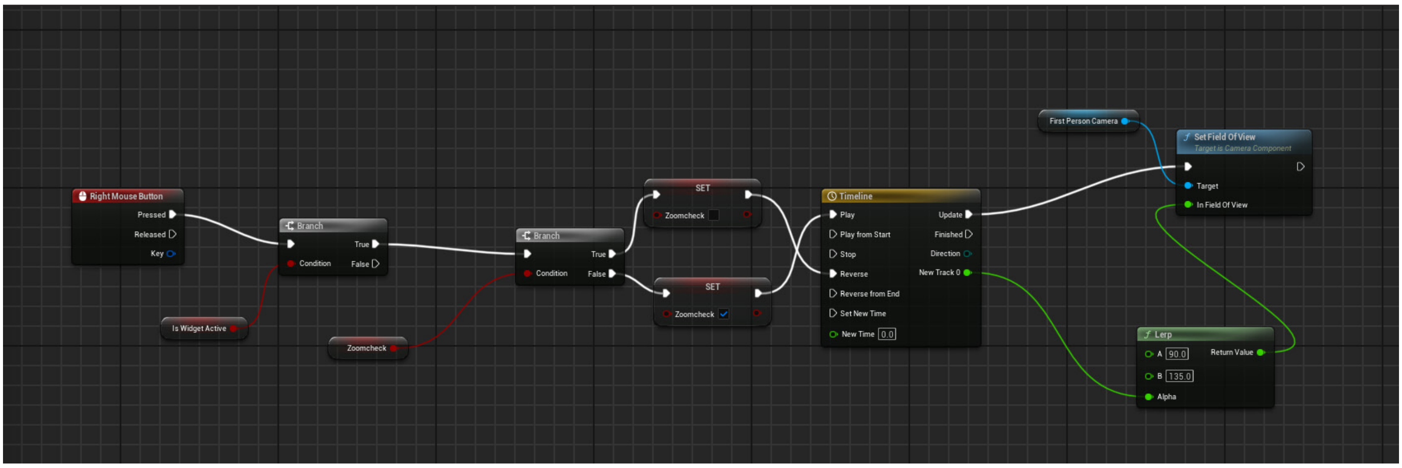


Figure 45. Right mouse button. Blueprint script in Unreal Engine. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

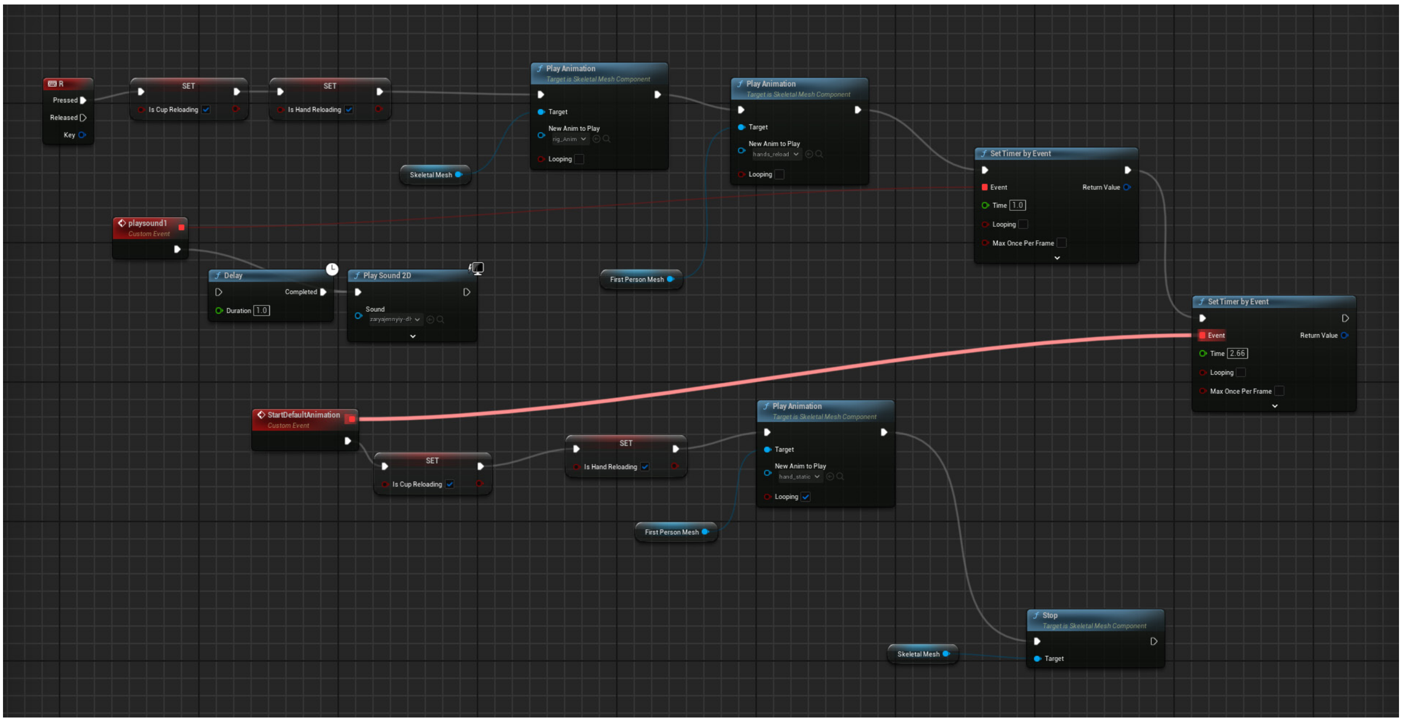


Figure 46. Right mouse button. Blueprint script in Unreal Engine. Source:Ivan Karnitckii, Restoration and integrated conservation B, 2024

As mentioned earlier, this application can also be used with a VR headset, but before doing so, two things must be done: first, reconfigure the controller from first-person to VR mode, and second, bake the shadows. The first step is straightforward, but the second is a bit more laborious—possibly optimizable, but I have not found a perfect solution yet. With real-time lighting, VR FPS dropped to 20 in my case, which was not comfortable for the user experience; the solution is to bake the light into a diffuse texture. Reflections can also be baked if needed, but there are few reflective objects in this scene, so baking light alone should be enough to reach a comfortable 60+ FPS in VR [100]. For shadow baking, you need a custom shader—since the shader obtained by transferring in .usd format does not support baked light maps.

3.7 Key takeaway.

As a result of this work, a first-person simulation was created, capable of maintaining a stable 45–50 FPS. This made it possible to accurately model a scenario of digital preservation for a heritage site in

Figure 47. Example of the final lens - demostration of Ar simulation. To view: open Snapchat and scan the snapcode.Source: Ivan Karnitckii 2025, Restoration and integrated conservation B, 2024

3.7 Key takeaway.

an AR environment—without the technical constraints of mobile devices. This experiment demonstrates how the preservation of architectural objects could look if there were no issues with occlusion, complex shaders, or limited computing resources. Thanks to the use of modern graphics technologies, we are much closer to achieving truly realistic visualization, and the dynamics of the industry—as described in "The Evolution of 3D Graphics in Video Games"[1]—suggest that this level of quality will soon be possible even on mass-market devices.
It is noteworthy that solutions like the Aximmetry plugin for Unreal Engine already make it possible to approach these results, albeit still with some technical and organizational limitations. This opens up new horizons for professionals working in digital conservation and the presentation of cultural heritage, as well as for demonstrating the process of aging and transformation of monuments as a reflection of society itself.
In this simulation, I combined the real layer of the Stabs showroom with an abstract one, where the avatar of the seller can be the Venus of Willendorf and the visitor can appear as a giant wooden figure, and instead of the ceiling we can see a portal into space. This is only my own vision of this place, but nothing stops us from replacing one virtual space with another — it is possible to see the space as it was in the times of Ludovico Bo or to create an even more fantastic scene. Instead of many words, **a short video run can be watched on the previous page, since augmented reality also makes it possible to bring this thesis to life.**

04| Case study 3. Old Nisa.

4.1 Introduction.

Having considered the previous two case studies, where the main focus was on scale, urban context, and working with space, it is now logical to move to a new, no less important dimension—museography. In this third case study, **I focus on the representation of an archaeological context within a museum exhibition.** While I previously noted that museums are becoming increasingly digitalized, here I will discuss in more detail how digitalization is changing the museum experience.

Digitalization allows museums not only to digitize works of art, but also to create new formats of interaction with visitors. Modern museums offer online collections with high-quality images of exhibits, video tours, digitized archival documents, and even three-dimensional models of monuments that can be viewed in detail. Many museum platforms provide personalization functions: users can create thematic selections, save favorite objects, or receive recommendations based on their interests. To maintain engagement, gamified elements are used—quests, quizzes, audio guides, virtual tours, and multimedia stories. All of this makes the digital museum experience accessible, interactive, and personalized for a wide audience. As noted on the SDT Museum website(Self-Determination Theory Applied To Museum Website Experiences): "Their efforts include digitizing cultural heritage objects into image, audio, video, or 3D representations... offering visitors personalized navigation, visual richness, and the opportunity to explore collections in-depth and at their own pace" [33].

As an example of such museum practices, one can mention Google Arts & Culture[101], which allows users to discover collections from many museums online. In the field of augmented reality, a particularly interesting example is the collaboration project between Snapchat and the Louvre—"Egypt Augmented." This is a series of AR experiments that allow visitors to see ancient Egyptian monuments in their original appearance. Using the Snapchat camera or QR codes (snapcodes) next to the exhibits, visitors can observe restored colors, decorations, and missing details on objects such as The Naos of Amasis, the Hall of Ancestors of Thutmose III, and the Dendera Zodiac. In addition, a virtual obelisk

appears in the Louvre courtyard, and users around the world can try on ancient Egyptian funerary masks via Face Lens. This project, created in collaboration with the museum's curators, clearly demonstrates how modern AR technologies make the museum experience more interactive and educational, literally bringing lost cultural heritage back to life [102].
Continuing this line, the next case study project involves the development of a model for an exhibition in Rome. This model is a scaled-down copy of the settlement of Old Nisa, where the Geomatics Lab for cultural Heritage of the Polytechnic University of Turin is conducting geomatics studies in cooperation with archaeological research. Under the guidance of Antonia Spano, my task is to link the information accumulated over years of Old Nisa research with a physical model of the territory. I plan to apply augmented reality tools to create an immersive experience and to integrate digital data with the physical object. This concept fully aligns with the objectives of the Piano Nazionale di Digitalizzazione del Patrimonio Culturale, offering a new way of showcasing and preserving heritage objects in the digital age.

4.2 Old Nisa.

Nisa is one of the oldest and most important cities, the first capital of the Parthian Empire (3rd century BC – 3rd century AD), located in present-day Turkmenistan, about 12 kilometers southwest of Ashgabat. The city was not only the residence of the Arsacids, but also an important political and cultural center, as well as a hub of strategic and trade routes where Persian, Greek, Roman, and Central Asian cultures intersected. The Nisa complex consists of two parts, situated on two hills about 1.5 km apart—Old Nisa and New Nisa. Old Nisa housed the royal citadel and the main palaces, while New Nisa was the city itself, which continued to exist even after the fall of Parthia. After the conquest of the Parthian Kingdom in 224 AD, the city gradually lost its significance, but life in New Nisa continued up to the Middle Ages. In the 12th century, the city was destroyed by the Mongols and eventually fell into decline [103].
Since the 1930s and up to the present day, Nisa has been the subject of major archaeological expeditions, with Turkmen, Russian, Italian, and other international teams participating [103]. Thanks to the preservation of its cultural layer and the uniqueness of its finds, Nisa was included in the UNESCO World Heritage List in 2007 [104] as an outstanding monument of Parthian culture, vividly illustrating the blending of Eastern and Western traditions.

To understand the history of Nisa's study, it is helpful to highlight the main stages and key figures [103,105,106]:

- **1930–1936:** The first planned expedition of Turkmenkult, led by A.A. Marushchenko.

- **1946–1967, 1975:** The YUTAKE (South Turkmenistan Archaeological Complex Expedition), led by V.N. Masson. Excavations at New Nisa were carried out over six seasons (1946-1949, 1955, 1958) but remained largely exploratory.

- **1991:** Parthian Expedition (leader: V.N. Pilipko), a joint expedition of the Institute of Archaeology of the Russian Academy of Sciences, Turkmen State and Moscow State Universities, and the Leningrad branch of the Institute of Archaeology.

- **1992–2005:** Russian expedition led by V.N. Pilipko.

- **1990–present:** Italian expedition of the University of Turin, directed first by A. Invernizzi and later by Carlo Lippolis. Since the 2010s, the mission — CRAST (Centro Ricerche Archeologiche e Scavi di Torino per il Medio Oriente e l'Asia) — has focused on the investigation of Old Nisa and on advanced digital documentation of the site

Figure 48. Panorama of Old Nisa. In the distance on the right, the citadel of New Nisa can be seen. Source: Muradov et al., 2023

4.2.1 Alexander Alexandrovich Marushchenko.

It is fitting to begin this overview with Alexander Alexandrovich Marushchenko, whose work marked the start of systematic study of Old Nisa. Thanks to intensive and diverse research conducted over

almost a century, Nisa has become a unique site for cooperation between specialists from different countries and schools. Each stage of archaeological work not only revealed new facets of the ancient city but also contributed significantly to the development of methodologies and approaches for studying historical parthian heritage.
Particularly important were the individuals who stood at the origins of Nisa's research and at various stages set the direction of studies. It was through their efforts that a scientific community was formed around the site, chronologies were refined, and new finds and sources were introduced into academic circulation. Let us take a closer look at the key archaeologists whose work has allowed a new perspective on the legacy of this unique complex.

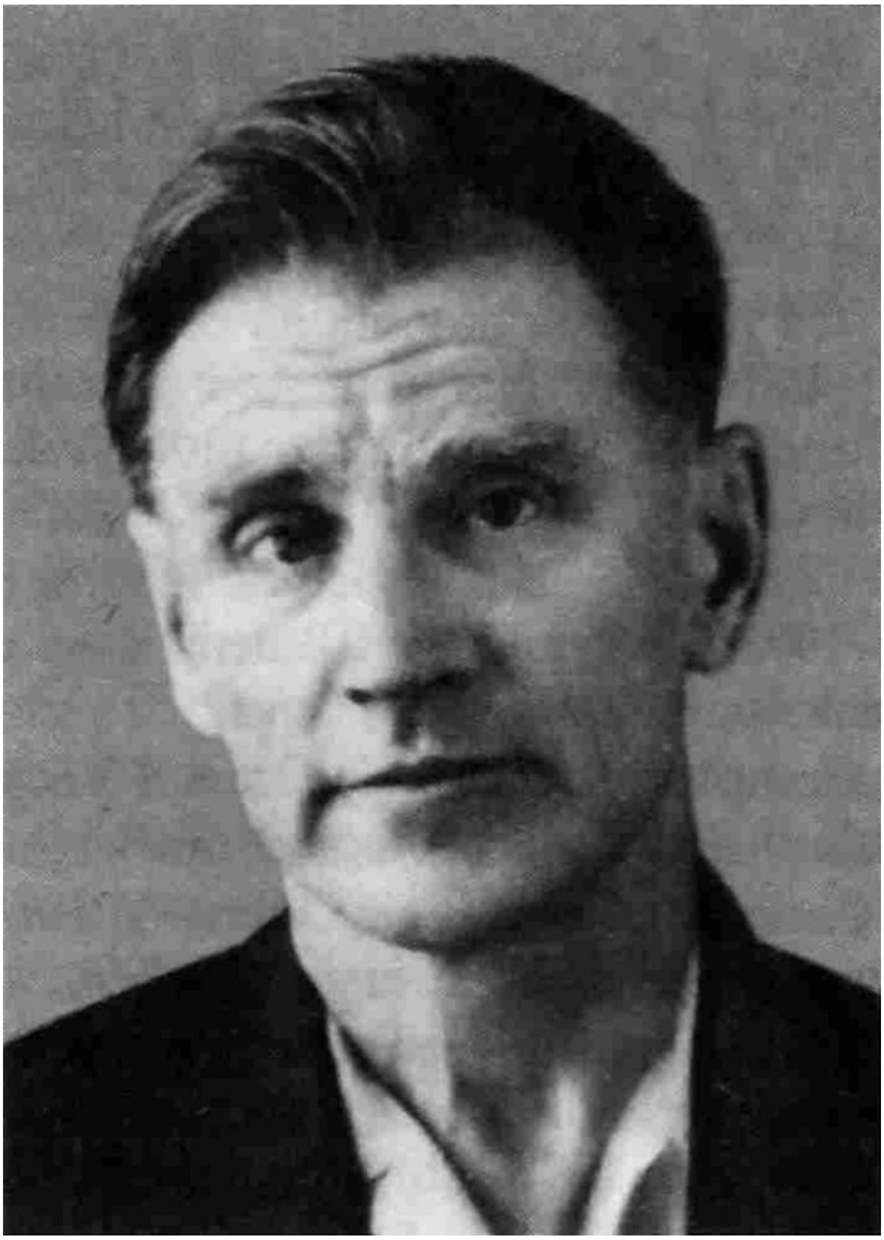


Figure 49. Alexander Alexandrovich Marushchenko. Source: Pilipko, 2005

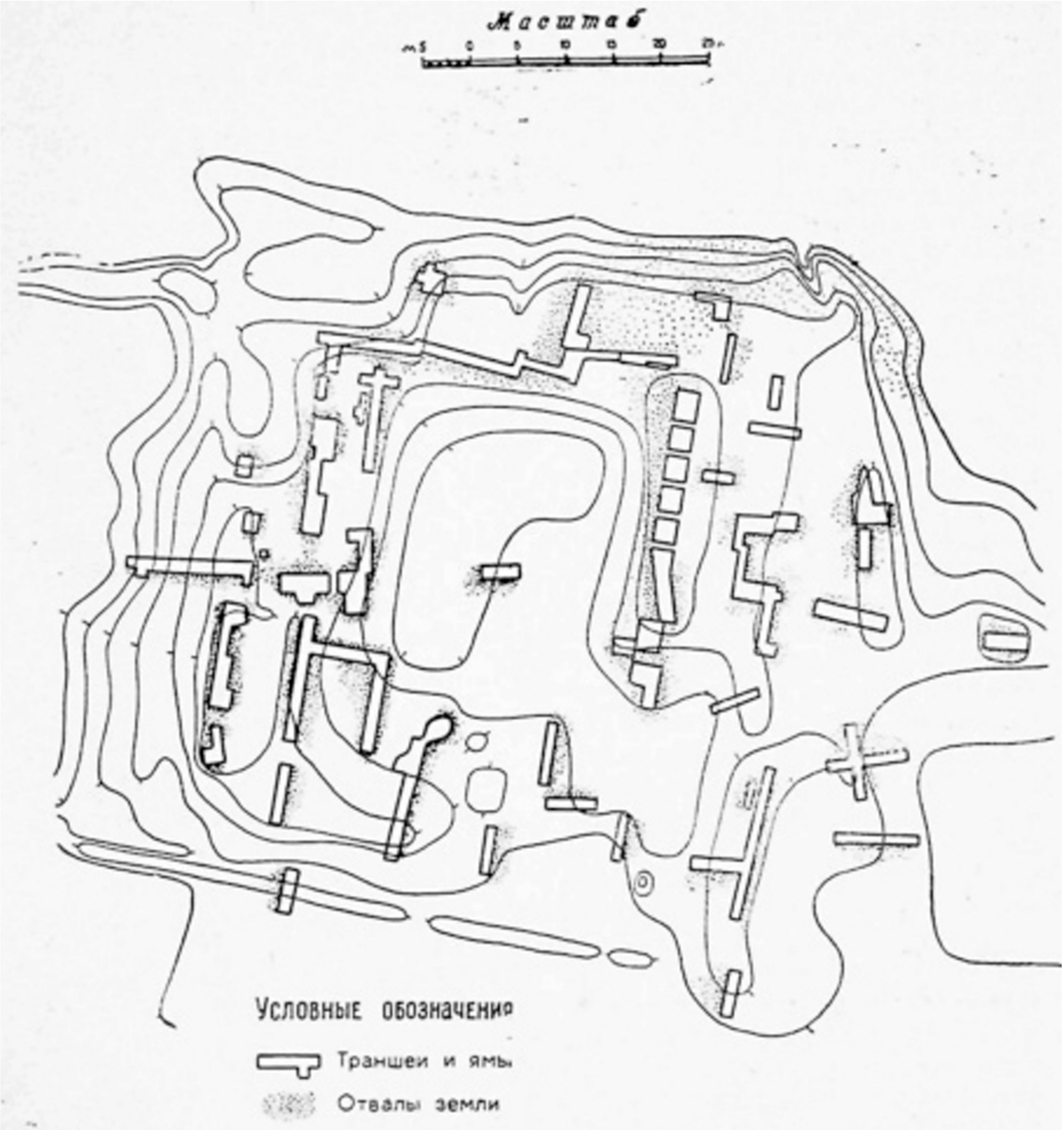


Figure 50. Plan of trenches and pits excavated on the Northern Complex of Old Nisa in 1935–1936. Survey by B.L. Litvinsky, 1948.Source: Masson & Pugachenkova, 1959

In 1930–1931 and 1934–1936, under the leadership of Alexander Alexandrovich Marushchenko—a distinguished Soviet archaeologist considered by his contemporaries to be an expert on Turkmen

monuments—major archaeological excavations were conducted in the southern part of Old Nisa by Turkmenkult. Marushchenko was not only the discoverer and researcher of Old Nisa, but also of other key ancient sites in the region, distinguished by his enthusiasm, breadth of vision, and deep knowledge of Turkmenistan's culture [107,108].
The results of the expeditions under his direction were major discoveries. First and foremost, the ancient site of Nisa was localized: excavations confirmed that Old Nisa indeed contains ruins belonging to the Parthian era. It was proven that Nisa is not a medieval or later monument but the actual residence of Parthian kings, corresponding to historical sources. In the course of work in the southern part of the site, trenches and small pits uncovered sections of buildings, corridors, and walls, allowing the creation of the first (albeit idealized) plan of the southern ensemble of Old Nisa.
Marushchenko's expedition was notable for its comprehensive approach: excavations were conducted in different parts of the site, including trenches on the northern hill, which provided a generalized picture of the structure and chronology of the monument [108].
After Marushchenko's initial discoveries, the next large-scale expedition took up the baton of Nisa research in the postwar period.

4.2.2 Mikhail Evgenievich Masson.

Next significant stage in the study of Nisa was the work of the South Turkmenistan Archaeological Complex Expedition (YUTAKE), which operated in the postwar years. The leader of this expedition was Mikhail Evgenievich Masson (1897–1986)—a prominent Russian orientalist and archaeologist, academician of the Academy of Sciences of Turkmenistan (since 1951), founder of ancient and medieval archaeology in Central Asia. He was the organizer and long-term leader of YUTAKE, which operated from 1945 to 1977. Among the expedition's members was his student and later wife, Galina Anatolyevna Pugachenkova, who was the first to scientifically substantiate the existence of a distinct Central Asian ancient art and to consider Parthian architecture as an independent, creatively significant direction. Among other students of M.E. Masson were V.M. Masson, Z.I. Usmanova, V.N. Pilipko, and others [109,110].
The YUTAKE expedition, led by M.E. Masson and other specialists, was the first in Turkmenistan to apply a systematic scientific methodology, including archaeological-topographical surveys, the division of areas into squares, layer-by-layer recording, and meticulous stratigraphy. The results of many years of work included uncovering the structure and topography of the ancient city, confirming Nisa's status as the first residence of the Parthian kings and one of the main centers of the ancient East. Unique complexes were discovered: ceremonial palaces, temple structures, utility rooms (including wine storages and khumkhanas), as well as a large burial necropolis [108].
Of particular significance was the discovery in the northern complex of the so-called "archive"—about two thousand ostraca with business records in the Parthian language. These documents became key written sources for the history of Parthia: "...Soviet archaeologists recovered from the cultural layers about two thousand ostraca from the end of the 2nd–1st centuries BC, which are the first local historical written sources from the very heartlands of Parthia..." [108]. In addition, the expedition discovered and rescued the famous ivory rhytons—works of Hellenistic and Eastern art with no analogues in Central Asia: "...an outstanding event was the discovery in Old Nisa of the first residence of the Parthian kings, almost literally a treasure trove of numerous, highly artistic Parthian rhytons..." [108].

Figure 51. M.E. Masson and his wife G.A. Pugachenkova. Source: Turkmenistan.gov.tm, 2021

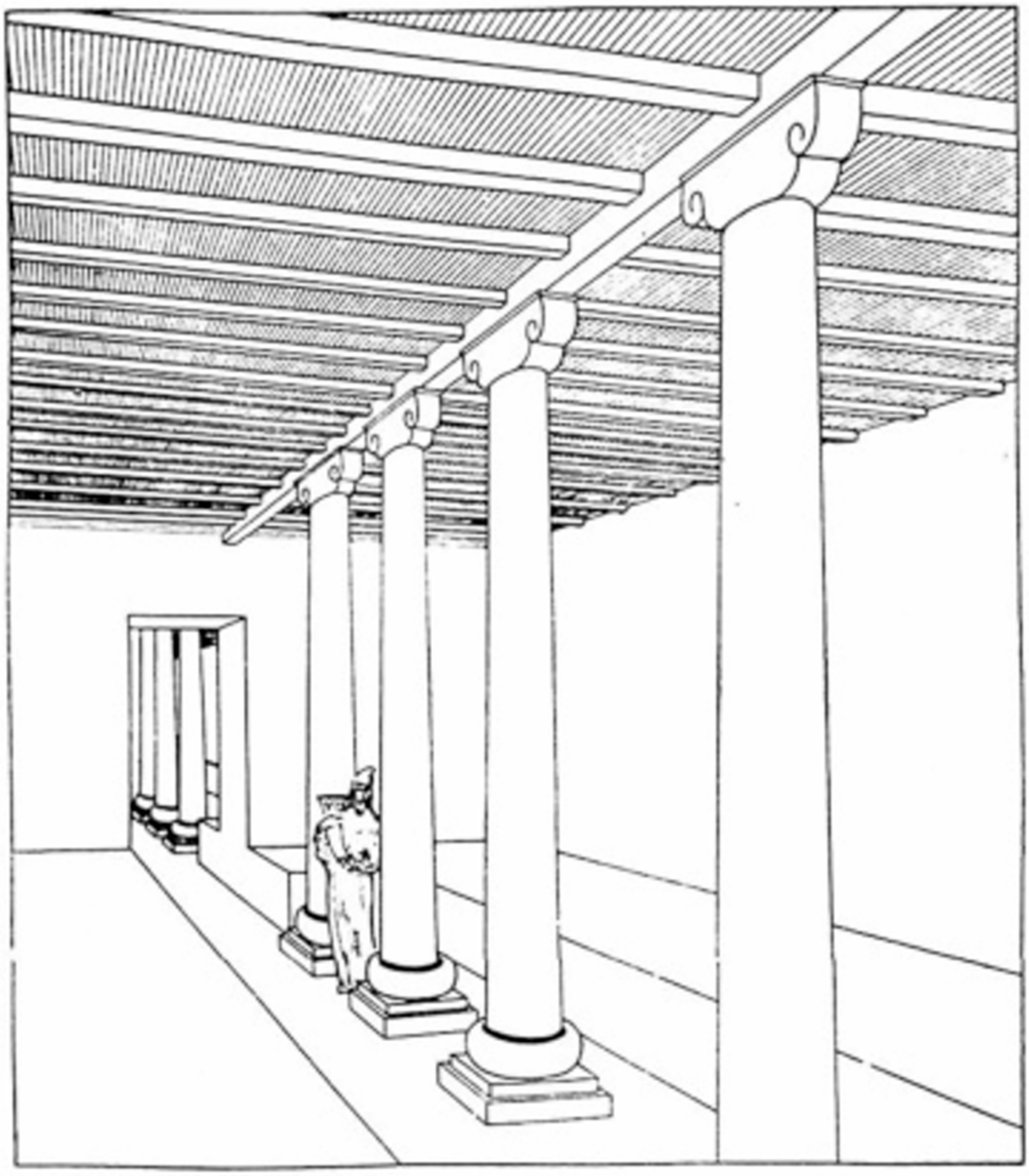


Figure 52. Hall of Rhytons. Reconstruction by G.A. Pugachenkova. Source: Masson & Pugachenkova, 1959

The work of YUTAKE not only greatly enriched our understanding of the history, culture, and daily life of the Parthian period but also set a new standard for archaeological research throughout the region: “The archaeological study of Nisa was conducted according to the unified scientific methodology adopted by YUTAKE...” [108]. Thanks to the efforts of the expedition, a number of ideas about the cultural development of Parthia and all of Central Asia were revised and clarified, and the site itself became one of the most important objects of world archaeological heritage.
M.E. Masson’s and his colleagues’ work at Nisa took a central place in archaeological research in Central Asia. In subsequent decades, research at Nisa not only continued but expanded, as new generations of specialists became involved, continuing and developing the scientific traditions established by their predecessors. One of the leading researchers of Nisa was Viktor Nikolaevich Pilipko, who managed to bring the study of the complex to a fundamentally new level.

4.2.3 Viktor Nikolaevich Pilipko.

A student of M.E. Masson and G.A. Pugachenkova, Viktor Nikolaevich Pilipko continued Nisa research and became one of the most renowned specialists in the ancient archaeology of Central Asia. He is the author of more than 200 scholarly works, many of which are dedicated to the monuments of Turkmenistan. Born in the Novosibirsk region, Pilipko graduated from the Faculty of History of Tashkent University. Since the 1960s, he has actively participated in and led archaeological expeditions, specializing in ancient monuments of Southern Turkmenistan, especially Old and New Nisa. He defended his candidate dissertation "Settlements of Northern Parthia" in 1971, and his doctoral dissertation on Parthian culture in the region in 1989. Since 1995, he has been a leading researcher at the Institute of Archaeology of the Russian Academy of Sciences and has continuously continued fieldwork at the Nisa sites, largely thanks to which these sites were included in the UNESCO World Heritage List [111,112].

Figure 53. Viktor Nikolaevich Pilipko. Source: Muradov et al., 2023

Pilipko's work related to Nisa can be roughly divided into three stages:

- **First stage (late 1970s – early 1980s):** preparatory surveys and initial clearings at Old Nisa. In 1979, under Pilipko's direction, the first major clearing of the Building with the Square Hall (ZKZ) took place, marking the start of his independent research at this unique site. Classical methods of archaeological excavation were used: manual recording of layers, creation of topographical plans, and collection and systematization of materials. This work made it possible for the first time to gain a holistic understanding of the preservation and structure of the main buildings of the citadel. At this time, a team was formed, strategic excavation targets were identified, and preparation began for large-scale research. The significance of this period lay in creating a solid base for subsequent work and identifying prospects for further archaeological study of Nisa as a whole [111,112].

Figure 54. The example of ostraca CH12.01. Source: Muradov et al., 2023

- Second stage (1980–1994): the period of the Parthian Expedition, when Pilipko led systematic and comprehensive excavations of Old and New Nisa, making this site one of the most studied centers of the Parthian kingdom. During these years, the Square Hall, Round Hall, tower-like and utility structures, small and eastern towers, and the White Room were thoroughly investigated, with numerous stratigraphic trenches and architectural clearings carried out. Particularly valuable are the collections uncovered during this period: thousands of ostraca with administrative records that for the first time allowed reconstruction of the administrative and economic system of Parthian Nisa. Rhytons, terracottas, fragments of wall paintings, coins, and household items were also introduced into academic circulation. The use of modern methods of stratigraphy, architectural recording, and photofixation at that time, as well as cooperation with restorers, made it possible to study in detail the stages of construction and reconstruction of the fortress. As a result, many scientific ideas about the internal structure of the citadel, its cultic and economic role, and the interaction of local Parthian tradition with Hellenistic and Eastern cultural heritage were revised. Materials from the expedition formed the basis of numerous publications, monographs, and catalogues, and the scientific conclusions were included in Pilipko's monograph "Old Nisa" (2001) [111].

- Third stage (post-Soviet period, 2001–2019): the work of the Nisa detachment of the Institute of Archaeology RAS and international research consortia. Regular excavations resumed, with a focus on comprehensive study and conservation of the Tower structure, the Median block, as well as stratigraphic sections and burial complexes of New Nisa (especially the North-Eastern excavation, Tower III).
The introduction of modern methods—3D documentation, georadar research, precise total station surveying—significantly improved the scientific accuracy of the research and led to updated master plans of both sites. For example, in 2006 "reconnaissance geophysical investigations were carried out with the help of the georadar Loza V ... most actively probing the Tower structure" [111]. Later, in 2018 "the participation of experienced operators with a total station made it possible to produce a new Master Plan of New Nisa and obtain precise data on the North-Eastern excavation" [111]. Work in 2012 also emphasized detailed documentation: "the walls of Arsacid time were exposed ... detailed fixation of structures and layers was carried out" [111].
Special attention was paid to the restoration of architectural and artistic finds, including wall paintings and sculpture, made possible through close cooperation with restorers and specialists from Russia and Turkmenistan. The results of this period not only greatly expanded our understanding of the chronology, structure, and functions of the monument, but also made it possible to prepare and justify the nomination of Nisa for the UNESCO World Heritage List (2007). Recent scientific discoveries and conservation projects have made Nisa a model of a comprehensive approach to the study, preservation, and popularization of archaeological heritage of world significance [111].

Figure 55. Old Nisa, central architectural complex. 1 – “Red” Building. 2 – Round Temple. 3 – Tower structure. 4 – Square Hall. 5 – “Palace”. Source: Lippolis, n.d.

4.2.4 Carlo Lippolis and Antonio Invernizzi.

In parallel with the work of Russian researchers, since the 1990s an Italian expedition together with Turkmen colleagues has been participating in excavations at Old Nisa.
Another key researcher is Antonio Invernizzi (early–mid 1990s; topographic survey completed in 1992), who plays an important role in the study of the art and material culture of Old Nisa as the leader and analyst of the Turin (Italian) expedition. He specializes in the re-edition and scientific interpretation of finds from both earlier (YUTAKE, Moscow, Turkmen) and contemporary expeditions. Invernizzi pays great attention to the artistic analysis of artifacts, especially clay sculptures from the Square and Round Halls, as well as unique items such as the silver disk with a stag protome. His research allows one to trace the close ties between Nisa's art and Hellenistic and steppe traditions, showing the complexity and originality of Parthian court culture. The scholar himself writes in 1996 that he is preparing a new, complete re-edition of the archaeological materials:
"a complete re-edition of the old materials is being prepared by the author of these lines" [113].
Thanks to Invernizzi and his colleagues from the Turin mission, accumulated and newly discovered monuments receive comprehensive scholarly analysis, and Nisa itself is seen as a unique center of cultural and artistic synthesis during the Arsacid era [103,113].

Figure 56. Antonio Invernizzi. Source: Accademia delle Scienze - Invernizzi

The expedition was later led by Carlo Lippolis, director of the Centro Scavi di Torino [114]. The Turkmen-Italian archaeological mission under Lippolis conducted extensive research at the site of the citadel's central ensemble, with the main focus being the so-called "Red Building" (1995; 2000–2006) and, earlier, the Round Hall (1990–1996; 1999); since 2007 the team has also worked in the south-western corner of the citadel (South-Western and Eastern Buildings) [114]. The Italian team emphasized stratigraphic excavations and the study of construction layers, which allowed for a more precise understanding of the phases of construction and reconstruction of the complex, as well as its layout and functions. Special attention was paid to architectural details, interior finishes, and artistic decoration of rooms. Numerous fragments of wall paintings, stucco, ornamental and floral decoration were identified, pigments and painting techniques were analyzed:

"Systematic excavations of the Red Building have revealed several construction phases, the use of colored plaster, decorative stucco, and a wealth of finds, including painted pottery and terracotta figurines. The combination of stratigraphic methods, restoration, and scientific analysis has provided a new understanding of the complex history and function of Old Nisa's central buildings" [114].

In addition, the mission assembled a large collection of ceramics, terracotta figurines, sculpture fragments, and household objects, and carried out comprehensive restoration and physicochemical analysis of the finds. Italian research has significantly revised previous ideas about the chronology,

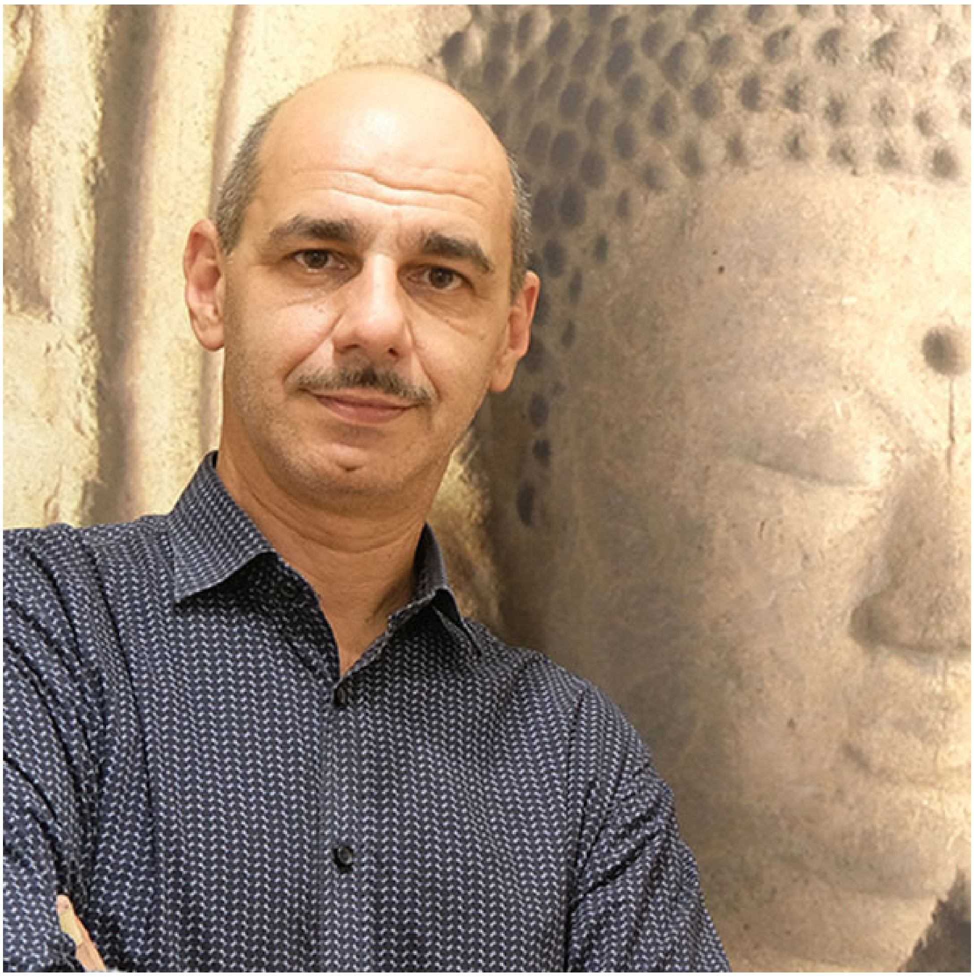


Figure 57. Carlo Lippolis. Source: CRAST Torino - Lippolis

functions, and appearance of the central ensemble of Old Nisa, and introduced new categories of artifacts into academic use, ensuring the preservation of unique monuments of Parthian architecture and art [114].

Since the late 2010s, the focus has shifted to the investigation of peripheral zones and comprehensive digital documentation. In 2019, stratigraphic excavations began on the northern boundary of the site (Sector M), where the first massive walls were uncovered, leaning against the outer fortification, with traces of representative architecture (including a stone column base with torus) — evidence of an "official" function. This complements the picture of the central ensemble and the southwestern economic block (South-Western / Eastern Buildings), where large storage jars (khums), ostraca recording wine, flour, and oil, as well as clay sealings had previously been documented — the administrative logistics of the citadel are becoming increasingly clear[106].

As of summer 2025, the Department of Geomatics at Polito, headed by Antonia Spano in collaboration with Carlo Lippolis, is preparing the results of digitization project of Old Nisa to be presented at an exhibition dedicated to recent research and 3D modeling of Nisa, as well as the creation of a physical model based on this data. The model is being printed and developed by architecture student Biwei Kong as part of her thesis project, while I plan to test the possibilities of interacting with the model using augmented reality.

4.3 Concept and environment selection.

Moving from the contributions of researchers to the practical implementation, the logical first step is to choose the environment in which the model concept will be developed. When I discussed the first case study on the House of Soviets in Kaliningrad, SnapAR was chosen as the AR engine—mainly due to its cross-platform capabilities and the ability to view content (lenses) directly through the Snapchat app. For the current project, SnapAR is also well suited, since the exhibition will be visited by many people with different smartphone models, so SnapAR enables almost any visitor to use augmented reality [57].

Regarding the physical model—the territory of Nisa is divided into rectangular tiles, which, according to Biwei Kong's concept, will be 3D printed and joined together with magnets. The model displays the excavation area, including building foundations, and these elements can serve as AR markers. For example, if the foundation is painted with a contrasting color, it becomes a tracking point for AR content. Visually, this fits into the architectural language where building walls on plans are shown with black fill.

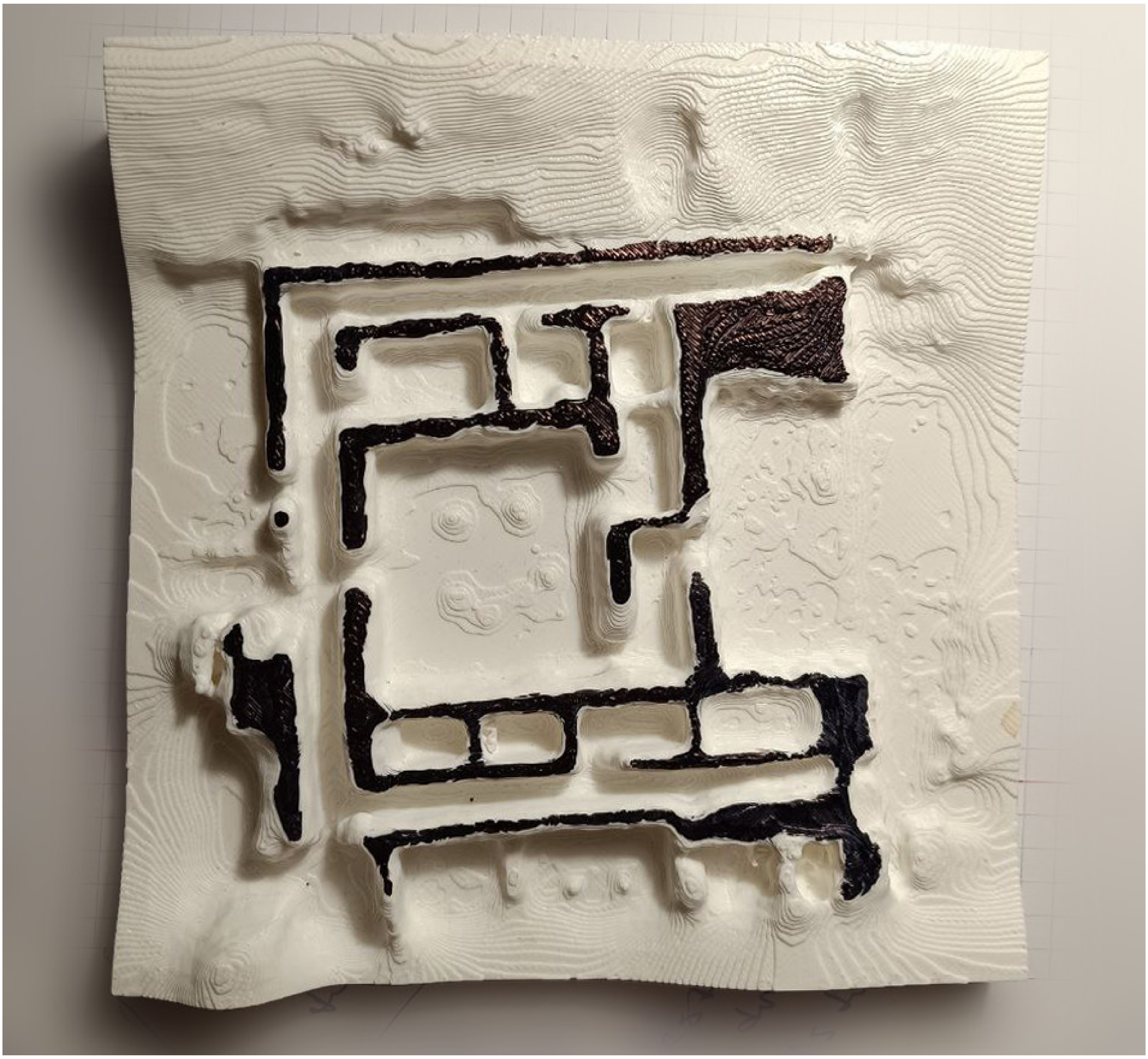


Figure 58. Example of the "Red building" model tile with marker sections applied to the walls. Source:Ivan Karnitckii, Geomatics Lab for cultural Heritage,CRAST, 2025

To illustrate the idea, I prepared a conceptual scheme for the project. Importantly, my proposal is not the main one for the exhibition, but rather an alternative: I won't be able to use the entire model. The idea is to create a hybrid effect, combining 3D printing, printed topographic diagrams/infographics, and augmented reality. I suggest a layout where a grid the size of one model tile is applied to a contrasting surface, with printed fragments of the model placed on this grid, either individually or in groups. Below these fragments or groups of fragments will be QR codes: by scanning them, the user will launch lenses with different AR content. Nearby, printed infographics will explain the corresponding areas.

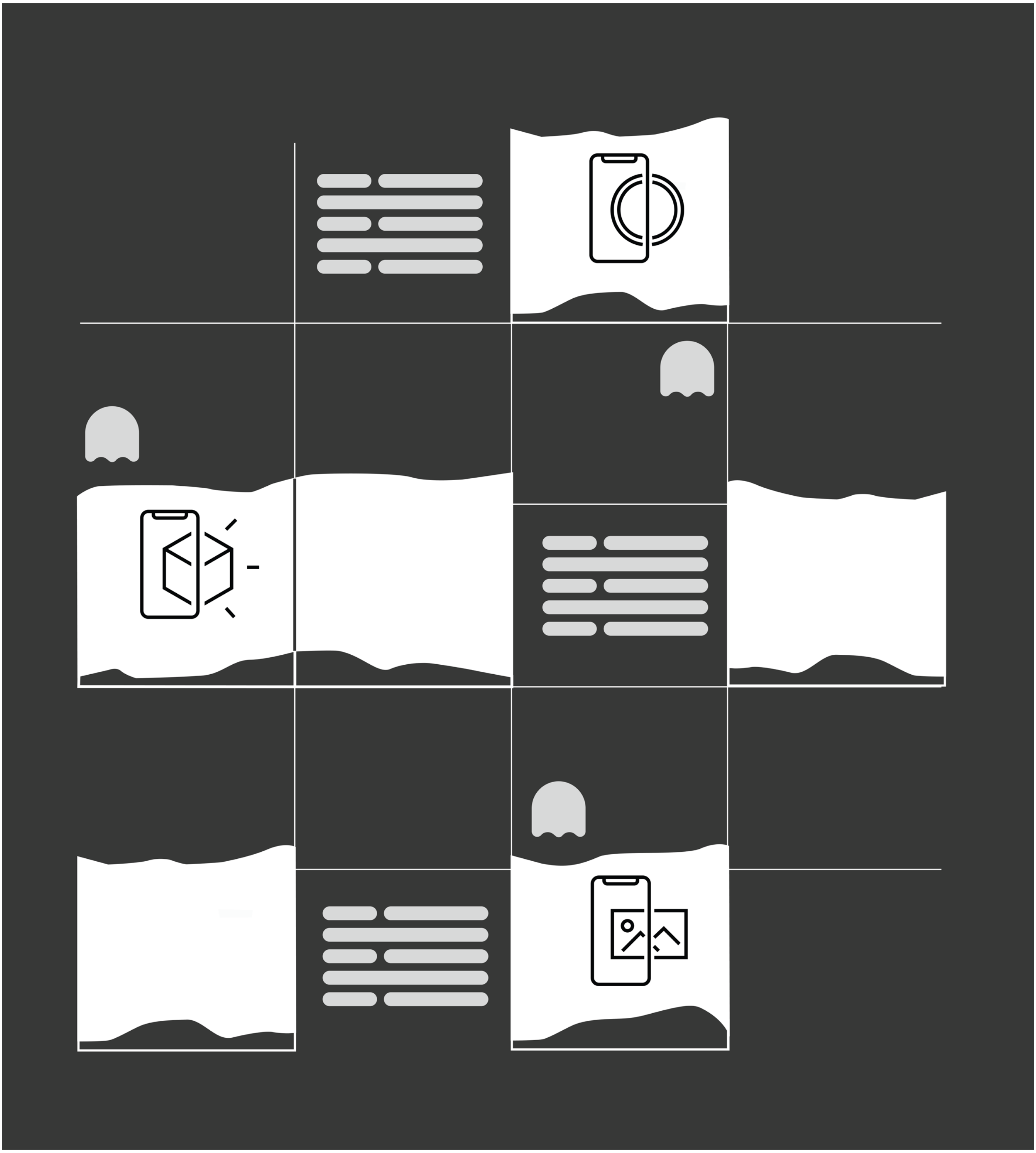


Figure 59. The diagram shows several layout tiles placed in their positions according to the plan of Old Nisa. Under some of the tiles there are ghost icons—snapcodes—that, when scanned, allow users to view various AR content such as panoramas, models, texts, and more. Next to the tiles, there are also textual descriptions. Source:Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

The content I use for linking to the model based on materials which provided by literature, CRAST and Geomatics Lab for cultural Heritage. At present, three types of AR content are linked to the tiles:

- 360 panoramas obtained from 3D scanning of Nisa,

- Brief historical summaries and information about the main archaeologists of Nisa,

- 3D scans of artifact exhibits found during excavations.

Thus, the chosen concept makes it possible to combine a physical model with digital technologies, making the exhibition both visual and interactive. Below, I will discuss each type of AR content used in this project in detail, as well as their preparation and integration into the model.

4.3.1 360 panoramas.

To create 360° panoramas viewable in AR, I used data obtained from 3D scanning of the site - images from the coaxial camera of Faro Scanner . For exporting the panoramas, the program SCENE LT was used. As a result, I obtained .png images at 10152×5076 pixels, with an average size of about 50 MB. This size does not meet the technical requirements for AR lenses in Lens Studio, where the maximum file size for publication is 8.5 MB[57]. To optimize, I reduced the texture size to 4048×2024 pixels in Photoshop and re-saved the files in .jpeg format, reducing the average size to 1.7 MB instead of 50 MB.

Figure 60. Panorama from coaxial camera of Faro scanner. Source: Geomatics Lab for cultural Heritage,CRAST, 2025

Next, I created a uv-sphere in Blender and correctly positioned the texture on the sphere's surface. The sphere with its assigned texture was exported as .fbx or .glb. In Lens Studio, the file is imported and the texture is applied to a flat shader. An important step for enabling camera rotation when viewing the 360 panorama was to set Device Tracking with Tracking Mode: Rotation. In this scene, a distinctive point is that the sphere geometry is not attached `as a child` to the camera in the hierarchy. Additionally, by adding an Orthographic Camera with a linked Screen Text to the hierarchy, I provided a label with an explanation of which excavation point the 3D scan was made from—this information is displayed on the smartphone screen when the lens is active.

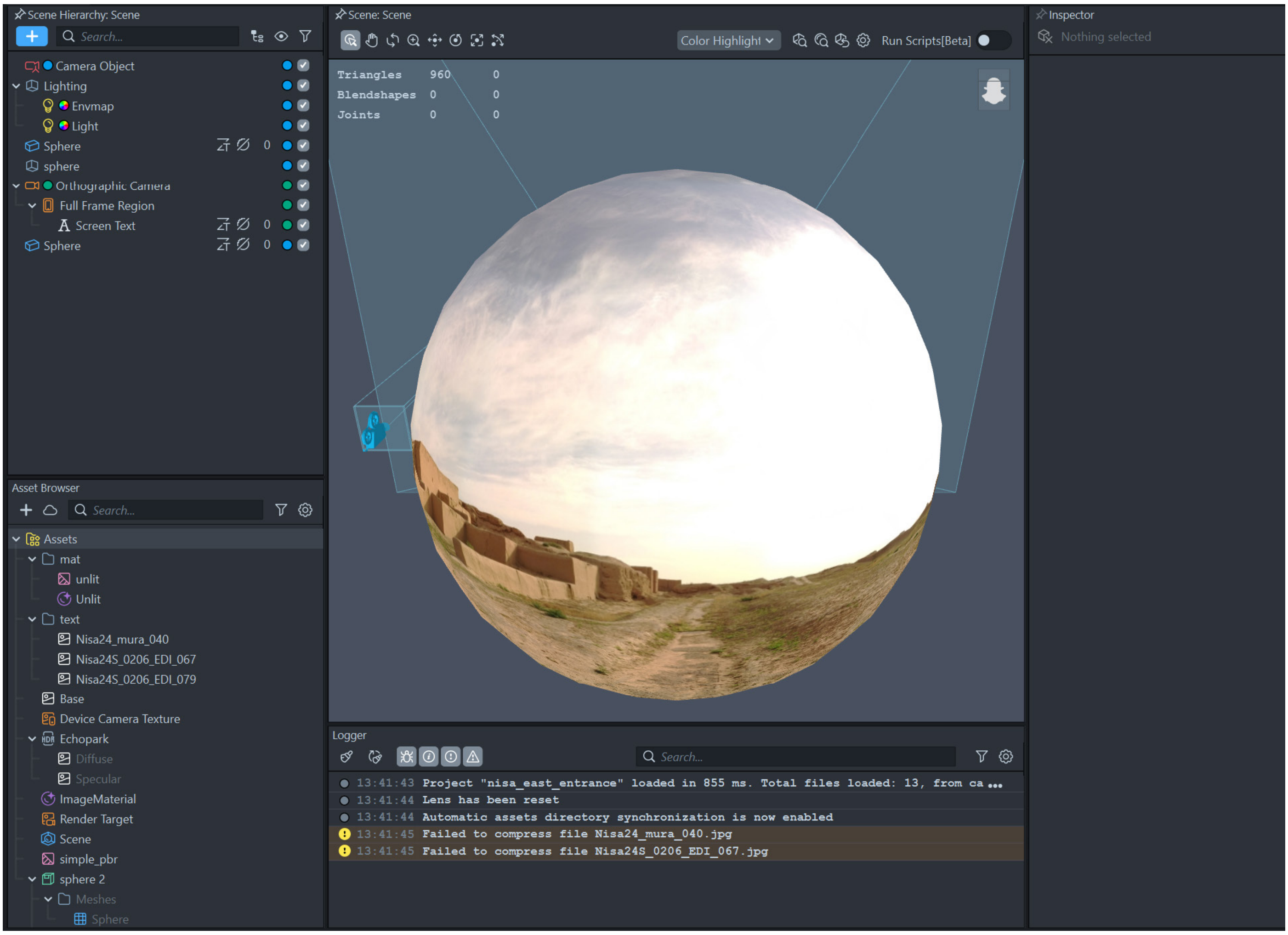


Figure 61. UV sphere with panorama texture in Lens Studio. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

Once the lens is ready, it needs to be published. In the publishing settings, activating use of the rear camera is mandatory. If this option is not enabled, the camera's behavior will be incorrect: for example, during testing with the front camera, when turning the phone right, the image would rotate left, and sometimes the panorama would "tilt" sideways.
As a result, three lenses were prepared: by scanning the Snapcode, a panorama of the corresponding excavation area can be viewed.

Figure 62. Lens results. Download Snapchat, scan the snapcode. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage,CRAST, 2025

4.3.2 3D artifact scans.

The second type of content is 3D models of artifacts found during the Nisa excavations, which are being digitized by CRAST. For demonstrating the models, I prepared a template: after scanning a Snap code and pointing the camera at a tracker, interactive icon-markers appear. By tapping on them, the user can view a 3D model of the artifact with an information card; tapping again returns to the markers.

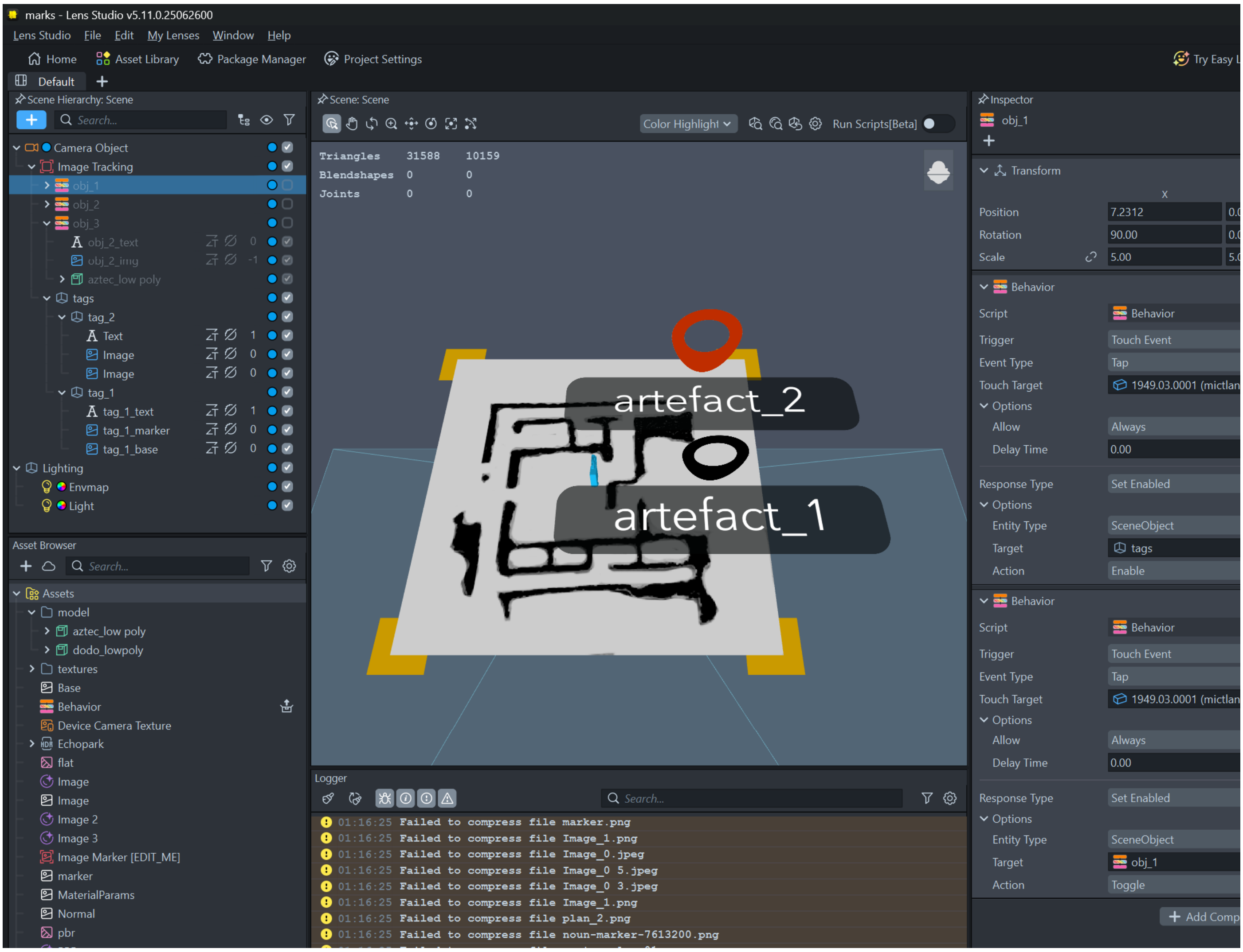


Figure 63. Scene hierarchy and tracker with markers in Lens Studio. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

For this scene, I linked the models to an image of a building plan from the excavations ("Red Building"). Switching between the model and the marker icon is handled by a `behavior script`, which is triggered by a `touch event`—when the relevant object is tapped. The script can make the model visible, invisible, or toggle its state (`enable/disable/toggle`). Behavior is configured individually for each object; for two models, I used a total of eight behavior scripts.

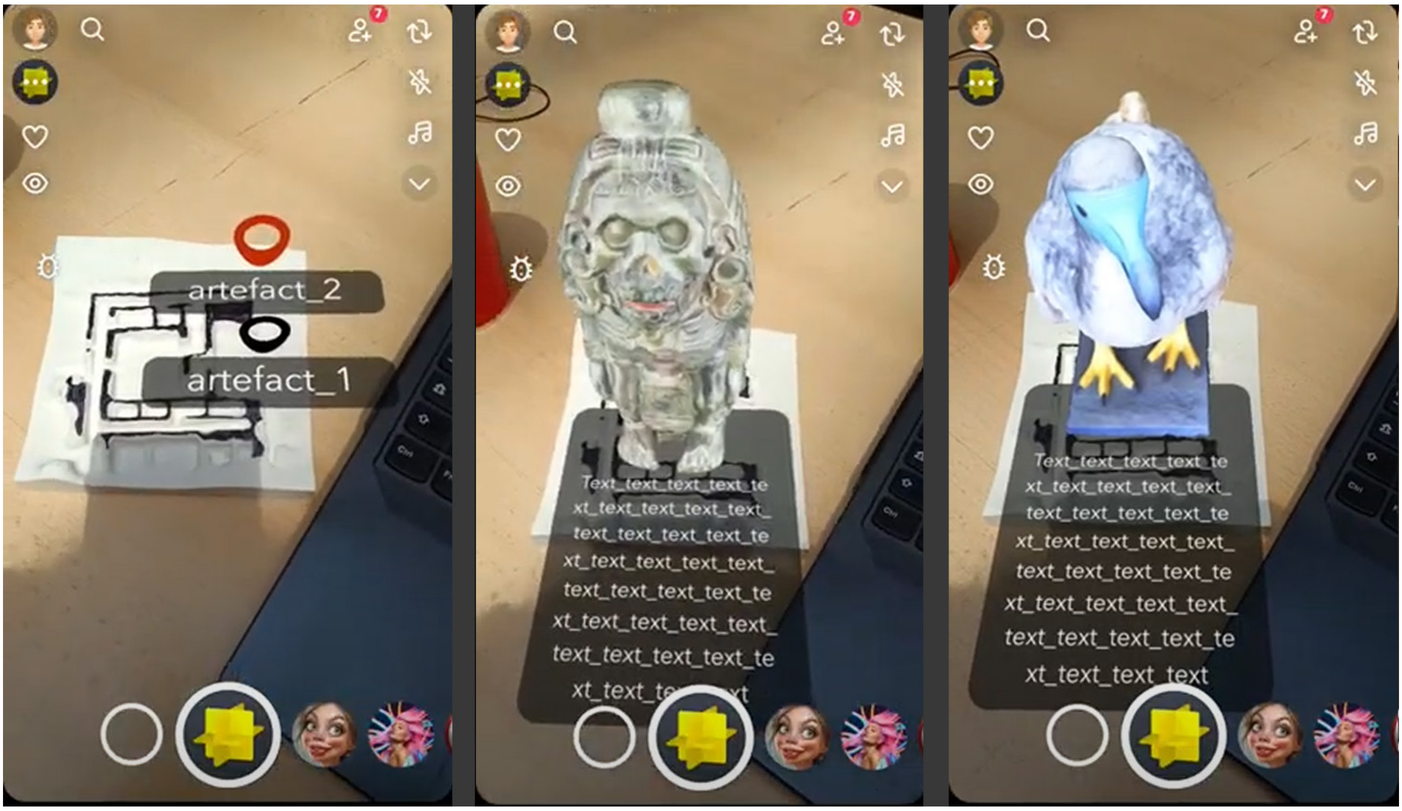


Figure 64. Example of a lens with 3D artifact models and info card.For the tes I used models from Sketchfab, for the final resul will change them on CRAST models. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

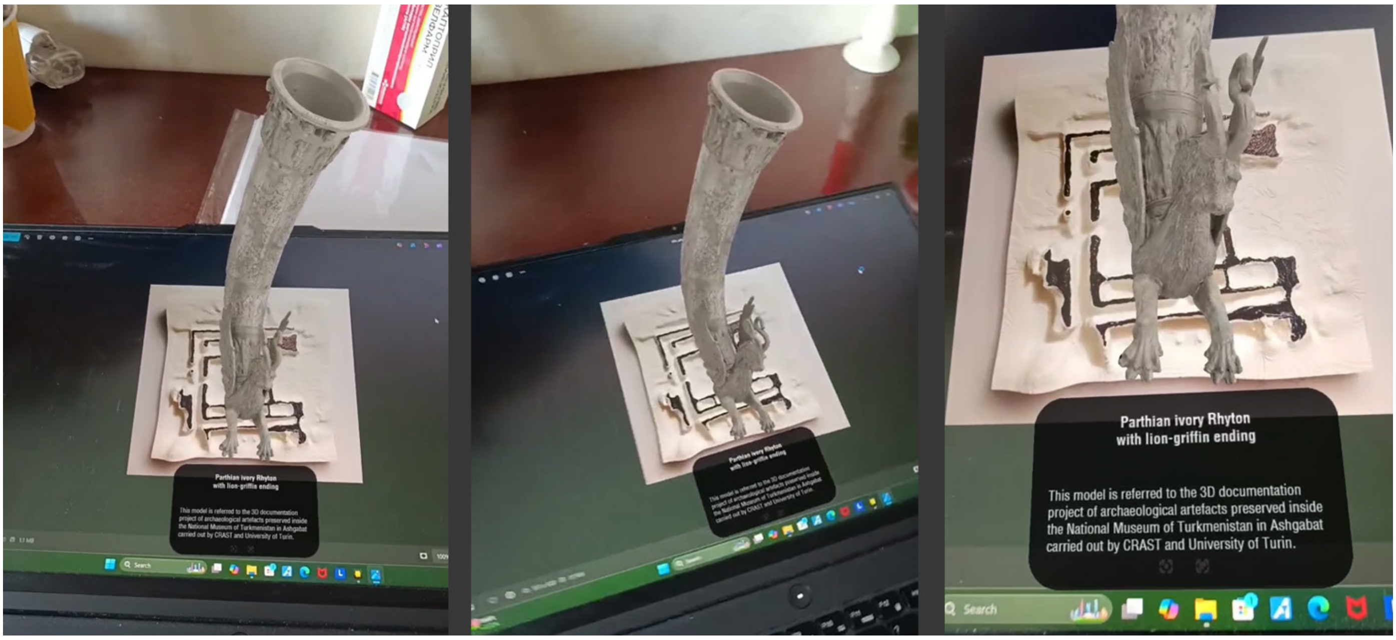


Figure 65. Example of CRAST provided model, lens without switching between different artefacts. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

4.3.3 Brief historical summary.

The last type of content is a brief historical summary, which I implemented using `pop-up widgets` on the smartphone screen. When the camera is pointed at a tracker, an icon appears, which can be tapped to activate a widget with information about Nisa. The widget is a container with photos and text, which can be scrolled up/down by swiping or closed by tapping outside the widget.

UI Scroll View

```
// UI Scroll View.js
// Event: onAwake
// Version 3.0
// Description : A Scroll View is a custom component that allows one to scroll one screen transform within the bounds of another.
// It can be used when content that takes up a lot of space needs to be displayed in a small area - for example a map, a long block of text or a long list of items.

// @input Component.ScreenTransform contentScreenTransform {"label" : "Content"}
/** @type {ScreenTransform} */
let contentScreenTransform = script.contentScreenTransform;

//@input bool useMask
/** @type {boolean} */
const useMask = script.useMask;

//@input float radius = 0.25 {"label" : "   Radius", "showIf" : "useMask", "widget":"slider", "min":0.0, "max":5.0, "step":0.01 }
/** @type {number} */
const radius = script.radius;

// @ui {"widget":"separator"}
// @ui {"label" : "<b>Scrolling</b>"}
// @input bool dragX = true {"label": "Horizontal"}
/** @type {boolean} */
let dragX = script.dragX;

// @input bool dragY = true {"label": "Vertical"}
/** @type {boolean} */
let dragY = script.dragY;

// @input int scrollType = 0 {"widget":"combobox", "values":[{"label":"Restricted", "value":0}, {"label":"Elastic", "value":1}]}
/** @type {number} */
let scrollType = script.scrollType;

//@input float elasticity = 0.5 {"label" : "   Elasticity", "widget":"slider", "min":0.0, "max":0.99, "step":0.01, "showIf" : "scrollType", "showIfValue": 1 }
/** @type {number} */
let elasticity = script.elasticity;

//@input bool inertia
/** @type {boolean} */
let inertia = script.inertia;

//@input float dampening {"label" : "   Dampening", "widget":"slider", "min":0.00, "max":0.99, "step":0.01, "showIf" : "inertia", "showIfValue": true }
/** @type {number} */
```

```
 * @returns {Rect} copy of rectangle
 */
function copyRect(rect) {
    return Rect.create(rect.left, rect.right, rect.bottom, rect.top);
}
/**
 *
 * @param {Rect} from
 * @param {Rect} to
 * @param {number} t
 * @returns {Rect} rect between `from` and `to` determined by ratio `t`
 */
function lerpRect(from, to, t) {
    from.left = lerp(from.left, to.left, t);
    from.right = lerp(from.right, to.right, t);
    from.bottom = lerp(from.bottom, to.bottom, t);
    from.top = lerp(from.top, to.top, t);
    return from;
}

/**
* Returns the number between `a` and `b` determined by the ratio `t`
* @param {number} a Lower Bound
* @param {number} b Upper Bound
* @param {number} t Ratio [0-1]
* @returns {number} Number between `a` and `b` determined by ratio `t`
*/
function lerp(a, b, t) {
    return a + (b - a) * t;
}

script.isDirty = isDirty;
script.markDirty = markDirty;

/** @enum { number } */
script.ScrollType = ScrollType;
/** @enum { number } */
script.ScrollBarType = ScrollBarType;

script.createEvent("OnStartEvent").bind(onStart);
```

Figure 66. Example of a UI Scroll View script. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

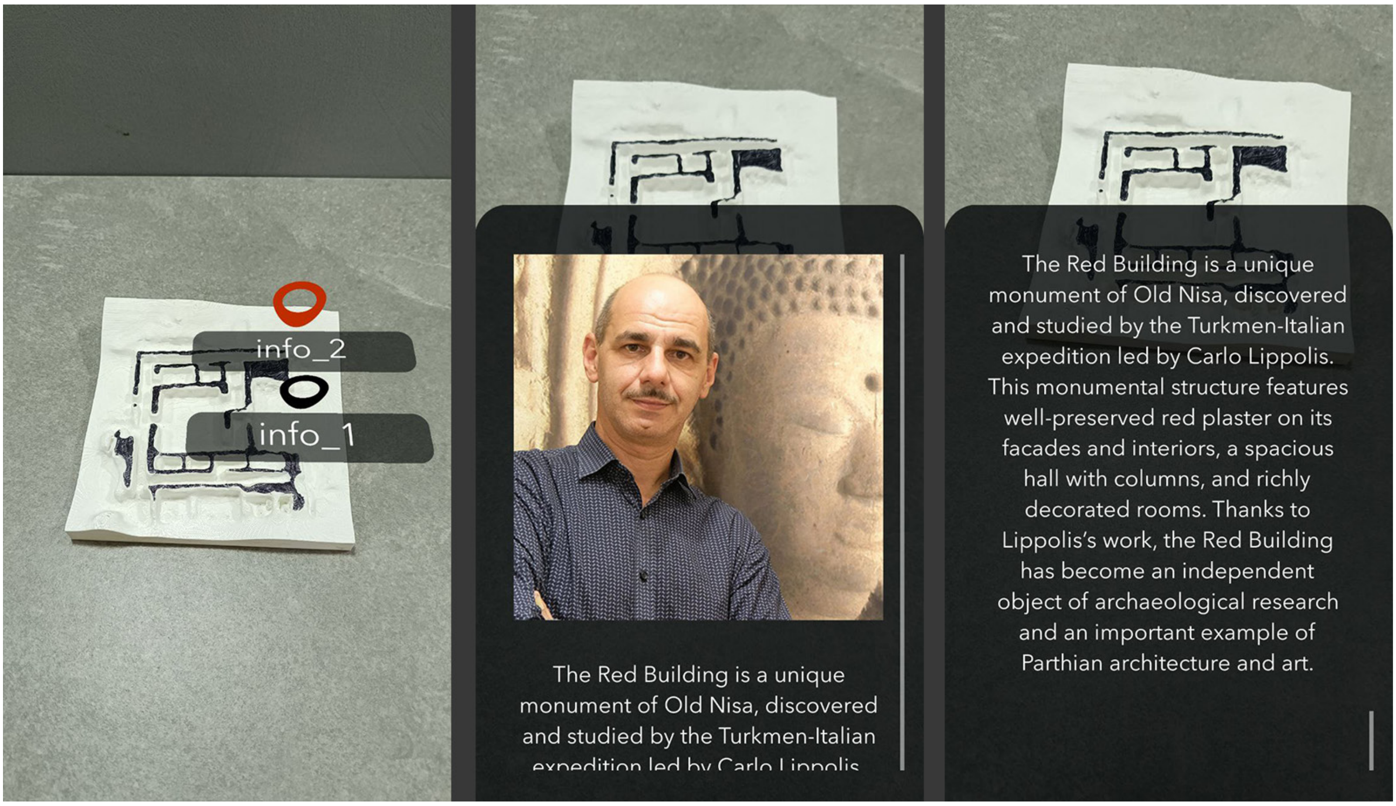


Figure 67.Example of a lens with a historical summary. Source: Ivan Karnitckii, Geomatics Lab for cultural Heritage, 2025

To achieve this, I used the camera scroll preset from Lens Studio assets. It allows you to set an area on the screen for scrolling content vertically or horizontally. The preset consists of three JavaScript files: the main one (`UI Scroll View`) and two auxiliary ones (`EventModule_101` and `DestructionHelper_100`), which are referenced by the main script—a total of about 1,100 lines of code. In the hierarchy, the script is placed inside the Screen Transform (Orthographic Camera component), with text and images added a`s a child` elements.
During setup, I encountered an issue where upward scrolling worked incorrectly: the text would slowly return to its original position. Since the script is quite large, I exported it to ChatGPT[115] for troubleshooting and was able to adjust the scrolling behavior as needed.
It is worth noting that although ChatGPT helped to solve the script issue—the return of the text to its initial position during scrolling—by suggesting that some lines of code be rewritten, this led to new problems in the script's behavior that I have not yet been able to resolve. At the moment, the text can be scrolled infinitely both upwards and downwards.
The icon in the layout can be tapped, and the switching logic works the same way as in the previous content type with 3D models. I wanted to show that by tapping similar icons, users can access different hidden content, creating their own exploration of the layout. In this case, I attached information about the Red Building, which we use as a marker, and a photo of Carlo Lippolis is italian archaeologists, one of the main researchers of this site,who contributed a lot to the studies of the Red Building.

05| Thesis conclusion.

The aim of this research was to define how an accessible augmented reality application may look and be applied in different environments, ensuring the preservation of cultural heritage and creating for the user the possibility of interacting with it. The work considered both the technological aspects of AR and its use in various cultural and geographical contexts.

The conducted case studies have shown that in many situations the main limitation of augmented reality is the performance of mobile devices. From this follow the problems of visualization quality and insufficiently realistic shaders. However, these very limitations stimulate creativity: in one of the cases it was demonstrated that stylization can become an effective solution for presenting the material, although it requires significantly greater effort from the author than simply loading a 3D model of a heritage object and attaching it to a marker. At the same time, it is worth emphasizing the quality of marker recognition technology and optimization in Snap AR: they allow digital content to be stably fixed and reproduced on a wide range of devices.

Another case illustrated the potential of AR technologies in the future: with the growth of hardware performance and the development of such platforms as Aximmetry and Snapchat, the visual quality of AR is increasingly approaching the level of modern realistic games.

In general, augmented reality opens the possibility of seeing what is hidden from everyday view: lost cultural heritage, its possible reconstructions, as well as inaccessible artifacts or even the process of archaeological excavations. It allows the creation of exhibitions with objects that cannot be physically delivered and provides a new dimension of museum communication.

Thus, by finding a balance between technical optimization and creative presentation, AR technologies become a tool for engaging wider audiences with the theme of cultural heritage, while preserving non-invasiveness and accessibility of perception.

become a tool for engaging wider audiences with the theme of cultural heritage, while preserving non-invasiveness and accessibility of perception.

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