BIM SPEED

VR/AR demonstrations of deep renovation scenarios

Deliverable report D7.5

Deliverable D7.5 (accompanying report): Version DRAFT, issue date on 31.10.2022

BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

VR/AR demonstrations of deep renovation scenarios

Deliverable report D7.5

Issue Date	31.10.2022
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Type	Report
Version:	DRAFT
Reviewed by	Jan-Derrick Braun (HTV), Piotr Dymarski (MOW)
Approved by	Timo Hartmann (TUB)
Dissemination	Public

Colophon

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

Change log

Description	Author	Date
Initial version Table of Content	Jessica Steinjan (HTV)	04.02.2022
List of specific for XR terms and abbreviations with links	Nadya Stamatova (ASP)	05.05.2022
Safety training scenario	Piotr Dymarski (MOW)	24.06.2022
Game design document (GDD) template and examples	Nadya Stamatova (ASP)	06.07.2022
Use cases & tools table; illustrations; references	Nadya Stamatova (ASP)	13.07.2022
Delivered illustrations for demo sites Vitoria 1, Vitoria 2	David Grisaleña Rodríguez (VIS)	26.07.2022
State of the art of XR in AEC industry	Rahul Girish (UNS)	26.07.2022
Adding Illustrations to parts state-of-the-art and demonstrations	Nadya Stamatova (ASP)	29.07.2022
Formatting texts and illustrations – 1st D7.5 version (uploaded to SharePoint)	Nadya Stamatova (ASP)	31.07.2022
Formatting texts and illustrations – 2nd D7.5 version (uploaded to SharePoint)	Nadya Stamatova (ASP)	25.08.2022
Finalizing Part2 by HTV	Jessika Stejnjan (HTV)	14.09.2022
Importing illustrations from the demonstrations in Malko Tarnovo and Varna, preparing for uploading the files of the Appendix 1 (XR applications) and Appendix 2 (videos) – 3rd version of D7.5	Nadya Stamatova (ASP)	08.09.2022
Formatting the 3rd D7.5 version, exporting as PDF, uploading with the appendixes to SharePoint for internal review	Nadya Stamatova (ASP)	10.10.2022
Improving the accompanying report after initial review and comments by Jan-Derrick Braun (HTV)	Nadya Stamatova (ASP)	21.10.2022
Meeting in Berlin with the reviewers Jan-Derrick Braun (HTV), Piotr Dymarski (MOW) and the BIM-SPEED coordinator Timo Hartmann (TUB). No more comments.	Nadya Stamatova (ASP)	28.10.2022
Adding the results of the AR tests on the Spanish demo sites, reported by David Grisaleña Rodríguez (VIS). Final formatting.	Nadya Stamatova (ASP)	31.10.2022
Adding links to the videos of Appendix 2, uploaded in the playlist "Demonstrators for VR/AR" in BIM-SPEED YouTube channel; adding 2 new references from a conference on 28 October 2022	Nadya Stamatova (ASP)	11.11.2022

Publishable executive summary

The deliverable analyses the state-of-the art of the use of the VR/AR in the AEC industry (focusing especially on building renovations); describes the demonstration results from the work on the Task 7.4 "VR/AR simulations of renovation scenarios"; points the contribution of the BIM-SPEED project in the domain of the XR for AEC; summarizes the conclusions and giving directions for future developing of use of the instruments of the extended reality in the AEC industry.

List of acronyms and abbreviations

AI: Artificial Intelligence
AR: Augmented Reality
AV: Augmented Virtuality
BEM: Building Energy Model
BIM: Building Information Modelling
BS: BIM-SPEED
DoA: Description of Action
ECM: Energy Conservation Measure
EEB: Energy Efficient Buildings
EPBD: Energy Performance Buildings Directive
EPC: Energy Performance Contract
ESCO: Energy Services Company
GDD: Game Design Document
GIS: Geographic Information System
HVAC: Heating Ventilation Air Conditioning
IAQ: Indoor Air Quality
IEQ: Indoor Environment Quality
IPMVP: International Performance Measurement and Verification Protocol
IPR: Intellectual Property Right
KPI: Key Performance Indicator
LCA: Life Cycle Assessment
LCC: Life Cycle Costing
LIC: Location Identification Code
LOD: Level of Development
LOG: Level of Geometry
LOI : Level of Information
M&V: Measurement & Verification
MEM: Model Element Matrix
MEP: Mechanical Electrical Plumbing
MR: Mixed Reality
nZEB: nearly-Zero Energy Buildings
PIC: Plant Identification Code
POE: Post Occupancy Evaluation
R&D: Research and Development

RES: Renewable Energy Source

RoI: Return on Investment

SLAM: Simultaneous Localization and Mapping

VR: Virtual Reality

XR: Extended Reality

Definitions

Business process

The Business Process describes the general task to be done in the design and construction phase to reach the Renovation Goal, e.g., energy analysis.

BIM use case

The BIM Use Case complies with BIM requirements. That means the **Business Process** is broken down into detailed use cases and automated processes and/or data analysis are implemented, e.g., BIM based energy analysis.

Clash Detection

Clash detection is a method of checking BIM model elements for the geometric intersection. The method is used in the context of BIM coordination and aims to avoid collisions.

Deviation Analysis

Deviation analysis is a method in which a BIM model is checked for geometric correctness. Specifically, the model is compared with a point cloud of the as-built state to identify possible deviations.

ETL Process

The ETL (extract, transform and load) process involves several individual steps through which data from different data sources can be loaded into a common database by means of extraction and transformation.

Model Checking

The procedure of model checking verifies the BIM model system description against a specification.

Content

List of Figures & Tables

1. Overview

1.1 Accompanying Report

The goal of the project is to accelerate development of the building project, increase mutual understanding, and reduce mistakes via innovative means for interactive visualizations. This report contains information about Extended Reality, Applications for AR, VR and MR, demonstrations of the tests, illustrations of the demo sites with different devices and Appendices listing the applications and project files corresponding to BIM-Speed SharePoint.

1.2 About Application

An application is runnable and installable software. We have developed applications for AR (Augmented Reality), MR (Mixed Reality) and VR (Virtual Reality).

AR Applications: This application is capable to scan real objects replacing them with virtual objects, while we are not able to interact with virtual objects. For instance, once the application starts, we must scan the building. Then, the application recognizes it, and show the virtual model while walking around the building and view from different positions. Also, we are able to switch between Proposal models, Existing models and Thermal models.

MR Applications: In addition to AR Application, we are able to interact with virtual objects such as, changing the position of virtual objects, scale them and rotate them. While in AR the virtual object is always in front of the real objects, in MR it can appear between them.

VR Applications: This application immerses the user in an entirely virtual world and lets the user to interact with the virtual environment. Unlike, AR and MR Applications, the user is not able to see the real world.

The developed application is user-friendly and easy to use, as the instructions are shown to the user, like to "Please scan the target".

Purpose: Each application has its own specific purpose, but the overall purpose is to reduce time for decisions on the client side, and win over the client, in case they are skeptical about the design, and reduce the errors that would normally be only visible after the completion of the project.

1.3 About Project

Project means Unity Project. Projects contain all assets and source codes for an application need. Projects are able to open in Unity Hub. Once, Projects are opened in Unity Hub, you can modify whatever changes you like in the project. To be imported to Unity, the 3D models are prepared and exported from other software. For example, the BIM models could be exported from REVIT, ArchiCAD, etc., the photogrammetric and the 3D thermal models based on 2D thermal scans could be exported from ReCap, Zephyr, Meshroom, etc.

1.4 About Demonstrations

Demonstrations are recordings made when testing the developed applications. Demonstration is a proof that our applications are working. This report contains the demonstrations for AR, VR and MR. Also, the demonstrations are recorded in front of the public that includes local government officials. Also, demonstrations

are performed during presentations in front of a public that includes local government officials and members of professional societies.

1.5 About Software

The projects can be opened using Unity Hub. It is advisable to use the latest version of Unity Hub. When the project is opened in Unity Hub, if required version of Unity Editor is not installed, "*Editor version not installed*" will be displayed as a warning. Required version of Unity Editor is written in the warning. After that, required version of Unity Editor can be installed from Unity Archive.

1.5.1 To install Application

The .apk files that are uploaded in the BIM-Speed SharePoint, can be installed on Android phones. For reference, follow this tutorial.

HoloLens 2 projects can be downloaded from .appx files.

For instance, from "*Appendix 1 (apps and projects)*" then open "*AR (Demo sites-applications and project)*" then "*Applications*" then "*01 Malko Tarnovo*" then "*210923_MTarnovo_Hololens2_InOffice_ASP*". This file must be unzipped.

Then open "*AppPackages*" then opening the following folders, then open "*220923_MTarnovo_Hololens2_Vuforia_ASP_1.2.0.1_ARM64*" which is .appx file format. To install .appx applications, for reference, follow this tutorial.

The video files uploaded to the BIM-Speed SharePoint, are of .mp4 format, which can be opened with VLC Media Player. VLC Media Player can be downloaded from here.

Similarly, other applications for demo sites Varna, follow the same method.

In BIM-Speed SharePoint, to open applications, follow the Applications folders. To see media, follow the Appendix 2 folder. To modify Unity Projects, follow the Projects folder

1.6 BIM-Speed SharePoint

Folder structure is structured as VR and AR, VR being Virtual Environment and AR aka Augmented Reality respectively is where the world around is used to by the software in an interactive manner. Software that uses recognition of the building and replacing it with our model does fit the AR description.

The main folder structure in BIM-Speed SharePoint is as follows:

- *221010 D7.5 + appendices*
    - *221010_BIM-SPEED_D7.5_Report*
    - *Appendix 1 (applications and projects)*
    - *Appendix 2 (videos)*

This *221010_BIM-SPEED_D7.5_Report* folder contains Accompanying Report as a .docx and pdf format.

The following is the structure of the subfolders:

- *Appendix 1 (applications and projects)*

- *AR (Demo sites-applications and projects)*
- *VR (Demo sites-applications and projects)*

The subfolders *AR (Demo sites-applications and projects)* and *VR (Demo sites-applications and projects)* contain "*Applications*" and "*Projects*" for respective demo sites.

If you want to download and install the applications, follow the *Applications* folder. If you want to access the project files, follow the *Projects* folder, in which the project can be modified.

- *Appendix 2 (videos)*
  - *AR (Demo sites recordings)*
  - *VR (Demo sites recordings)*

The subfolders *AR (Demo sites recordings)* and *VR (Demo sites recordings)* contain .mp4 video files for AR and VR for each demo site.

1.7 YouTube Channels

The BIM-SPEED H2020 EU project runs a YouTube channel where the contents for trainers, Extended reality, BIM-Speed tools and methodologies, and many more. Follow this link to BIM-SPEED H2020 EU project YouTube channel. There was created a playlist "Demonstrators for VR/AR" for presenting the videos included in Appendix 2 to this deliverable. Follow this link. The playlist "Volumetrization Techniques and Extended Reality" is a base for understanding how were produced the demonstrated applications. This is the link to these videos.

Architectural Spies EOOD has too a YouTube channel, where uploads videos about development processes, demonstrations, and technical tutorials. We will continue to upload videos regularly about demonstrations. Follow this link to Architectural Spies YouTube channel.

1.8 Purpose of the Project

The below table shows the benefits for the concerned professionals and the project members.

Table 1: To concerned professionals and their benefits

№	Addressees	Benefits
1	Clients / Developers	Spatial and thermal data visualization
2	Architects / Designers	Spatial visualization
3	Site Managers	Visualization the renovation process
4	BIM Managers	Spatial visualization
5	Engineers (thermal)	Visualization of thermal data and HVAC installations
6	Other Consultants	Spatial and other data visualization
7	Main Contractors (Builders)	Visualization the renovation process
8	Subcontractors (crafts)	Visualization of subcontracted works
9	Suppliers (construction component)	Visualization of construction components
10	Workers (Builders)	Training technical skills and safety

2. State of the art

2.1 What is Extended Reality?

The formal definition of Extended Reality (XR) is “a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables”. The Table 2. provides links to the definitions of the terminology for the technologies, covered by XR (AR, AV, MR, VR) and technologies used in its production. Some of the terms still are in a process of clarification and even have different formal meaning from the meaning, used by the professionals. Such a term is, for example Mixed Reality. Theoretically it is an umbrella term, including Augmented Reality (AR) and Augmented Virtuality (AV). But the meaning of the professional informal term of the MR developers relates to complex AR applications with the so called “occlusion” (as it is with HoloLens), to differ it from the simple AR. The MR puts the virtual objects “occluded” between the real objects, while AR, displays multiple virtual objects are arranged in layers with certain depth to it, and they are displayed by overlapping the real world objects.

Figure 1 is a clear example about the differences the terms AR and the used term MR as an informal term.

- On the left, the passing automobile at front of the real building but the AR of the 3D thermal model covers the image of the car, and the realistic impression is lost
- On the right, is an MR hologram, placed on the table in the real environment of the office of the partner Architectural Spies

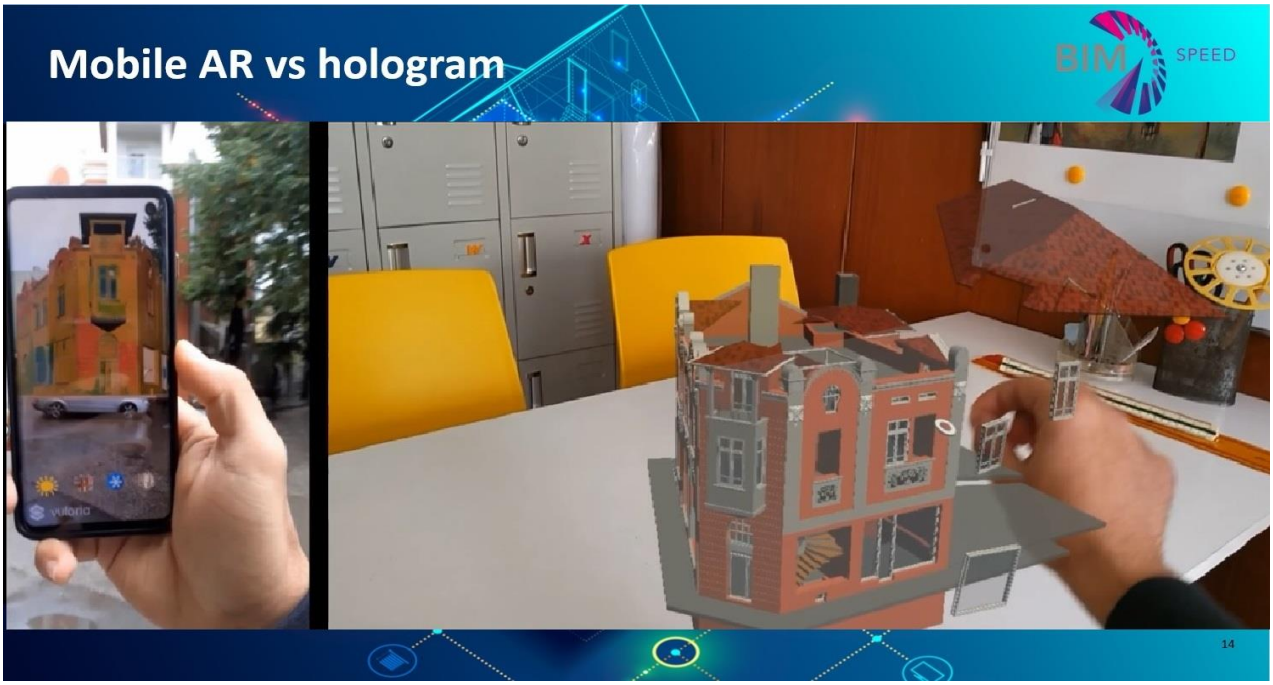

Figure 1: Differentiating AR and MR at presentation at the demonstration day in Varna, 8th October 2022

The authors of this document will use the term MR in its professional informal meaning, and in the cases, when is used the formal one, it will be written this way: MR (formal term).

Table 2. Sources of definitions of specific terms used in the XR production

№	Abbreviation	Term	Links to definitions
1	AI	Artificial Intelligence	https://en.wikipedia.org/wiki/Artificial_intelligence
2	AR	Augmented Reality	https://en.wikipedia.org/wiki/Augmented_reality
3	AV	Augmented Virtuality	https://en.wikipedia.org/wiki/Reality%E2%80%93virtuality_continuum
6	XR	Extended Reality	https://en.wikipedia.org/wiki/Extended_reality
7	-	Metaverse	https://en.wikipedia.org/wiki/Metaverse
8	MR	Mixed Reality	https://en.wikipedia.org/wiki/Mixed_reality
10	-	Photogrammetry, Stereophotogrammetry	https://en.wikipedia.org/wiki/Photogrammetry
12	VR	Virtual Reality	https://en.wikipedia.org/wiki/Virtual_reality

The hierarchical structure of the technologies included in the XR is presented by the following scheme:

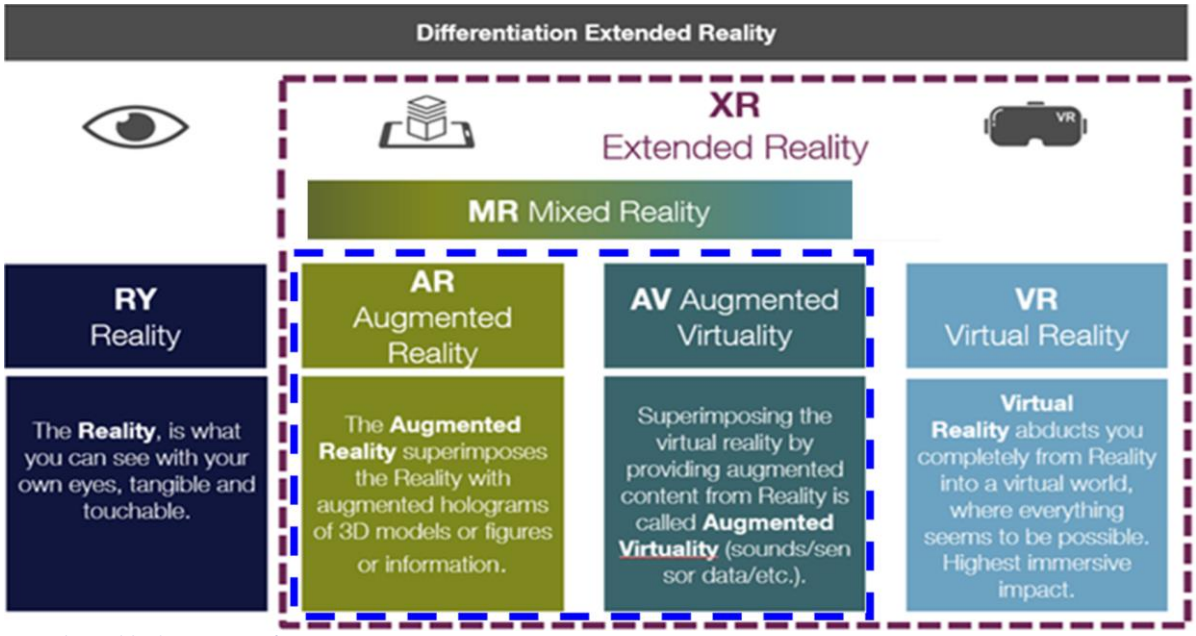

Figure 2: Hierarchical structure of XR

Intro to state of the art technologies in Architecture and Design industries.

Architecture is an ever-evolving field with new tools and technologies constantly emerging. Here are some state-of-the-art tools and technologies that are changing the way architects design and build:

1. Augmented Reality (AR): AR is being used by architects to visualize their designs in real-world environments. By overlaying digital information onto the real world, AR allows architects to see how their designs will look and function in the real world and make necessary changes before construction even begins.

2. Virtual Reality (VR): VR is another tool that architects are using to visualize their designs. VR allows users to immerse themselves in their designs and experience them in a way that is not possible with traditional 2D drawings or models.

3. Augmented Virtuality (AV) is a technology that allows architects to overlay computer-generated images on top of the existing physical environment. This allows for a more immersive experience when viewing architectural designs, as well as a better understanding of how the proposed design will interact with the existing structure. Additionally, AV can be used to create virtual walk-throughs of proposed designs, giving viewers a realistic sense of what the space will look and feel like once completed.

Detailed Overview – AR, VR and MR in Architecture

The way we interact with our built environment is changing. With the advent of new technologies like augmented reality (AR), virtual reality (VR), and mixed reality (MR), architects and designers are rethinking the way we interact with buildings and spaces.

These new technologies are changing the way we think about design, and the potential applications for architecture are endless. AR is a technology that overlays digital information on the physical world. This can be anything from a simple text message to a fully interactive 3D model. VR is a technology that allows users to immerse themselves in a digital environment. MR is a hybrid of AR and VR, blending the physical and digital worlds.

Applications for these technologies in architecture are numerous and varied. AR can be used for everything from pathfinding and navigation to educational tours and historical preservation. VR can be used for everything from design review and construction coordination to marketing and sales. MR can be used for everything from training and education to disaster response and recovery. The possibilities for these technologies are endless, and the potential for their impact on architecture is tremendous. As these technologies continue to develop and become more widely adopted, we will continue to see new and innovative ways in which they are used to shape the built environment.

Uses of AR, VR and MR in Architecture

When one thinks of Architecture, they generally think of the physical buildings and structures that make up the landscape around us. However, there is a growing trend in the industry towards using AR, VR and MR technologies

to create digital representations of architectural designs. This allows for a greater level of flexibility and creativity in the design process, as well as providing a way for clients to experience the design before it is built.

One of the most common ways that architects are using AR, VR and MR technologies is through the use of 3D modelling software. This allows them to create realistic representations of their designs which can then be viewed from any angle. This is particularly useful when presenting designs to clients, as they can get a better understanding of the space and how it would look in real life. Another way that these technologies are being used is through the creation of digital twins. This is where a digital copy of a building is created which can be used for a variety of purposes such as testing out different design ideas or simulating how the building will respond to different conditions.

This is a valuable tool for architects as it allows them to explore a wide range of possibilities without having to physically build anything. One of the most exciting ways that AR, VR and MR technologies are being used in architecture is through the use of holograms. This allows architects to create 3D representations of their designs which can be interacted with in real time. This is an incredible way to bring designs to life and allow clients to experience them in a completely new way. As you can see, there are a number of different ways that AR, VR and MR technologies are being used in architecture. This is just the beginning of what is possible, and we can expect to see even more amazing and innovative uses for these technologies in the future.

HoloLens

(Source: HoloLens 2: Technische Daten und Funktionen – Microsoft HoloLens 2)

Figure 3: Microsoft HoloLens 2

HoloLens is a device that projects holograms into your field of view, providing an immersive mixed reality experience. This allows you to interact with digital content in a more natural way and has a number of potential uses in architecture. For example, you could use HoloLens to view a 3D model of a building under construction, or to explore a virtual version of an existing building. You could also use it to plan and visualize renovations, or to create a virtual model of a proposed building. HoloLens can also be used to create interactive presentations, or to view and annotate blueprints and drawings.

Oculus Quest

(Source: Oculus Quest 2: Unser neues und fortschrittlichstes all-in-one VR-Headset | Oculus | Meta Store

Figure 4: Oculus Quest 2

Oculus Quest is a virtual reality headset that allows users to immerse themselves in three-dimensional environments. Architects can use Oculus Quest to create virtual models of their designs, which can be used to explore the space and get a feel for the proportions and layout. Additionally, Oculus Quest can be used to create virtual tours of completed buildings, allowing potential clients to experience the space before it is built. This can be a valuable sales tool, as well as a way to get feedback on the design.

VR Box + Smartphone

Figure 5: VR Box + Smartphone

The VR box headset is a device that is mounted as a helmet, with goggles for eyes to view the virtual objects, that is generated by a computer into reality to the user for immersive experience of the virtual world for watching 360 videos, games, for architecture and other uses, having android and IOS compatibility. The device displays when the smart phone is placed at the dedicated front mounting place.

Anaglyph glasses (Desktop AR)

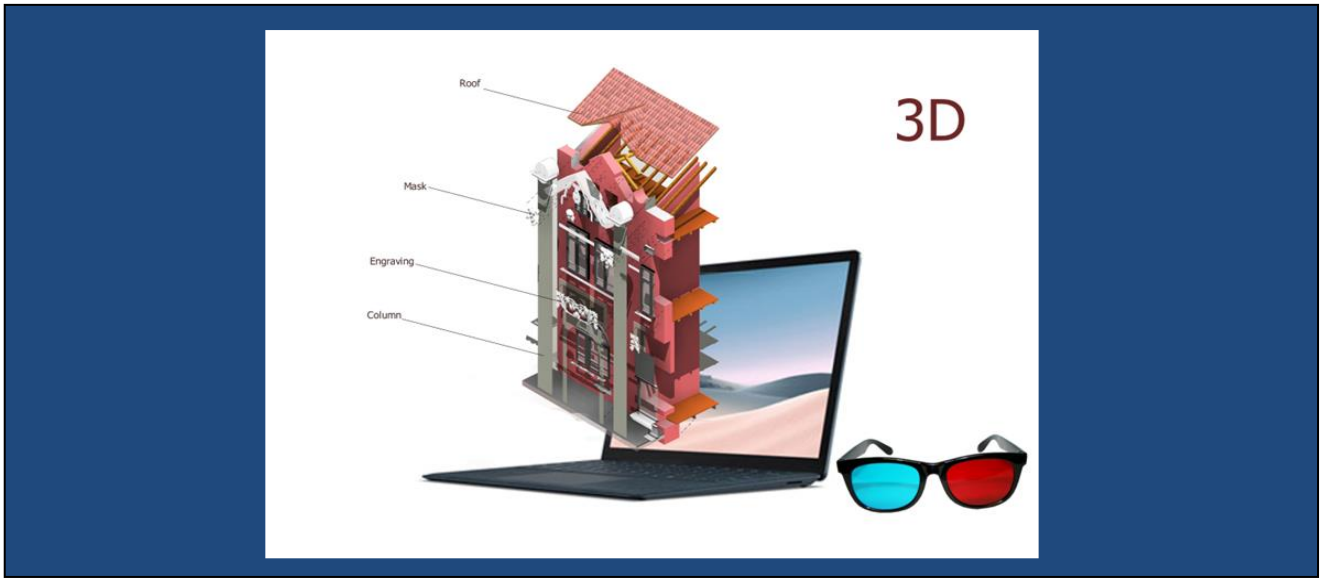

Figure 6: Anaglyph glasses (desktop AR)

Anaglyph glasses uses popular combination of red and blue glasses for 3D glasses. These glasses function the same for any combination and the two shifted images with slightly shifted perspectives, the user's brain blends the image it receives from each eye and by developing depths to it, creates a normal stereographic image without requiring the viewer to cross his or her eyes.

2.2 Development Framework

Development Framework for XR technologies in Architecture

The importance of XR in architecture is evident. By providing an immersive and interactive experience, XR can give users a better understanding of spatial relationships, scale, and proportions. XR can also be used to create a realistic environment for design collaboration and review. There are numerous XR development frameworks available. Each has its own strengths and weaknesses, and the best choice for a particular project will depend on the specific needs and objectives. Some of the most popular XR development frameworks include Unity, Unreal Engine, and Sketchup. Unity is a powerful and versatile engine that is well suited for architectural applications. Unreal Engine is also a popular choice and offers high-end graphics and rendering capabilities. SketchUp is a less popular but still viable option and is particularly well suited for conceptual design and early-stage visualizations. When choosing an XR development framework for a particular project, it is important to consider the specific needs and objectives of the project. The most important factor is likely to be compatibility with the existing workflows and tools. Other important factors to consider include performance, graphics quality, and cost.

Applications used for AR, VR and MR in Architecture

There are a variety of different software programs that can be used for augmented reality (AR), virtual reality (VR), and mixed reality (MR) in architecture. Some of the most popular ones include Autodesk Revit, SketchUp, and Unity. Autodesk Revit is a 3D modelling software that is often used for architectural design and construction. It allows users to create and edit 3D models of buildings and other structures. Revit can be used for AR, VR, and MR applications. For example, it can be used to create a 3D model of a building that can be viewed in AR on a mobile device. Revit can also be used to create a VR experience of walking through a building. And it can be used to create an MR experience of interacting with a building in a real-world environment. SketchUp is a 3D modelling software that is often used for architectural design and construction. It allows users to create and edit 3D models of buildings and other structures. SketchUp can be used for AR, VR, and MR applications. For example, it can be used to create a 3D model of a building that can be viewed in AR on a mobile device. SketchUp can also be used to create a VR experience of walking through a building. And it can be used to create an MR experience of interacting with a building in a real-world environment. Unity is a game engine that can be used for developing AR, VR, and MR applications. Unity can be used to create 3D models and simulations of buildings and other structures. For example, Unity can be used to create an AR experience of walking through a building. Unity can also be used to create a VR experience of walking through a building. And Unity can be used to create an MR experience of interacting with a building in a real-world environment.

3. General Use Case Development

Generally, use cases are required to describe a specific process and workflow that are performed to achieve one or more superordinate objectives of a renovation project. Within the scope of BIM Speed projects several use cases have been identified and documented in a standardized way. All this has been done within the framework of the buildingSMART Use Case Management System (UCM). With finalizing this report 14 use cases have been published already, more will come until the end of BIM Speed project.

3.1 General Use Case Definition

To describe a BIM-SPEED use case within the framework of the buildingSMART UCM in a standardized way, a template document has been developed and provided to the project partners. Several sections have to be filled in this template to complete the BIM-SPEED use case documentation.

Scope and objectives

First of all, the scope and objectives of the specific use case has to be described. This should highlight the purpose of the use case and how it will help to achieve one or more of the aimed BIM Speed superior project goals. If needed the use case can be assigned to relevant disciplines, which helps the user to find out the required use cases for the specific project.

Process and workflow

Next is a detailed description of the process and workflow, including definitions for input and output data as well as exchange requirements to set up this use case. For better understanding, a process map will outline the sequence of the different process steps.

Following table shows an extract of the already published use cases within the buildingSMART UCM framework and related tools that have been developed during the past operational period of BIM Speed project.

Table 3: List of published use cases in UCM

BIM SPEED Use Case	Related BIM SPEED Tool
Site analysis and planning	GIS data provider
3D Modeling of Existing Assets based on Point Clouds	3DASH
Existing building Data collection, download based on IFC model	BACN2BIM
BIM to BEM Approach	BIM-BEM
Thermal Comfort and Indoor Air Quality Analysis	Comfort eye
Lighting and Visual Comfort	Lighting and visual comfort
Decision-making in residential building renovation	Multi-criteria decision making tool
Holistic Evaluation	BEM Generator

3.2 XR Use Case Development

This chapter describes the general approach about how to design XR use cases and outlines the specific process steps.

BIM Speed buildingSMART UCM

The defined BIM-SPEED use case descriptions within the framework of the buildingSMART UCM have been used as base for developing the XR use cases. Examining these use case descriptions, outlined first ideas on possible use cases that came into consideration to be enhanced when providing a XR approach.

XR Evaluation

The defined process map of the use case shows the different process steps in detail. Investigating the several process steps enables the identification of specific opportunities to integrate XR applications to enhance the use cases. Once identified, the specific requirements for the XR integration can be derived and documented.

XR Design

Identification of the process steps and defining the XR requirements enables the possibility to design the new process by implementing XR applications. Important is here the differentiation between AR and VR. As outlined in the state of the art section, both XR-variants are aiming at different scenarios and have to be implemented differently.

XR Development

Based on the generated design and workflow the development of the app can be initiated. It has to be considered that some BIM-SPEED use cases can only be enhanced in a meaningful way by either a VR- or an AR-application. Other use cases might be enhanced by both XR-variants.

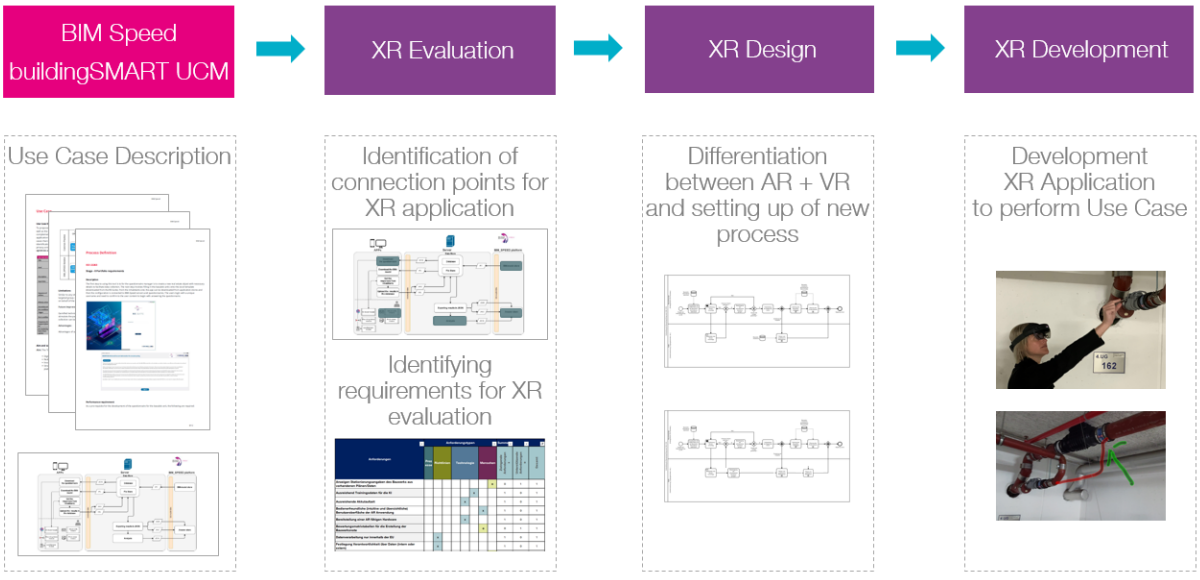

Figure 7: Process of XR Use Case Development

3.3 Example

A detailed description of the new XR use cases can be provided as soon as the relevant connection points to integrate XR workflows, tools or apps into the usual use cases process have been identified.

General Description Use Case No. 02 „Crowd Data Collection“
The use case provides the means to collect crucial data from the inhabitants of the buildings. The better and accurate understanding of the as-is situation as well as the needs and preferences of the prospective users will result in proposing enhanced renovation scenarios.

PROs

- Additional data source to increase the inhabitants comfort
- Involving habitants in refurbishment process
- Direct linkage of raised data with the BIM model

CONs

- Success highly depends on the inhabitants acceptance
  - ➢ Smooth explanation of content to inhabitants
  - ➢ Continuous motivation of inhabitants

Figure 8: XR Use Case Example - General Description, Pros & Cons

The next section provides the corresponding process chart XR integration points are highlighted in pink.

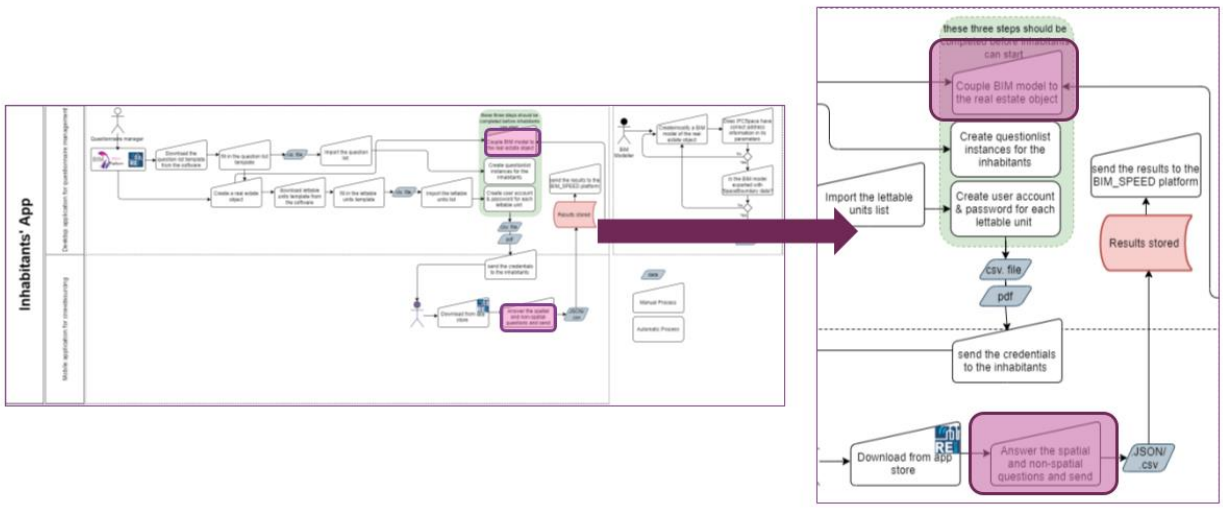

Figure 9: Integration Points for XR

In this example two process steps have been identified that enable XR-integration to the given BIM-SPEED use case definition:

1. The first one is the coupling of the 3DBIM model to the real estate project. While this is limited to the data structure environment in the former process step, in future the 3DBIM model will be provided as AR Model on site, overlaying the reality.

2. Second integration is the process step, when the inhabitants will answer the questionnaire on spatial and non-spatial topics. While this is done by using a paper document, in future this formula can be provided as AR app on a mobile device. This App then automatically will guide the inhabitant to the relevant location within the flat and provide needed information of the room or building element, overlaying the reality, to enable him answering the relevant question. Using this technology is part of gamification of a usual questionnaire and support the willingness of the inhabitants to really answer.

Table 4. Integration Points for XR

Identification of process steps to be supported by AR/VR	
Couple BIM model to real estate object	Visualization of renovation Designs in VR Participation of the user in the design process of the renovation measures. • Development of designs through the selection of objects corresponding to the renovation and placement in AR by the user
Answer the spatial and non-spatial question in the user survey app	Selection of specific objects corresponding to the questions in the model. • Support in the selection of objects through the visualization of the model in AR • Display of relevant object-specific information to answer the question in AR

Last but not least, all general requirements are highlighted to enable the XR Developers to really set up the designed XR use case, which are summarized in the following picture:

General Requirements

- User acceptance for new technologies Usability should be a mandatory during the development of the ARNR Plug-In / application
- Preparation of a BIM model for further use in ARNR - Sufficient amount of inventory and information
- Provision of a catalogue with various objects corresponding to the renovation measures, so that the user can work out designs independently

4. Transfer from Use Case to Demonstration using GDDs

4.1 Various Use cases & tools

The following table lists various use cases for applying different technologies of augmented and virtual reality in AEC, stressed on the energy efficient renovations use cases. The cells marked with "Y" (Yes) relate to various opportunities, and the specific tools and concrete demo sites are listed in each one Y-cell. The created VR and AR apps in the frames of the project BIM-SPEED project, as well videos demonstrating how they work, are listed in Appendix 1 (applications and projects) and Appendix 2 (videos) to this deliverable.

Table 5: AR/VR Use Cases & Tools

TOOLS (horizontally) USE CASES (vertically)	**Universal 3D viewer (VR or AR) Devices: PC, laptop, tablet, smartphone**	**Mobile AR Device: Smartphone**	**Desktop AR Device: PC/laptop _ anaglypth glasses**	**MR Device: HoloLens**	**VR Device: VR headset**	**VR Device: VR box + smartphone**
Off-site visualization of data from on-site surveys in small scales	Y PCs, laptops, tablets, smartphones demo site: Malko Tarnovo	Y Smartphones, demo sites: Malko Tarnovo, Varna	Y PC, laptops + anaglyph glasses, demo site: Varna	Y MS HL2, demo sites: Malko Tarnovo, Varna	Y OculusQuest 2, demo sites: Malko Tarnovo, Varna	Y VR box + smartphone Demo site: Varna
Off-site visualization of data from on-site surveys in scale 1:1	N	Y Smartphones	N	Y MS HL2, demo sites: Malko Tarnovo, Varna	Y OculusQuest 2, demo sites: Malko Tarnovo, Varna	Y VR box + smartphone Demo site: Varna
On-site visualization in scale 1:1 of	N	Y Smartphones, demo sites:	N	Y MS HL2, demo sites:	N	N

data from on-site surveys		Malko Tarnovo, Varna, Vitoria		Malko Tarnovo, Varna		
Off-site visualization of BIM projects in small scales	Y PCs, laptops, tablets, smartphones demo site: Malko Tarnovo	Y Smartphones, demo sites: Malko Tarnovo, Varna	Y PC, laptops + anaglyph glasses demo site: Varna	Y MS HL2, demo sites: Malko Tarnovo, Varna	Y OculusQuest 2, demo sites: Malko Tarnovo, Varna	Y VR box + smartphone Demo site: Varna
Off-site visualization of BIM projects in scale 1:1	N	Y Smartphones, demo sites: Malko Tarnovo, Varna, Vitoria	N	Y MS HL2, demo sites: Malko Tarnovo, Varna	Y OculusQuest 2, demo sites: Malko Tarnovo, Varna	Y VR box + smartphone Demo site: Varna
Health and safety training for construction workers	N	Y Smartphones	N	Y MS HL2	Y OculusQuest 2, demo site: Warsaw	N
Collaborative work on the projects	N	N	N	Y MS HL2	Y OculusQuest 2	N
Remote help for workers on-site	N	Y Smartphones	N	Y MS HL2	N	N
Training on evacuation (emergency cases: fire, earthquakes, flooding, terrorist' attacks)	N	N	N	Y MS HL2	Y OculusQuest 2	N

Remote maintenance of the buildings during the exploitation	Y PCs, laptops, tablets, smartphones	Y Smartphones	N	Y MS HL2	Y OculusQuest 2	N
Renovation elements library	Y PCs, laptops, tablets, smartphones	Y Smartphones	Y PC, laptops + anaglyph glasses	Y MS HL2	Y OculusQuest 2	N

The demonstration opportunities of the AR/VR tools cover a large palette of use cases. Some of the BIM-SPEED demonstrated applications compile two or more use cases. The AR or VR applications are developed on the basis of the known from the game industry GDD (Game Design Document) with the following content:

- Goal: What is the goal of the demonstration
- The benefits and to whom
- Scenario of the use case(s)
- The demonstration site(s), (some of the solutions are demonstrated by two or more demo sites)
- The type of XR
- The device for XR consumption
- Platform
- Game engine for creating the content
- Illustrations like:
    - Process Description, block-scheme, or logical scheme
    - Story board
    - Other illustrations
- Logline (one-sentence presentation of the content, known from the film industry)

4.2 GDDs for AR/VR applications

Table 6. List of GDDs for AR applications

№	Title	Description
GDD-AR-1	On-site mobile AR application for demonstrating the project of renovation and results of on-site surveys of a still not renovated building by prefabricated elements (demo Malko Tarnovo)	The mobile AR app shows on-site on the background of the still not renovated building of the municipal dormitory of Malko Tarnovo the project for its renovation, as well the results from on-site surveys (thermal and photogrammetric) and HVAC system elements.
GDD-AR-2	On-site mobile AR application presenting the past condition and on-site surveys of a renovated building, cultural heritage (demo Varna)	The mobile AR app shows on-site at the background of the renovated facades of the house its past condition like photogrammetric model, vertical sections, exported from the BIM model ("view behind façades"), 3D models produced from the 2D thermal scans in different seasons, and detailed 3D view of fragments and details. Developed for the demo in Varna (Cultural heritage).
GDD-AR-3	Mobile AR applications presenting the past condition, on-site surveys, analysis and renovation design of 2 apartment buildings in Vitoria, Spain	The on-site mobile AR app shows on the background of the already renovated building the BIM model of the building before renovation, 3D model produced by 2D thermal scans before and after the renovation, graphic analyses of the surveys, 3D model of the renovation design and its elements.
GDD-AR-4	On-site immersive AR (hologram in scale 1:1) at the still not renovated building, presenting the project for renovation (demo Malko Tarnovo)	This AR (MR) application ensures a walk into the building, scheduled for renovation. The user could obtain on-site impression how the interior spaces would look when the project would be realized. Architectural, structural and HVAC elements are shown, and the interior spaces are furnished.
GDD-AR-5	Double use off-site simulations in scale 1:1 of a remote building into another building (demo Malko Tarnovo)	This immersive AR (MR) application provides a solution for obtaining a realistic impression and dynamic experience about a remote demonstration site and the variants for its renovation via holograms, activated into another existing demonstration site. The holograms, based on the BIM model of the remote building is visualized via Microsoft HoloLens 2

		into another space with relatively similar size of the interior spaces.
GDD-AR-6	Off-site small scale holograms "jumping" to interior spaces in scale 1:1 (demo sites: Varna, Malko Tarnovo)	These very interesting AR solutions, developed for Microsoft HoloLens 2, present small-scale holograms of the 3D models of the buildings before the renovation (photogrammetric and BIM), the BIM models for renovation, and the thermal condition in different seasons, produced from the 2D thermal scans by the methods developed by ASP in WP1.
GDD-AR-7	Universal 3D viewer for comparing variants for renovation (web AR)	The application based on the produced by ASP universal 3D viewer could show volumetrically the different scenarios for renovation imitating a hologram on a transparent background (view from the opened camera). This case study helps the clients (owners, tenants) to obtain volumetric impression about the different variants for renovation of their building.
GDD-AR-8	Renovation elements library presented by universal 3D viewer (web AR)	The application based on the produced by ASP universal 3D viewer for showing volumetrically on a transparent background (view from the opened camera) a library of elements for renovation is addressed to the architects, structural and HVAC engineers to compare and take decision for choosing the elements for renovation.
GDD-AR-9	Desktop AR demonstration of BIM model with anaglyph glasses (demo Varna)	The BIM model of the demo site is visualized at front of the monitor of the PC or laptop, looking through anaglyph glasses. The desktop AR can illustrate volumetrically the model and view the fragments and details, "floating" at front of the monitor, or if needs, in-the depth "behind" the frame of the monitor.

Table 7: List of GDDs for VR applications

№	Title	Description
GDD-VR-1	VR demonstration of the scenario for maximum renovation, and the on-site surveys via device Oculus Quest 2 (demo Malko Tarnovo)	Fully immersive virtual reality demonstration of the on-site surveys and the project for renovation of Malko Tarnovo using Oculus Quest 2, with interactive functions for the user with the virtual environment, with high-quality displays, by hand recognition and gestures, which improves the user's interactivity.
GDD-VR-2	VR Demonstration of the past condition, on-site surveys and the project for renovation via photogrammetric and BIM models by VR box and smartphone	This VR demonstration allows the user to experience the past condition of the un-renovated building of the demo site with the generated BIM model and visualize the difference with the future model of the building and experience the new design, to view the details of the architecture, photogrammetry and explore the BIM model, using VR box and smartphone.
GDD-VR-3	Universal 3D viewer for comparing variants for renovation (web VR), demo Malko Tarnovo	The application based on the produced by ASP universal 3D viewer shows volumetrically the different scenarios for renovation on an artificial background (neutral or 360 video of a reproduced real environment). This case study helps the clients (owners, tenants) to obtain volumetric impression about the different variants for renovation of their building.
GDD-VR-4	Renovation elements library presented by universal 3D viewer (web VR)	The application based on the produced by ASP universal 3D viewer for showing volumetrically on an artificial background (neutral or 360 video of a reproduced real environment) a library of elements for renovation is addressed to the architects, structural and HVAC engineers to compare and take decision for choosing the elements for renovation.
GDD-VR-5	Environmental performance impacting the building, presented by the universal 3D viewer (web VR)	The data from sensors to analyze the impact caused by the temperature, lighting, atmospheric pressure etc., could be incorporated with the BIM model of the existing building. Rotating the 3D model on the screen, touching by a finger (for smartphones) or clicking with the mouse (for PCs or laptops) on the location of the installed controller (group of sensors) could give access to the remote server where the IoT data are stored. The data could be exported and presented visually.

GDD-VR-6	Health and Safety Awareness for Construction Workers	The VR demonstration provides walk-through and demonstration to enable the user to understand the safety features and create awareness for the workers prior to the real-world application of construction works, by user interactive features in order to train to the situation and demonstrate the consequences for the actions and help educate the health and safety measures to improve the accuracy and efficiency of scenario designs.
GDD-VR-7	VR onsite implementation and a tool for deciding design alternatives	The VR provides an interactive tool by comparing the as-built 3D model and the planned state of the future model. The connection with BIM and virtual environment provides capability to identify and modify the environment. It demonstrates the use of VR by visualizing geometric aspects of the building, materials, and the design solutions.
GDD-VR-8	VR-enabled BIM design process	By implementing VR simulation into the training process, demonstrating the parts of the complex design, and provide insight of the HVAC system, its application in BIM.
GDD-VR-9	VR for visualizing photogrammetry and laser scanning	With the generated BIM, the 3D survey data is transformed into model representation and allows user to collaborate and help visualize and interact with immersive environment which is presented in VR by 360° panoramas and focus user's attention to specific points in the virtual environment.

The following section describes the demonstration cases, that are divided into two main groups: AR and VR:

5. Demonstration Cases

5.1 AR Demonstrations

The project BIM-SPEED provides the following types of AR demonstrations:

- Mobile AR (device: smartphone: *Samsung Galaxy A12)*
- Immersive AR (MR with device: *Microsoft HoloLens 2*)
- Desktop AR (device*: PC or laptop + anaglyph glasses*)

The created applications are for one use case or more complex, compiling two or more use cases.

5.1.1 On-site Mobile AR Application for Demo site Malko Tarnovo, Bulgaria

The mobile AR app shows on-site on the background of the not renovated building of the municipal dormitory of Malko Tarnovo:

- 3D models produced from the 2D thermal scans
- BIM model for renovation

The game design document of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-1.

Illustration: On-site test at demo site Malko Tarnovo

- Background: real view of the façade before renovation
- AR layer: BIM model

Figure 10: On-site test mobile demo site Malko Tarnovo, 2021

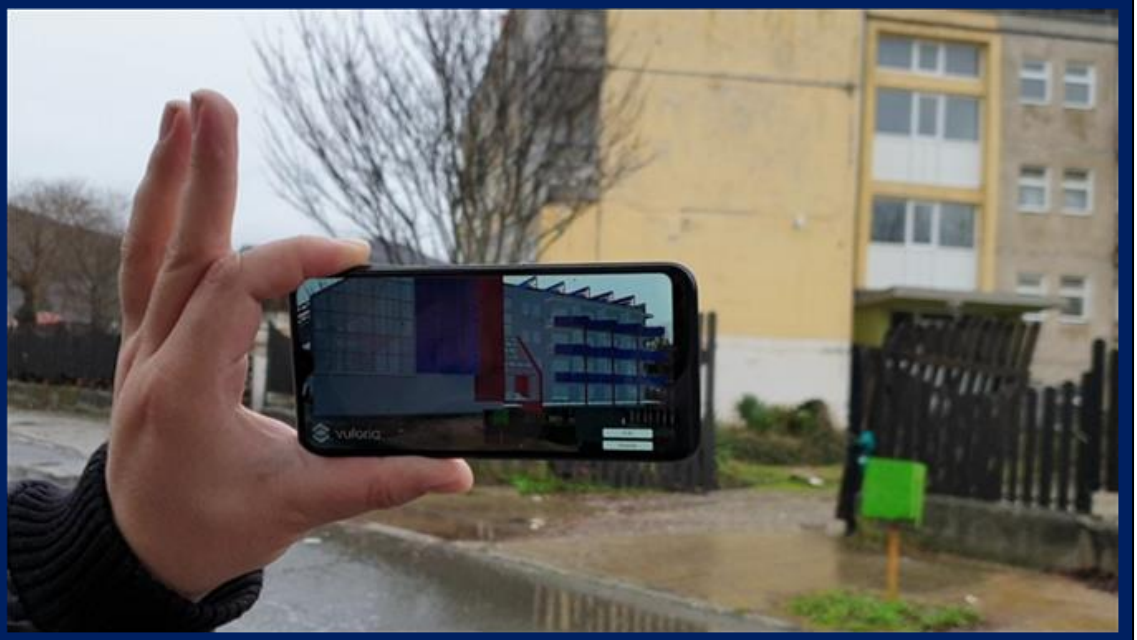

Illustration: On-site test at demo site Malko Tarnovo

- Background: real view of the façade before renovation
- AR layer: BIM model

Figure 11: On-site test mobile demo site Malko Tarnovo, 2021

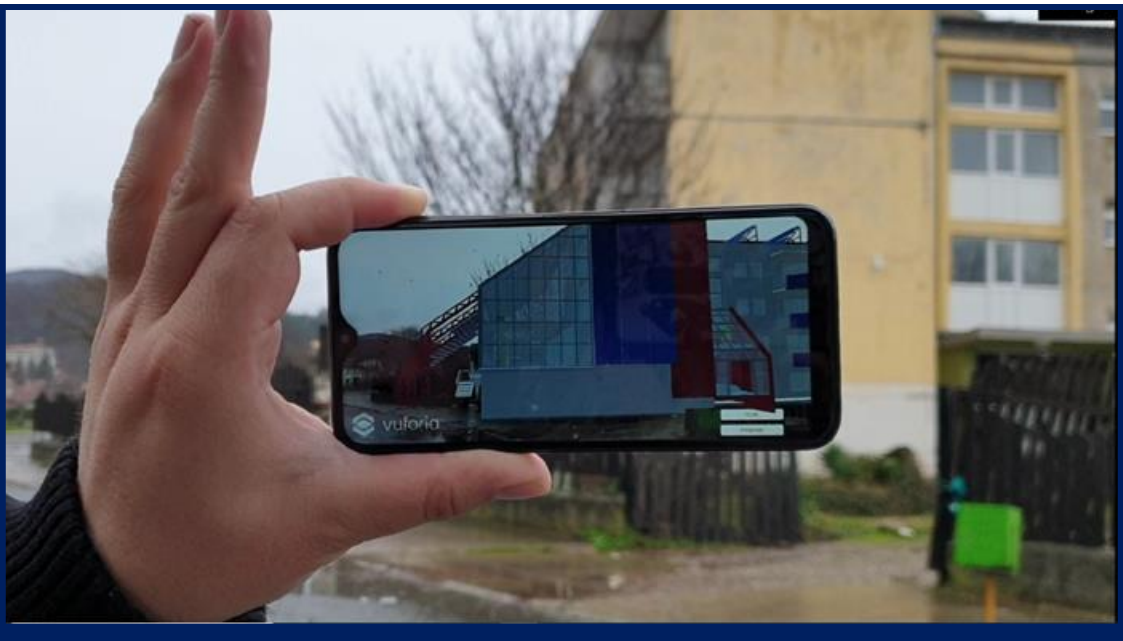

Illustration: On-site test at demo site Malko Tarnovo

- Background: real view of the façade before renovation
- AR layer: BIM model

Figure 12: On-site test mobile demo site Malko Tarnovo, 2021

Illustration: On-site test at demo site Malko Tarnovo

- Background: real view of the façade before renovation
- AR layer: BIM model – project for renovation

Figure 13: On-site test mobile demo site Malko Tarnovo, 2021

Illustration: On-site test at demo site Malko Tarnovo

- Background: real view of the façade before renovation
- AR layer: BIM model – project for renovation

Figure 14: On-site test mobile demo site Malko Tarnovo, 2021

Figure 15: On-site test mobile demo site Malko Tarnovo, 2021

The result of a good image recognition of the large-scale AR target (the demo building in Malko Tarnovo) was achieved in the autumn 2022. There was an important technological reason. The tests done at the end of 2021 (Figures 19 – 24) used the product Vuforia. Although the company producing this software (PTC) advertised recognition of 2D and 3D targets, its software in 2021 was able to recognize only small-scale 3D objects. ASP contacted another company (Vision Lib), announcing image recognition of large-scale 3D targets, received an offer for testing but the biggest target size of Vision Lib was an automobile.

Due to the technological gap in the recognition of volumetric large-scale targets (buildings), ASP devoted 4 persons, the entire summer of 2021 (outside of the efforts of the BIM-SPEED project) to produce a software for large scale targets recognition. The work was stalled after achieving 85% success. In the autumn of 2021 Vuforia still was acting for the large-scale objects as 2D recognition, was able to work only from specific positions, and was fruitful only for buildings with specific shape (for example the demo Varna). The recognition tests were repeated in the autumn of 2022 with the newest solution of Vuforia. ASP used AI training for the Malko Tarnovo mobile AR app, the results were better.

Figure 16: On-site test mobile demo site Malko Tarnovo, 2022

Figure 17: On-site test mobile demo site Malko Tarnovo, 2022

Figure 18: On-site test mobile demo site Malko Tarnovo, 2022

Figure 19: On-site test mobile demo site Malko Tarnovo, 2022

Figure 20: On-site demonstration of the 3D thermal model of demo site Malko Tarnovo, 2022

They are attached in the appendices, the files of both variants of the application: the one produced in 2021 and the other produced in 2022. The team did some corrections in the model of the as-built building (especially the slope of the roof) trying to achieve full overlapping of the imported to Vuforia model with the on-site building. This improvement gave only a partial result. The qualitative recognition, smooth performing of the application, and not losing contact with the target while going around the building. Vuforia actualized its 3D recognition software.

Follow this link to the video from the demonstration.

5.1.2 Mobile AR demonstration of the past condition of a renovated house - cultural heritage. Presentation of on-site surveys before and after renovation, demo site Varna, Bulgaria

The mobile AR app shows on-site at the background of the renovated house:

- photogrammetric model of the past condition
- vertical sections, exported from the BIM model ("view behind façades")
- 3D models produced from the 2D thermal scans before renovation
- 3D models produced from the 2D thermal scans after renovation

The game design document data of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-2.

The work on this mobile AR application did not face any difficulties related to the AR application of demo site Malko Tarnovo. The reason is, the uniqueness of the cultural heritage building, projected in 1912 and built in the following years. It is very ornamented, and the contour of the cornice is specific. The conclusion is that as more complex is the shape of any building, as easy is its image recognition as an AR target.

Figure 21: Collage for the game design document for the mobile application for demo site Varna

Figure 22: Collage for the game design document for the mobile application for demo site Varna

Figure 23: Collage for the game design document for the mobile application for demo site Varna

Figure 24: Collage for the game design document for the mobile application for demo site Varna

Figure 25: Demonstration of the mobile AR application for demo site Varna

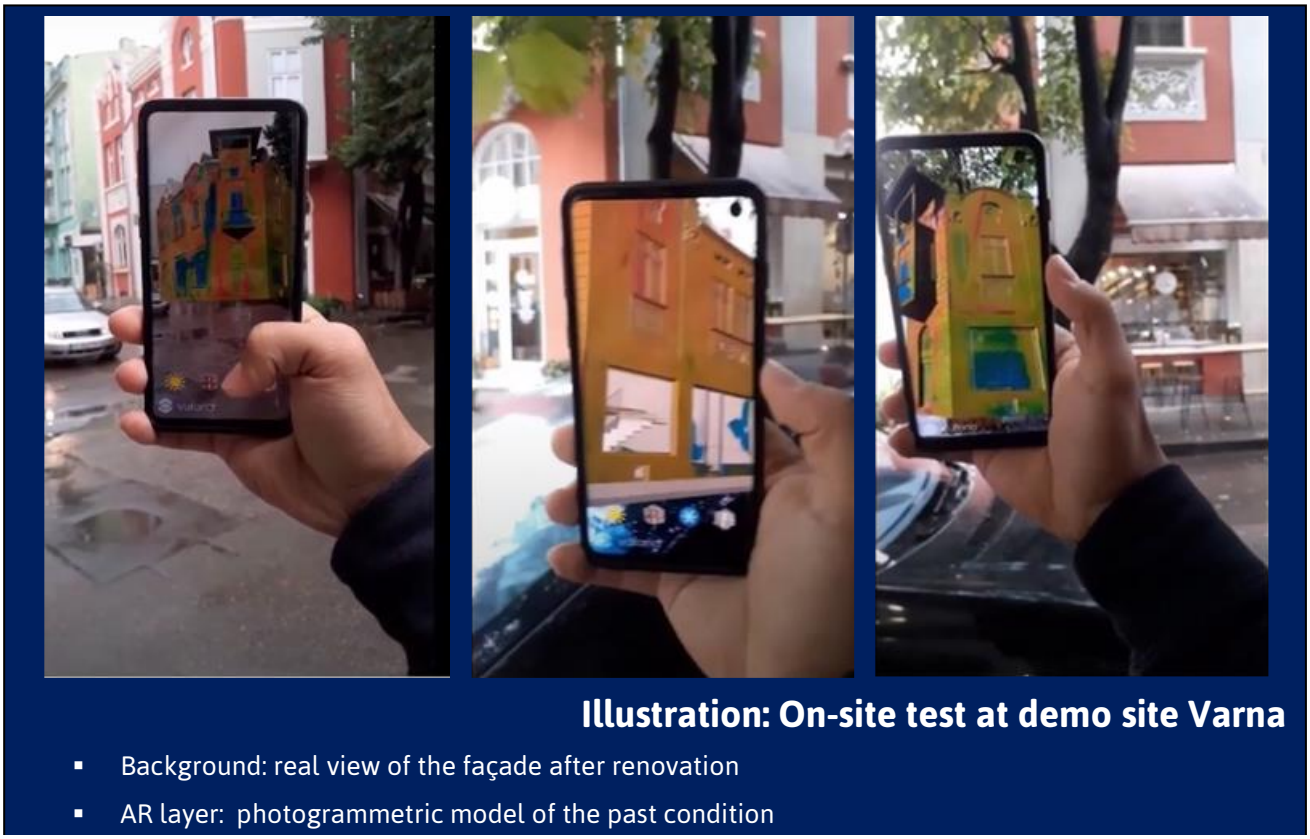

Figure 26: Demonstration of the mobile AR application for demo site Varna

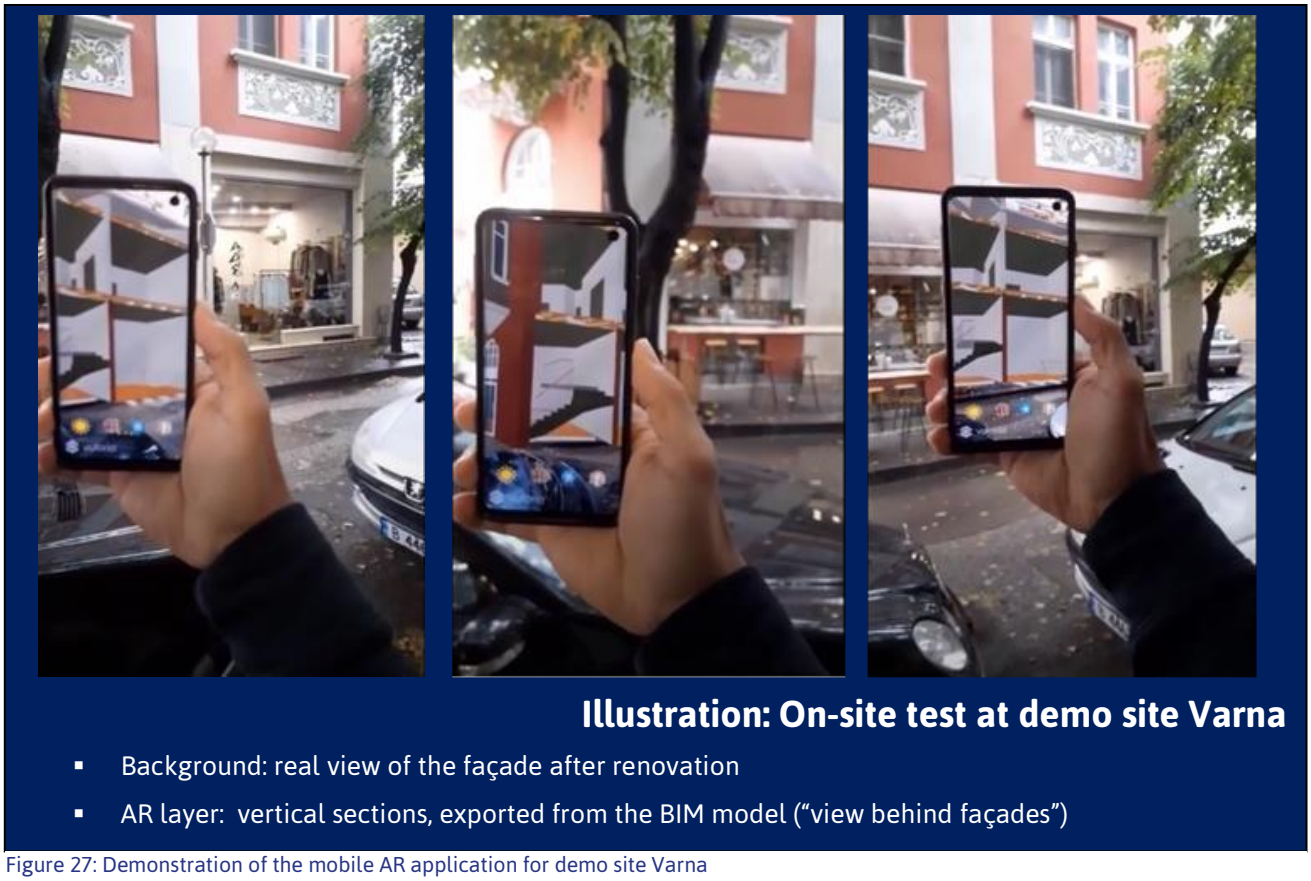

Figure 27: Demonstration of the mobile AR application for demo site Varna

Follow this link to the video from the demonstration.

5.1.3 Mobile AR demonstration of the past condition, surveys, analysis, and renovation design of 2 apartment buildings in Vitoria

The GDD of the on-site mobile AR app offers showing at the background of the already renovated buildings:

- BIM model of the building before the renovation
- 3D model produced by 2D thermal scans before the renovation
- 3D model produced by 2D thermal scans after the renovation
- graphic analyses of the surveys
- BIM model of the renovation design
- Elements of the renovation

The game design document of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-3. Five versions of the applications for both demo sites were produced. The versions, done with the old version of Vuforia (2021) were tested onsite and the recognition was not easy. There were 3 reasons:

- Both streets are very narrow, and the distance is not sufficient for the whole view of the facades
- Both buildings are with a flat cornice without any specific elements
- It was used the version of Vuforia from 2021, still not ensuring the 3D recognition of large-scale 3D targets

There were produced 3 new apps: one for 26 Aldabe str. and two for 5 Arkaya str.

Figure 28: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

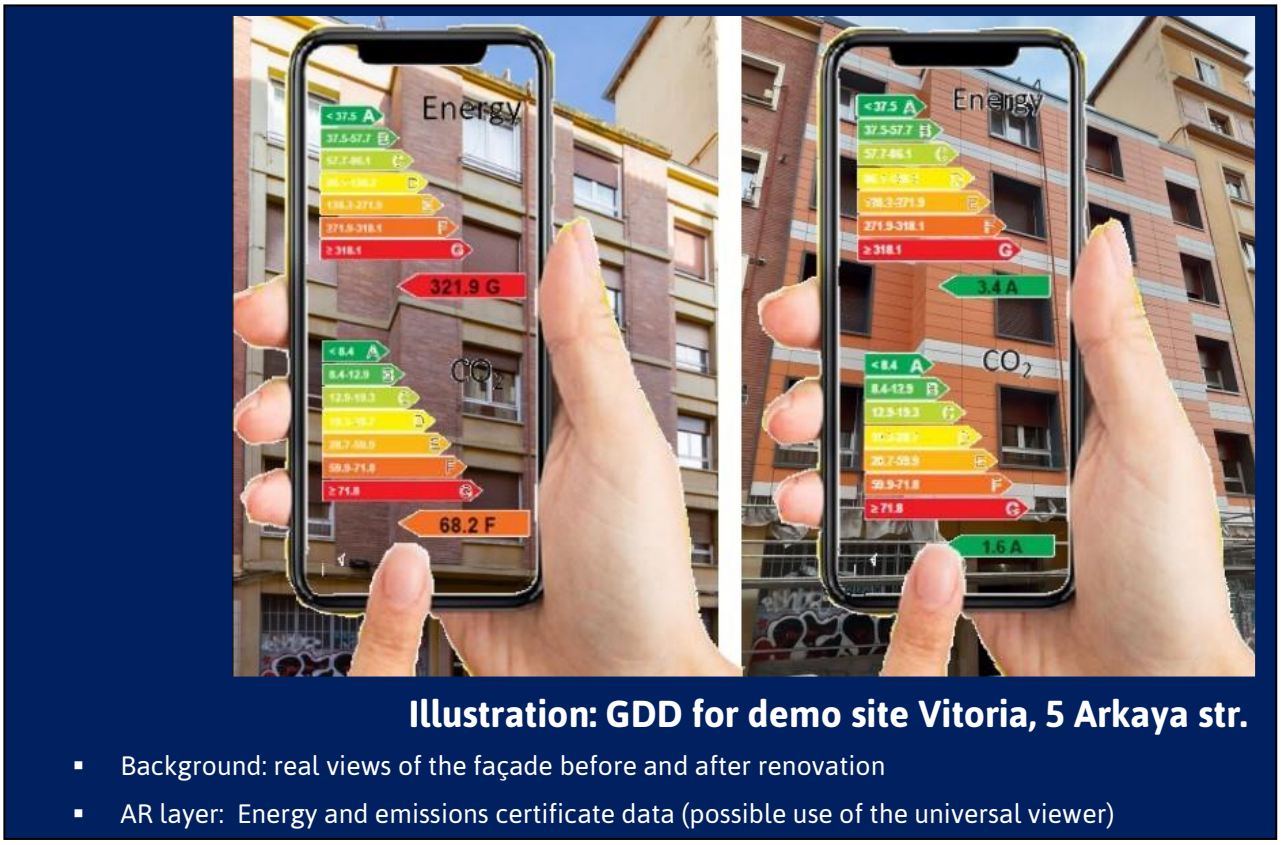

Illustration: GDD for demo site Vitoria, 5 Arkaya str.

- Background: real views of the façade before and after renovation
- AR layer: Energy and emissions certificate data (possible use of the universal viewer)

Figure 29: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

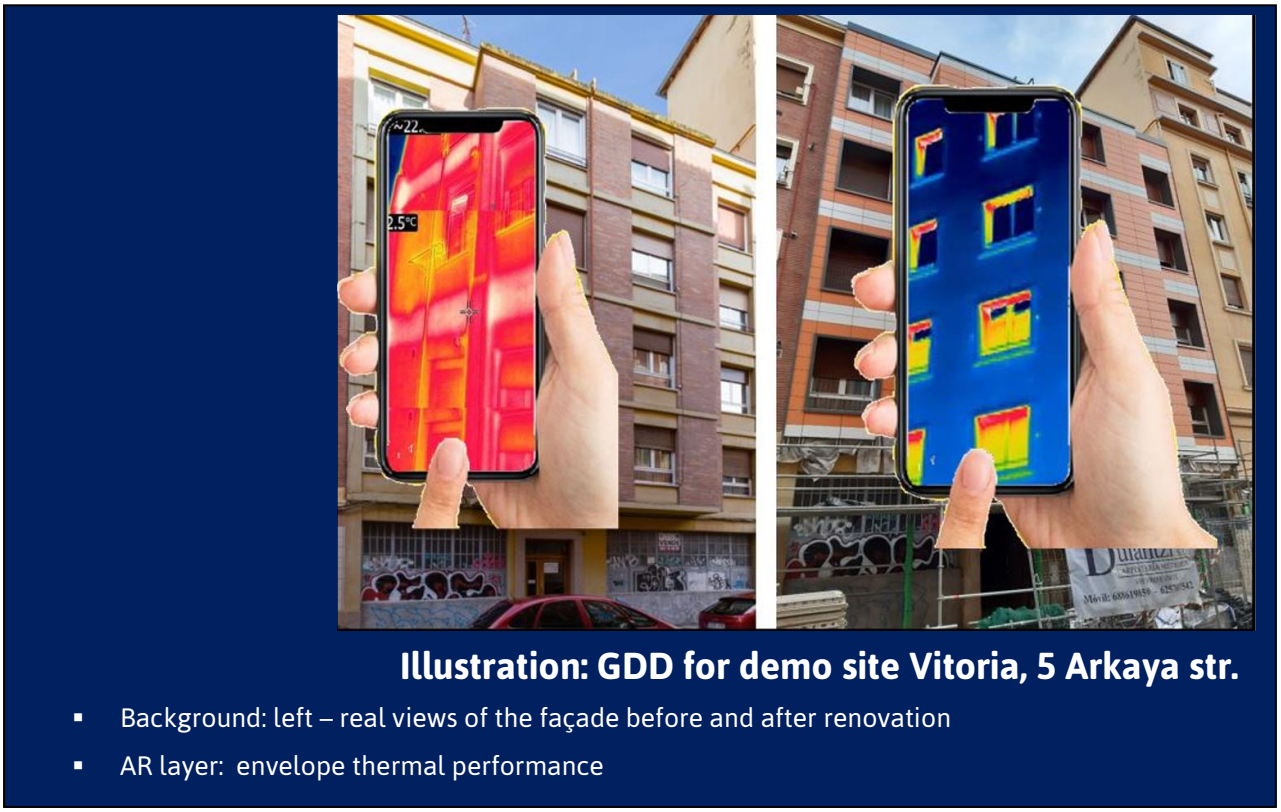

Illustration: GDD for demo site Vitoria, 5 Arkaya str.

- Background: left – real views of the façade before and after renovation
- AR layer: envelope thermal performance

Figure 30: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

Figure 31: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

Figure 32: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

Figure 33: Collage for a GDD for mobile AR application for demo site Vitoria, 5 Arkaya str.

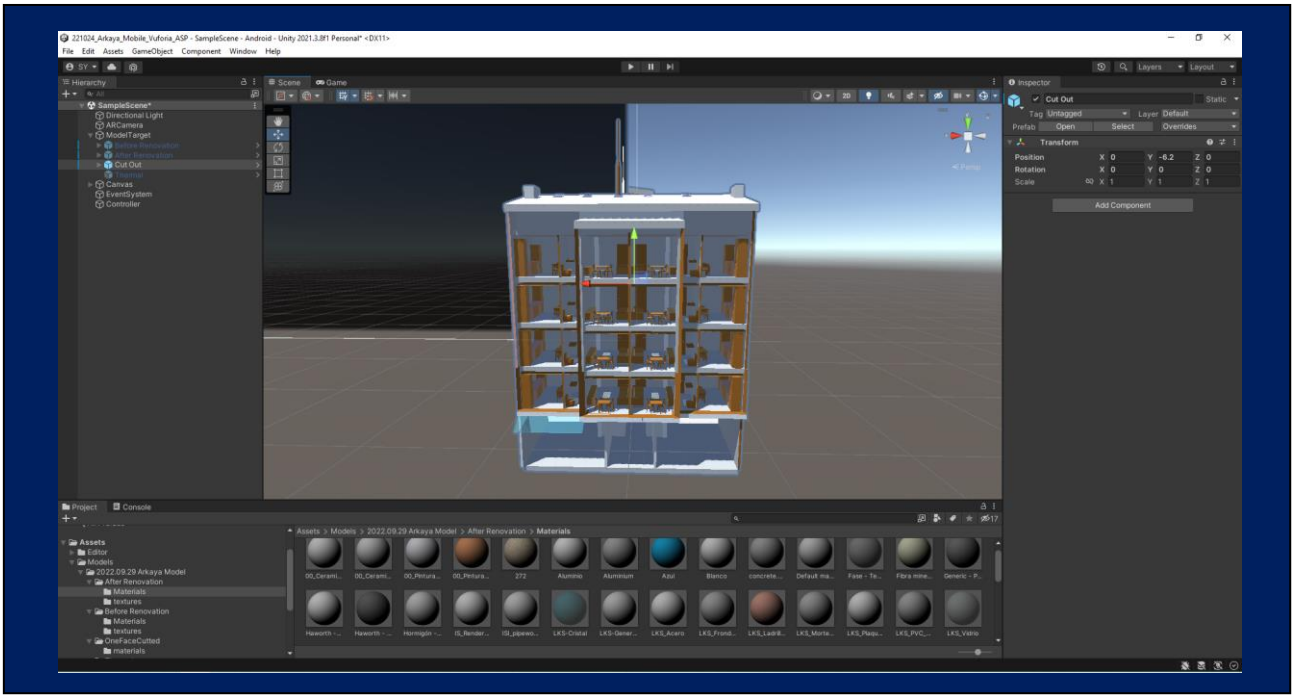

Figure 34: Cut Out model in the Unity editor

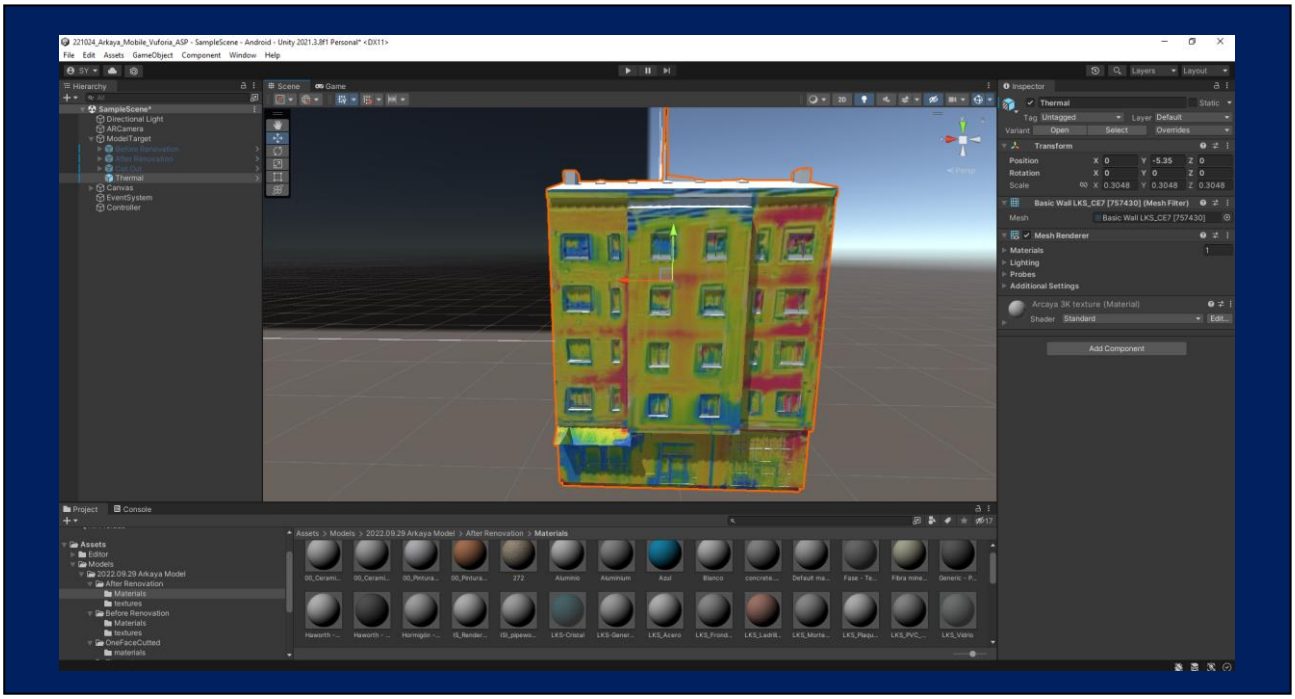

Figure 36: Thermal model in Unity editor

Here are a few images from the video. To watch the video, click this link for *"Demo site Arkaya Mobile with Vuforia"*.

Figure 35: On-site test mobile demo site Victoria, 5 Arkaya str.

Figure 37: On-site test mobile demo site Victoria, 5 Arkaya str.

Figure 38: On-site test mobile demo site Victoria, 5 Arkaya str.

Figure 39: On-site test mobile demo site Victoria, 26 Aldabe str.

Figure 40: On-site test mobile demo site Victoria, 26 Aldabe str.

Figure 41: On-site test mobile demo site Victoria, 26 Aldabe str.

From the Mobile AR tests performed for the demo sites in Vitoria, Spain, the AR technology displays the virtual objects on the real-world objects. Since the demo sites in 5 Arkaya and 26 Aldabe, the building is not independent and they are row of houses connected continuously in a residential area, it is a challenge for mobile AR technology to identify the unique property of the building.

Since the sidewalls are connected with other buildings which we are unconcerned of, for example, the right elevation of the Aldabe building model, overlaps the neighboring building`s façade. In order to solve this problem, the neighboring buildings on either side of our main building, should be modelled so that our main building`s model wraps around like the existing continuous row of buildings.

A compromised solution would be to only use the façade wall as a decoration and cut out modelled and due to time constraint, the neighboring buildings in Vitoria are not modelled and at present our Arkaya and Aldabe building model is undisturbed and used as such.

Follow this link for the video from the demonstration at 26, Aldabe str. demo site and this link for the video about 5, Diaz de Arkaya str.

5.1.4 AR (MR) application with dual use (on-site and off-site) for renovation scenarios simulations via holographic twinning

This MR application provides a solution for obtaining a realistic impression and dynamic experience about a remote demonstration site and the variants for its renovation via holograms, activated into another existing demonstration site. The hologram, based on the 3D model (BIM or photogrammetric) of the existing condition of the remote building is visualized via Microsoft HoloLens 2 into another space with a relatively similar size. If more than one floor would be explored, the staircase similarity in its position and clockwise / counterclockwise orientation should be considered. The mixed reality application could provide switching over the different variants for renovation according to the user's demands. The variants for renovation are presented by holograms of their BIM models.

The user obtains dynamic experience moving into the space of the real building, with an opportunity to inspect different levels of the remote building, walking around, up and downstairs, moving naturally on his own feet, approaching the constructive details, visualized in a scale 1:1. This mixed reality solution avoids the physical discomfort (dizziness), usual for the use of virtual reality.

Figure 42: Demonstrated building Malko Tarnovo (left); Demonstrative building Varna (right)

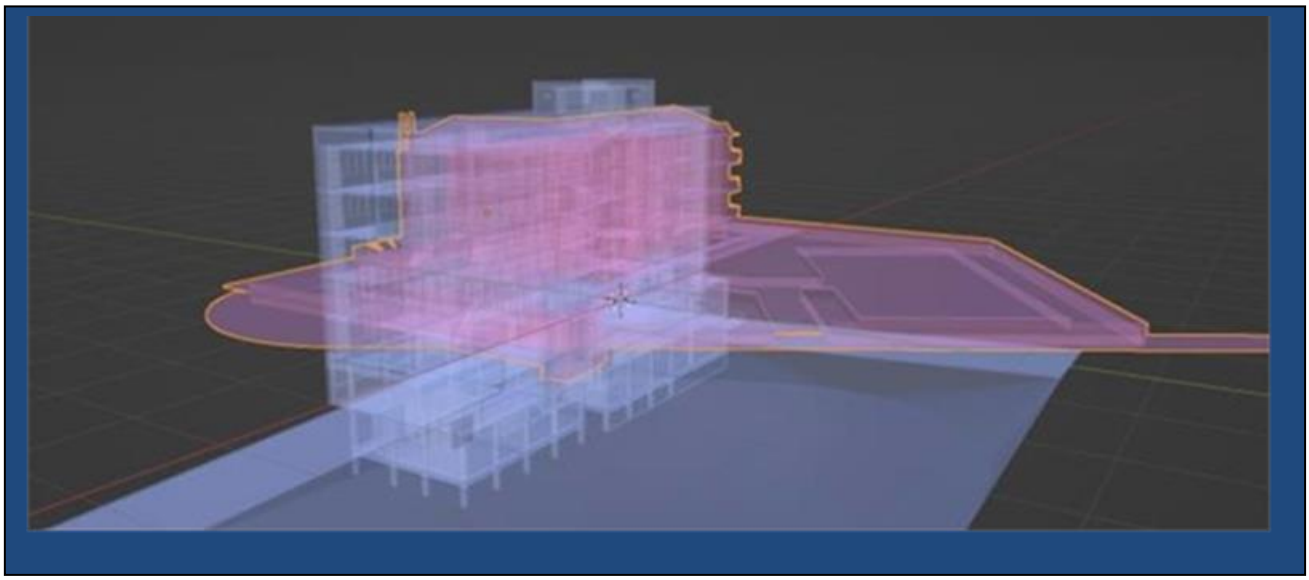

Figure 43: Illustration of demonstrated building (in pink) and the demonstrative building (in blue)

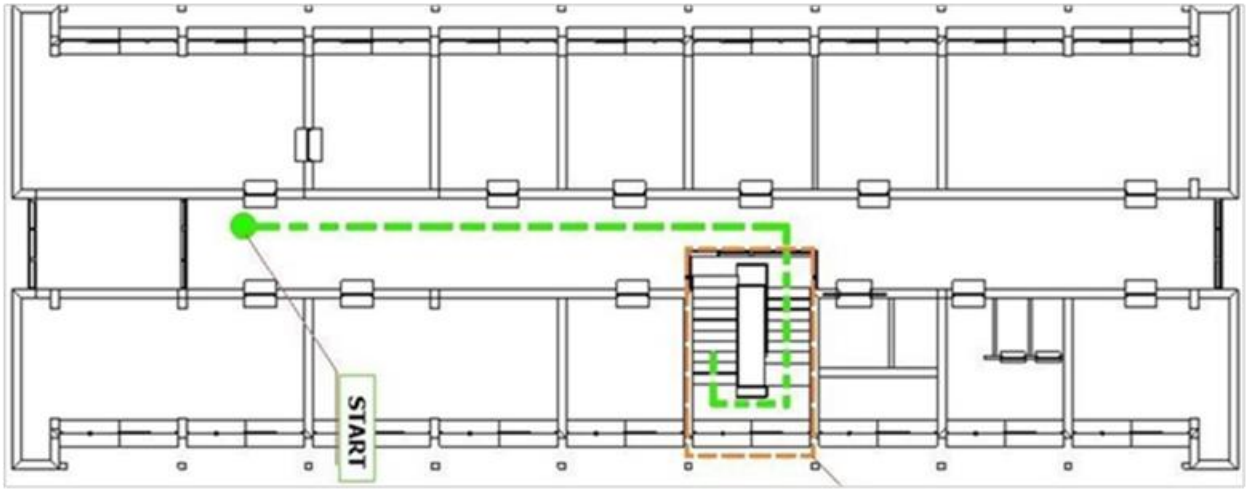

Figure 44: Floor plan of the demonstrative building indicating the path of illustration

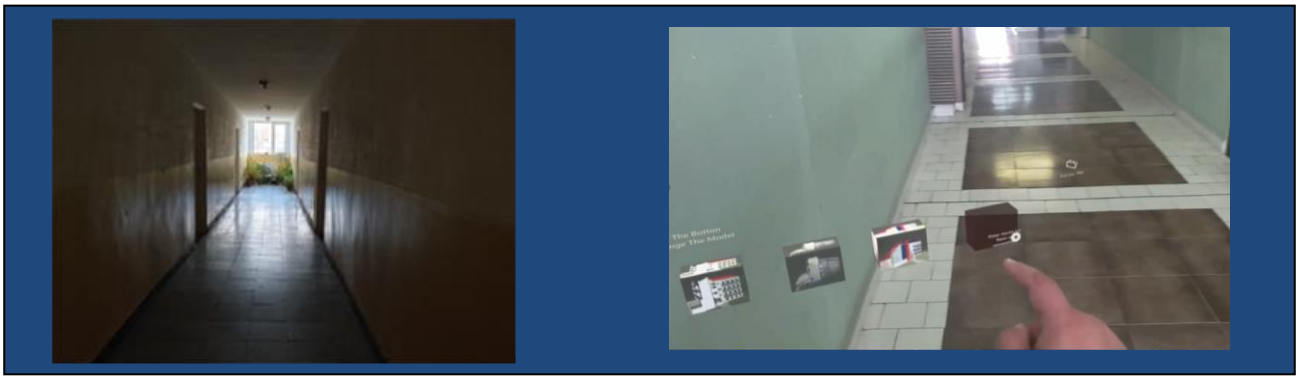

Figure 45: Corridor of the demonstrated building (left); corridor of demonstrative building (right)

Here are a few images from the video.

Figure 47: View to the staircase in the sunspace (lobby) of the demonstrated building, hosted in the corridor of the 5th floor of the demonstrative building

Figure 46: Moving in the 1st floor corridor of the demonstrated building, hosted in the corridor of the 5th floor of the demonstrative building

Figure 49: View from the glassed wall of the sunspace (lobby) of the demonstrated building, to the office of ASP on the 5th floor of the demonstrative building

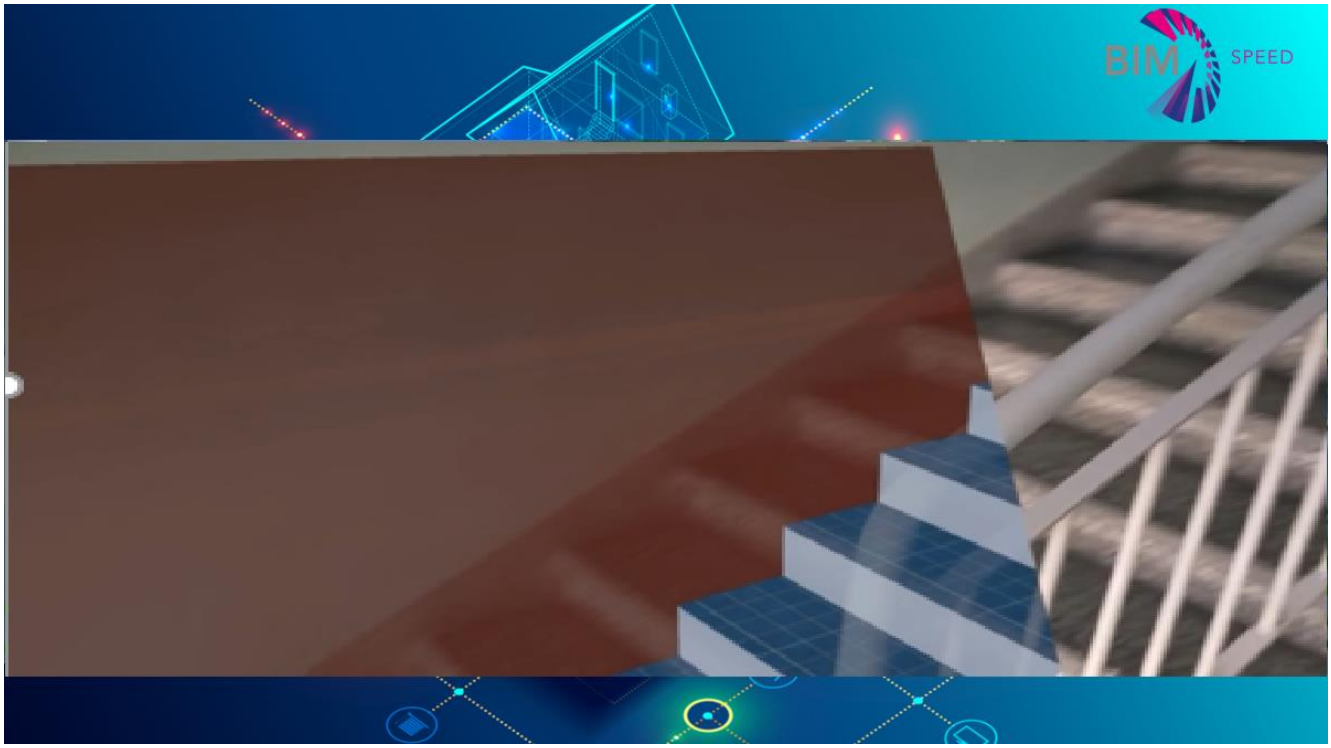

Figure 48: The staircase between 1st and 2nd floors of the demonstrated building, overlapping the staircase between the 5th and 6th floors of the demonstrative building

Follow this link to the video about demonstrating the MR hologram of the Malko Tarnovo demo site into the building of the Scientific Technical Unions - Varna, where are located the offices of Architectural Spies.

5.1.5 Simulations of Building Renovation Scenarios for demo Malko Tarnovo via small-scale Holograms and scale 1:1 photogrammetric model of the interior before renovation

Here are a few images from the video. To watch the video, click this link for *"Demo site Malko Tarnovo small to real scale with HoloLens 2"*. This interesting solution presents small and real scale models of the existing building (BIM, thermal and photogrammetric) and the project for renovation.

Figure 50: Small-scale hologram of the BIM of the renovation scenario for demo site Malko Tarnovo

Figure 51: Small-scale hologram of the 3D model of a thermal survey of demo site Malko Tarnovo

Figure 53: Small-scale hologram of the “opened” as-built 3D model of demo site Malko Tarnovo

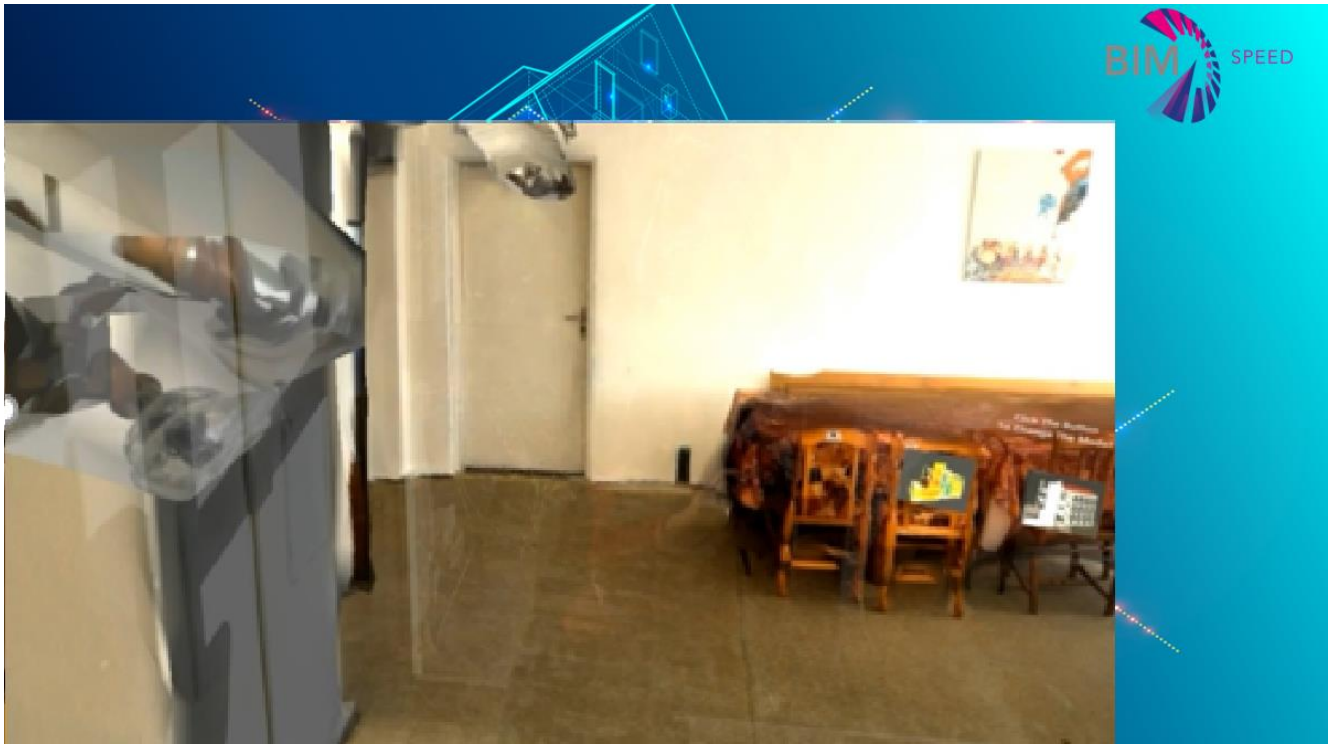

Figure 52: Real-scale (1:1) hologram, “teleporting” into the photogrammetric model of the existing dining room of demo site Malko Tarnovo

5.1.6 Off-site AR (MR) application for demo Varna via small scale holograms of the thermal, photogrammetric and BIM models and in scale 1:1 of the interior before renovation

This off-site mobile AR (MR) application presents the past condition and on-site surveys of the partially renovated building, which is a Bulgarian national cultural heritage. The renovation works were applied at the facades facing to the streets Bdin and Dragoman but the facades in the yard still are not renovated. The application is supplied with different models:

- Exterior photogrammetric model of the past condition
- Interior photogrammetric model of the past condition
- BIM model of the past condition
- BIM model of the project for renovation
- 3D thermal models based on 2D thermal scans

The application is developed for Microsoft HoloLens 2. The game design document data of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-4.

It provides the opportunity for "jumping" into the building after interactive observing different small-scale models. The user "teleports" from the real office environment (where the 3D models were put at a table) to the virtual 3D environment of the space under the roof of the building. If the transparency is minimized to 0 %, the augmented environment turns to 100 % virtual environment. This idea could be successfully applied for different AEC purposes.

Here are a few images from the video. To watch the video, click this link for *"Demo site Varna with real scale with HoloLens 2"*.

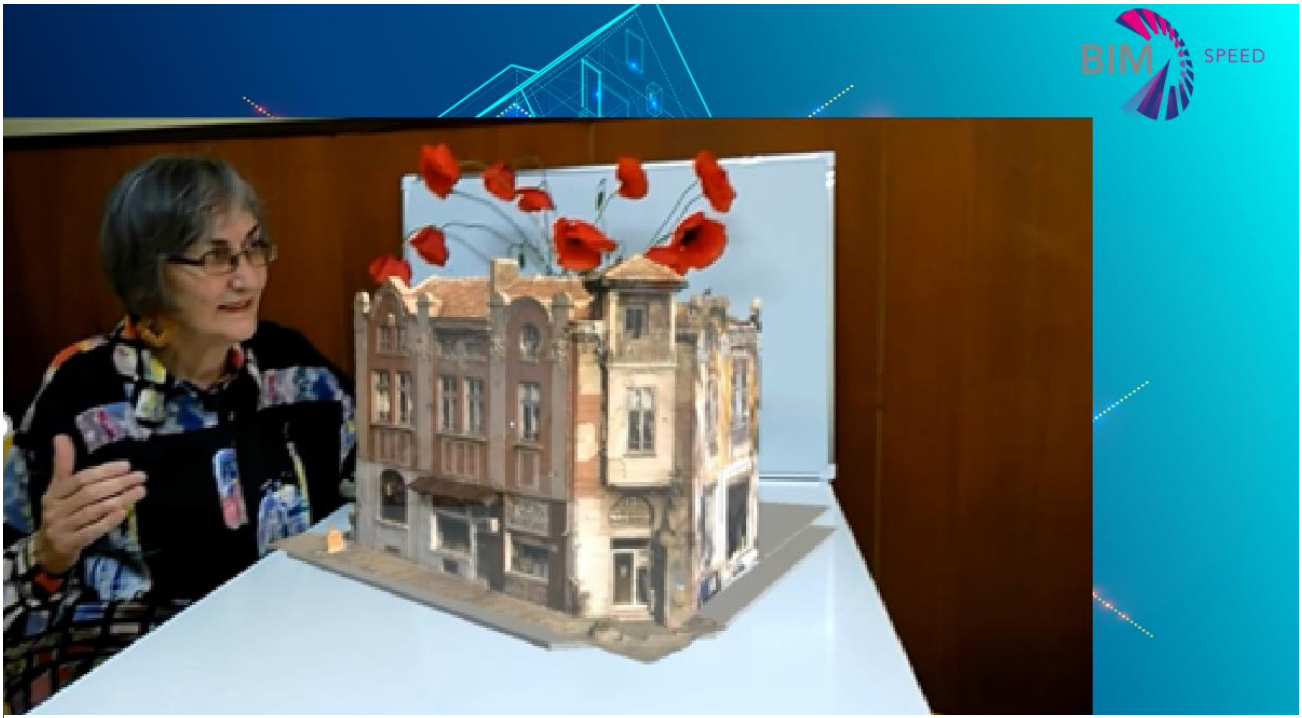

Figure 54: Small-scale hologram of the photogrammetric model

Figure 55: Small-scale hologram of a 3D thermal model

Figure 56: Small-scale hologram of a BIM model for renovation

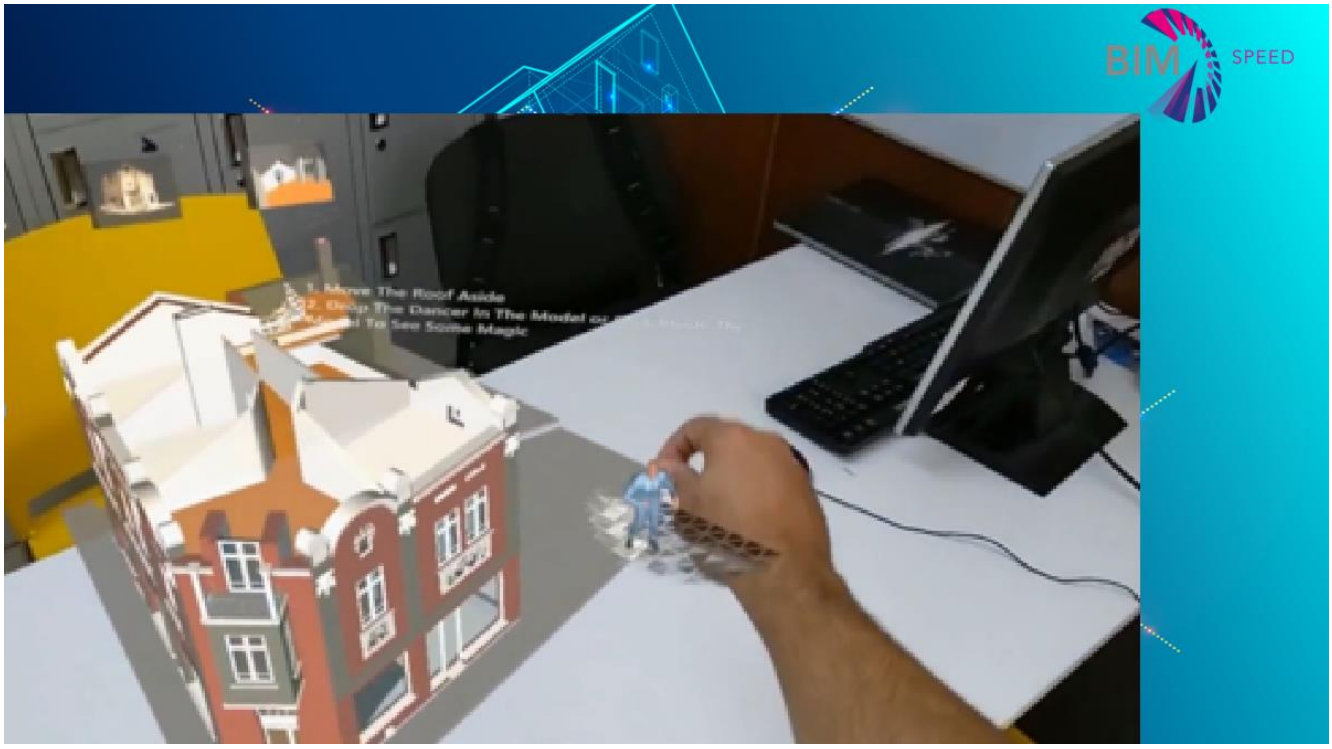

Figure 58: Changing the scale of the hologram from small-scale to scale 1:1 “jumping into the building

Figure 57: Photogrammetric model of the attics floor in scale 1:1

5.1.7 On-site AR (MR) application with a target recognition of demo Malko Tarnovo, presenting in a real scale 1:1 the project for renovation

On-site immersive AR (hologram in scale 1:1) for walking around and into the still not renovated building, presenting by Microsoft HoloLens 2 the project for its renovation. The user could obtain an on-site impression of how the interior spaces would look after the project would be realized. Architectural, structural and HVAC elements are shown, and the interior spaces are furnished.

This application gives similar result to that with double use (on-site and off-site), when used on-site. The app with double use is with a fixed starting point, and this app is with an image recognition of the target – the building (that is a much more complex solution).
The game design document data of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-4.

Here are a few images from the video. To watch the video, click this link for *"Demo site Malko Tarnovo on-site walkthrough with HoloLens 2"*.

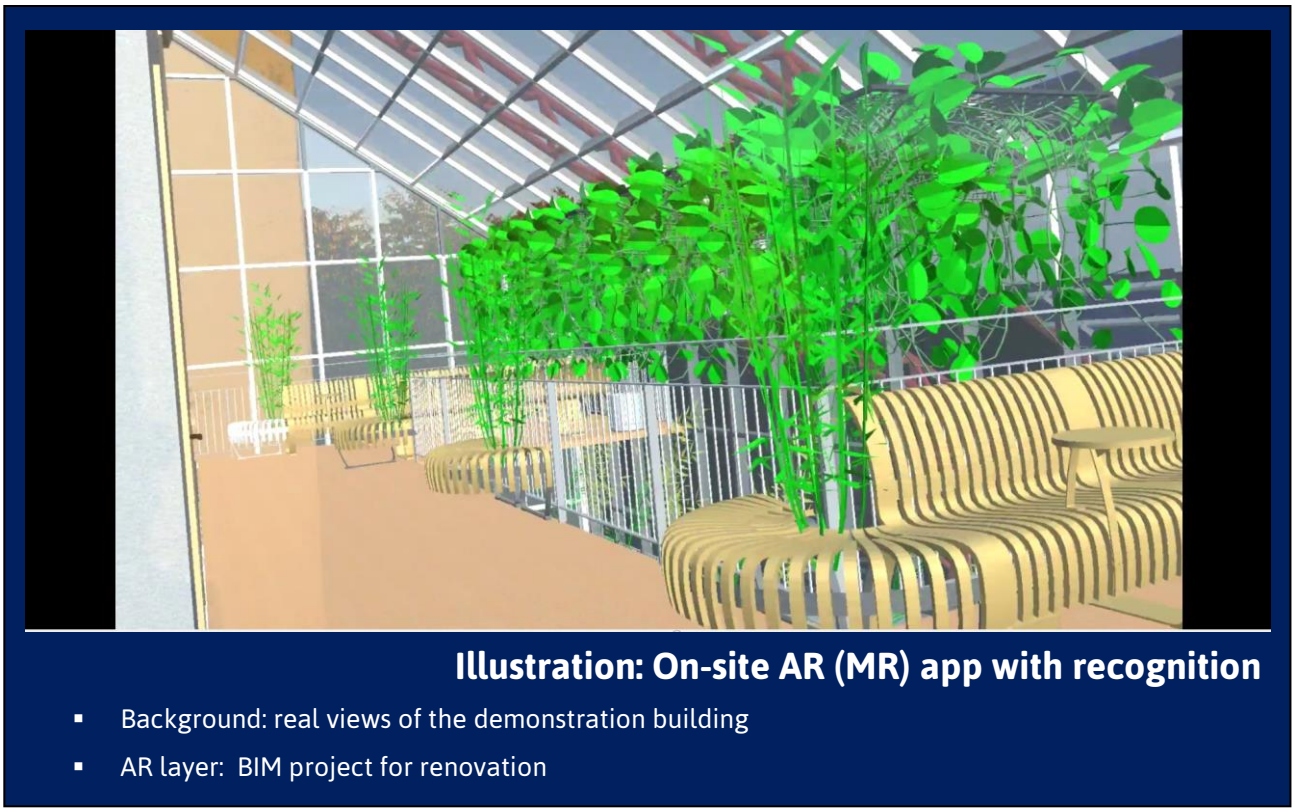

Figure 59: On-site hologram of the sunspace (lobby)

Illustration: On-site AR (MR) app with recognition

- Background: real views of the demonstration building
- AR layer: BIM project for renovation

Figure 60: Process of overlapping the real building with the holographic BIM model for renovation

Illustration: On-site AR (MR) app with recognition

- Background: real views of the demonstration building
- AR layer: BIM project for renovation

Figure 61: Hand recognition and gesture tracking

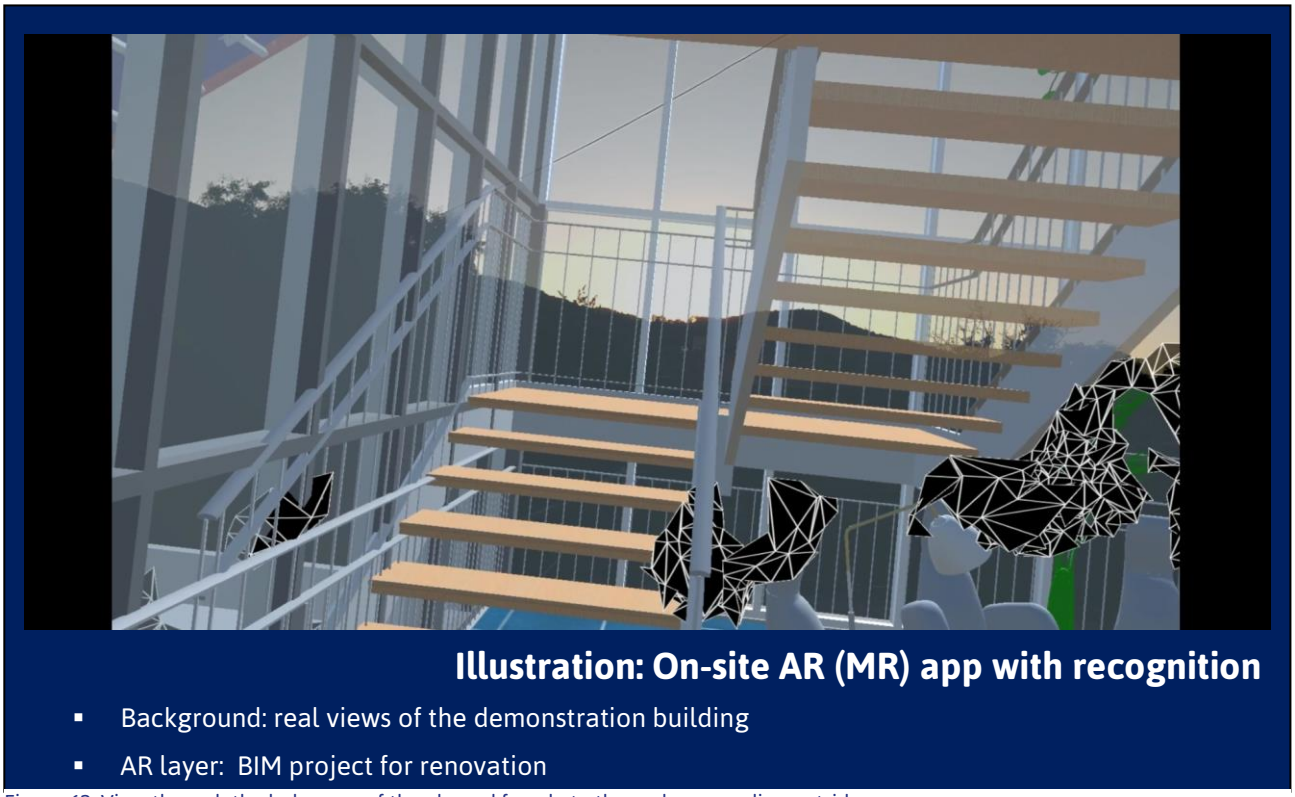

Figure 62: View through the hologram of the glassed façade to the real surrounding outside

Figure 63: View through the hologram of the glassed façade to the real surrounding outside

Illustration: On-site AR (MR) app with recognition

- Background: real views of the demonstration building
- AR layer: BIM project for renovation

Figure 64: View through the hologram glassed façade to the real surrounding outside and overlapping the existing parapet

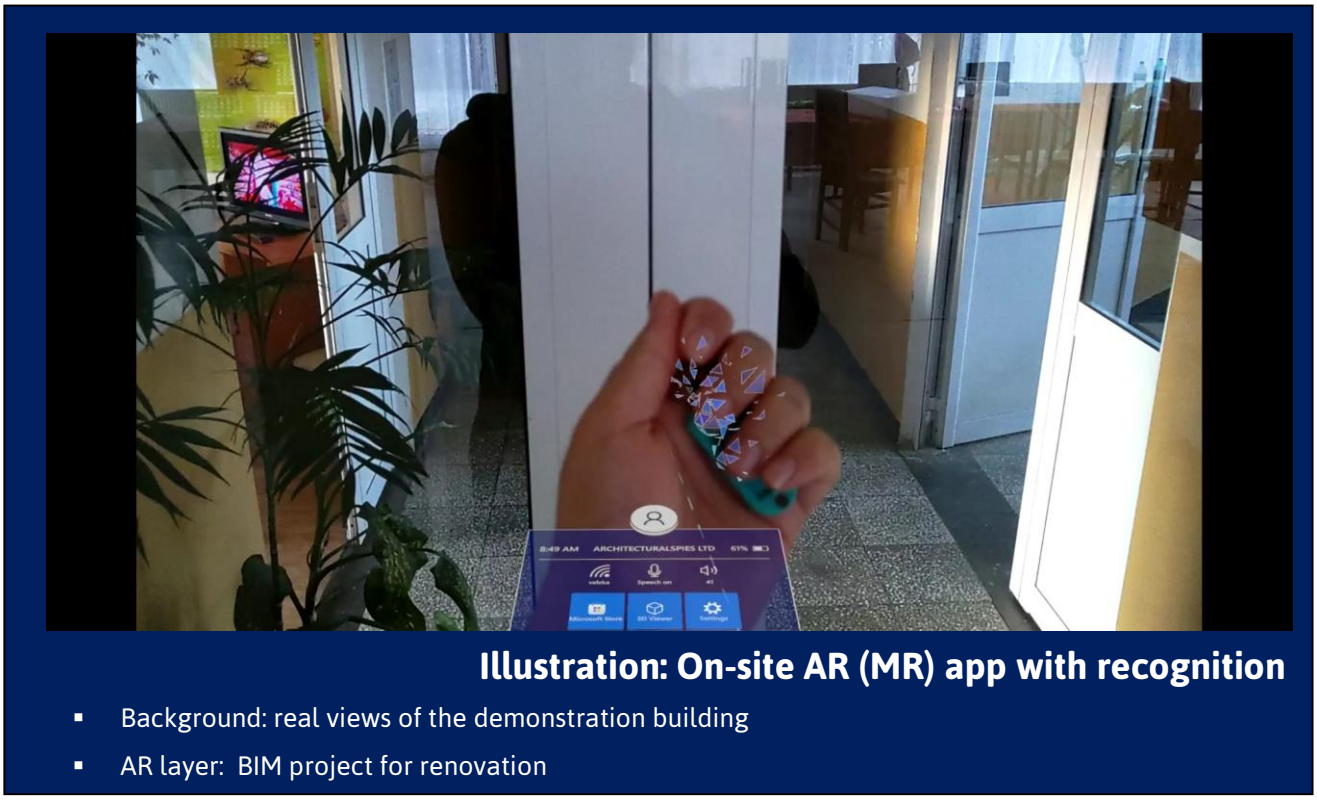

Illustration: On-site AR (MR) app with recognition

- Background: real views of the demonstration building
- AR layer: BIM project for renovation

Figure 65: End of the demonstration

5.1.8 Desktop AR demonstration of BIM, photogrammetric and thermal models of demo site Varna with anaglyph glasses

Another application in augmented reality is the AR solution for desktop with anaglyph glasses. It enables the users to visualize with anaglyph glasses the 3D photogrammetric models and the BIM models for different renovations scenarios of the demo sites and to compare the existing un-renovated building and with other design variants and solutions. Financially this solution is very affordable for the users, but it has limited opportunities in regard to the quality of the visualization and to be always used with a desktop. This link is to the video.

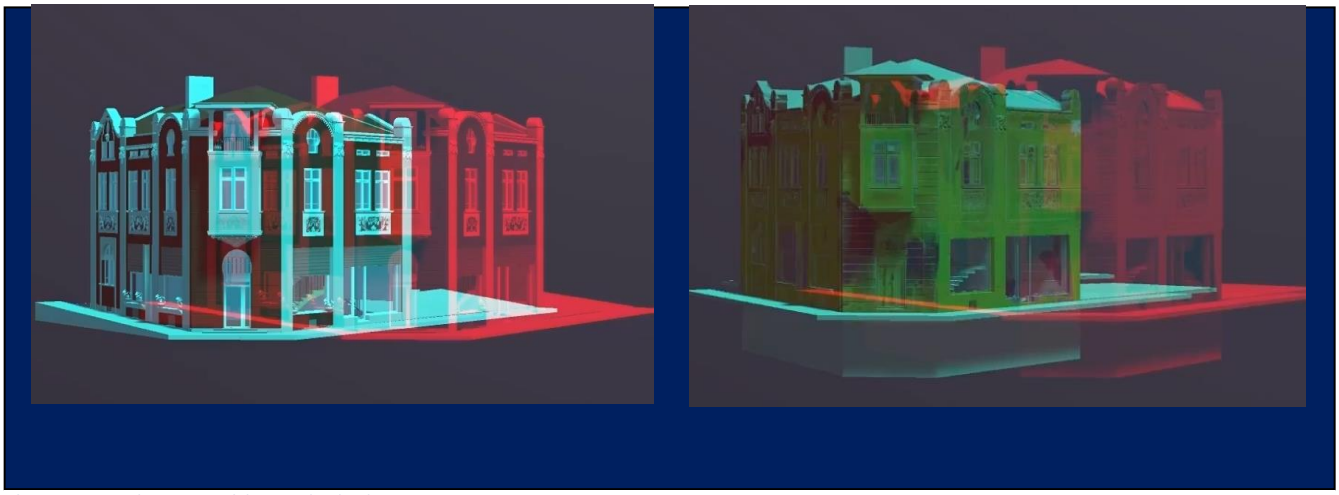

Figure 66: Desktop AR with anaglyph glasses

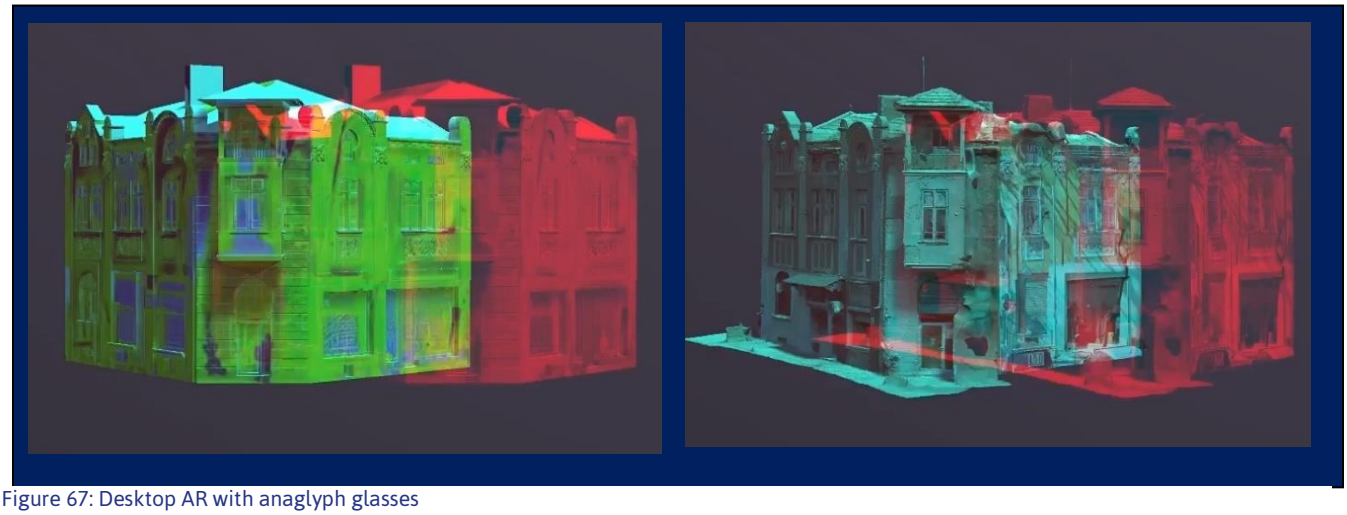

Figure 67: Desktop AR with anaglyph glasses

The game design document data of this application is listed in Chapter 3, under 3.2 in Table 2. under number GDD-AR-9.

5.2 VR Demonstrations

The provided VR demonstrations are:

- VR with headset (device: *Oculus Quest 2*)
- VR with smartphone + VR box (device*: smartphone + VR box with controller and VR box without controller*)
- Web VR – *universal 3D viewer*

5.2.1 VR application for the project for renovation for demo site Malko Tarnovo via device Oculus Quest 2 with hand tracking

The VR shows the project for renovation of the municipal dormitory of Malko Tarnovo. It is a virtual walk around and into the building, giving the impression in scale 1:1 about how the building will look after the renovation. This app differs from the VR app for Oculus Quest 2 with controllers. A special virtual control table was created and was used as the hand recognition function of the VR device. Also, the HVAC system was added to the BIM model.

The game design document of this application is listed in Chapter 3, under 3.2, in Table 3. Table 2 with number GDD-VR-1. Here is a link to the video.

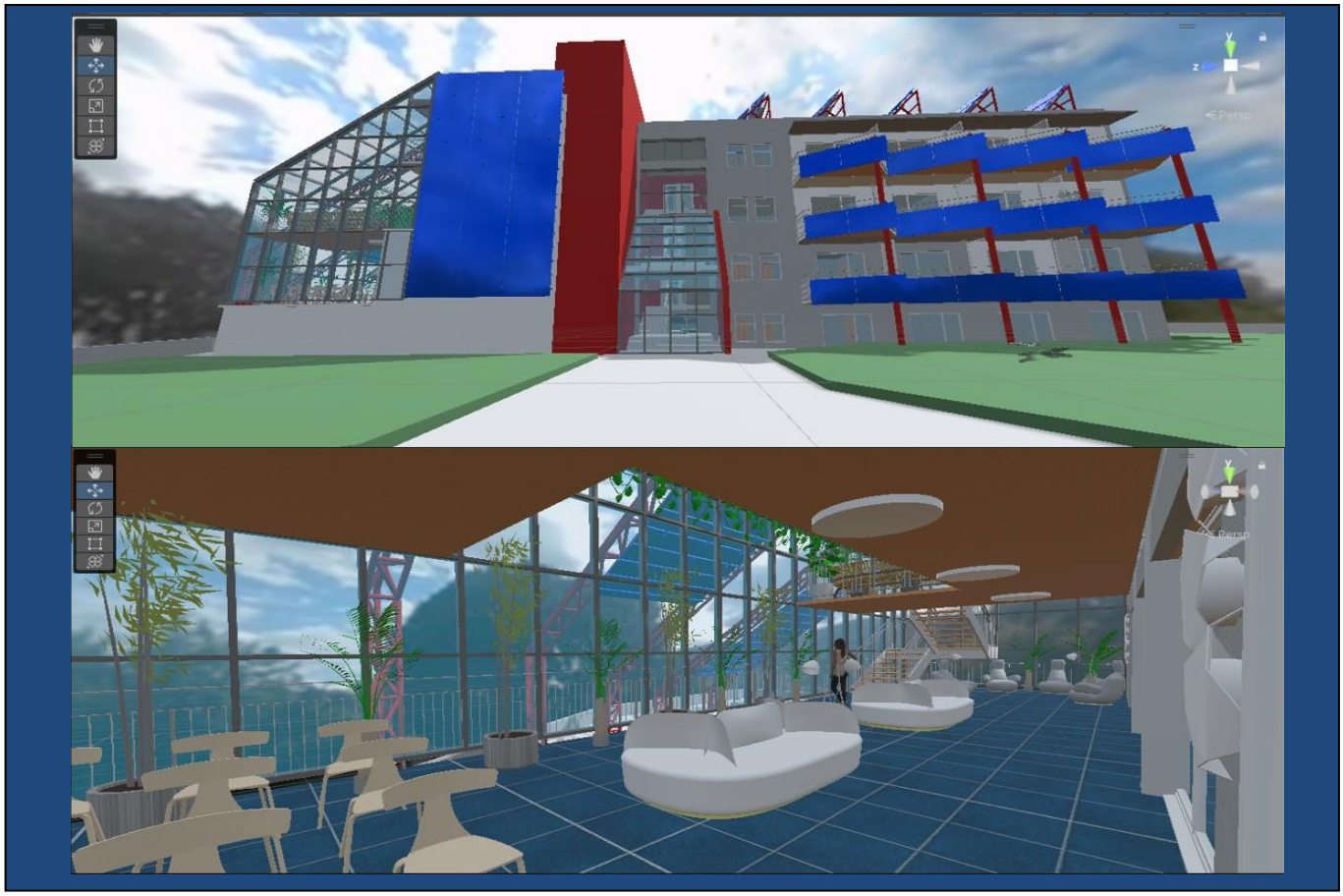

Figure 68: External view of the building – project for renovation; sunspace (lobby)

5.2.2 VR application for the project for renovation for demo site Malko Tarnovo via device Oculus Quest 2 with controllers

This VR application is technologically less advanced comparing to the previously listed. It uses the standard controllers of Oculus Quest 2. On the Figure 69 the user sees the VR models of hands, provided by the device software. The image of the hands is done for more friendly impression, replacing the image of the real hardware (controllers) used for directing the walk through the BIM model.

Here are a few images from the video, accessible via this link .

Figure 69: Left – external view, right - view of the sunspace (lobby)

5.2.3 VR application for demonstration of the demo site Varna via device Oculus Quest 2

This application demonstrates the BIM model for renovation, the same model with "removed fades" for better understanding of the building, and a 3D thermal model of the building, produced from the 2D thermal scans by FLIR camera, developed by ASP during the work in WP1. The surrounding environment is modelled in Blender. The initial work on the application started with surrounding environment made by photogrammetry (similar to the first VR app for Malko Tarnovo) but the app became very heavy, for smooth work with the device. Therefore, the newest VR apps for the both demo sites were done with 2 different methods: 360 photo (Malko Tarnovo) and 3D model (Varna).

Here are a few images from the video. To watch the video, click this link for *"Demo site Varna with Oculus Quest 2"*.

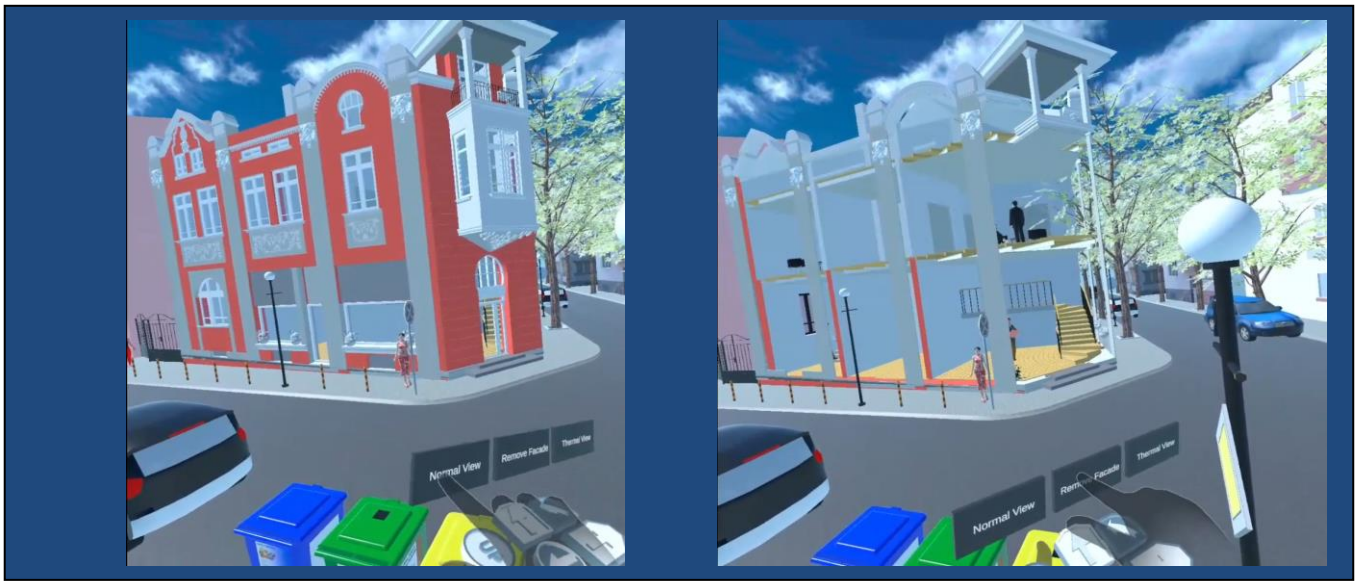

Figure 70: Left – exterior – view from the crossroad, right – view from the same position with "removed facades"

Figure 71: Thermal 3D model based on 2D geo-thermal scans, view from the smaller street (Bdin str.)

5.2.4 Application for VR Box + smartphone for demo Varna

This application is for the low-cost device VR box used with a smartphone. The screen is divided on 2 images – for the left and for the right eyes. There are shown the BIM model for renovation, sections (model with "removed facades"), photogrammetric model of the building before the renovation, and thermal 3D models in different seasons based on 2D thermal scans.

Here are a few images from the video. To watch the video, click this link for *"Demo site Varna VR Box"*.

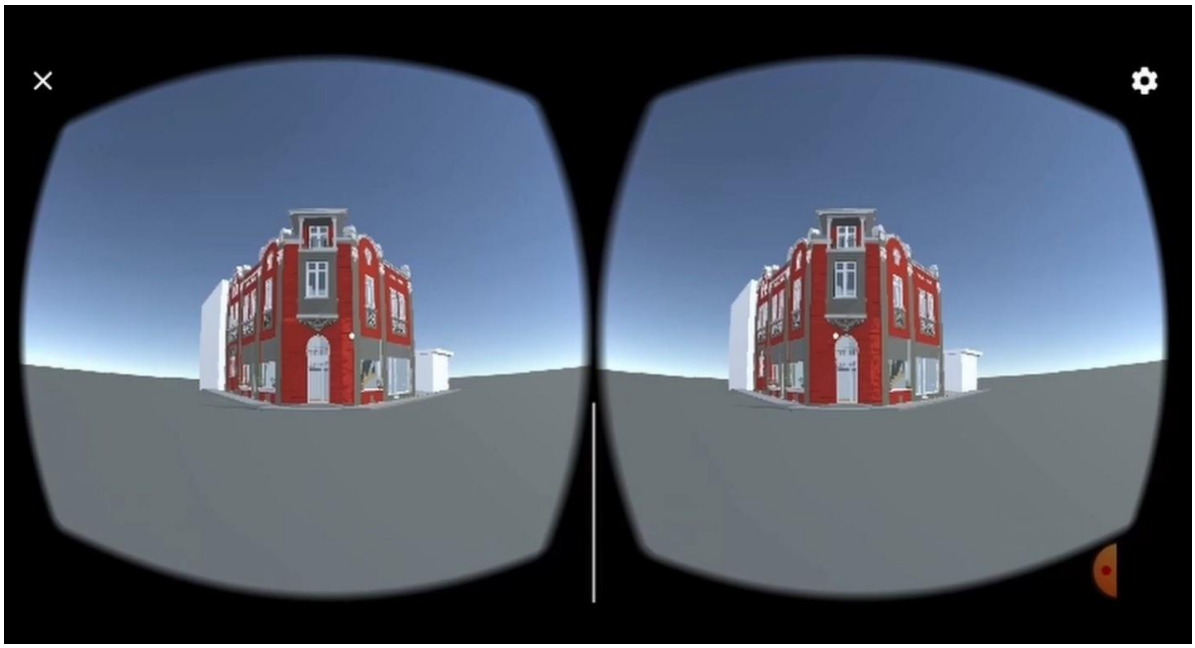

Figure 73: BIM model of the project for renovation

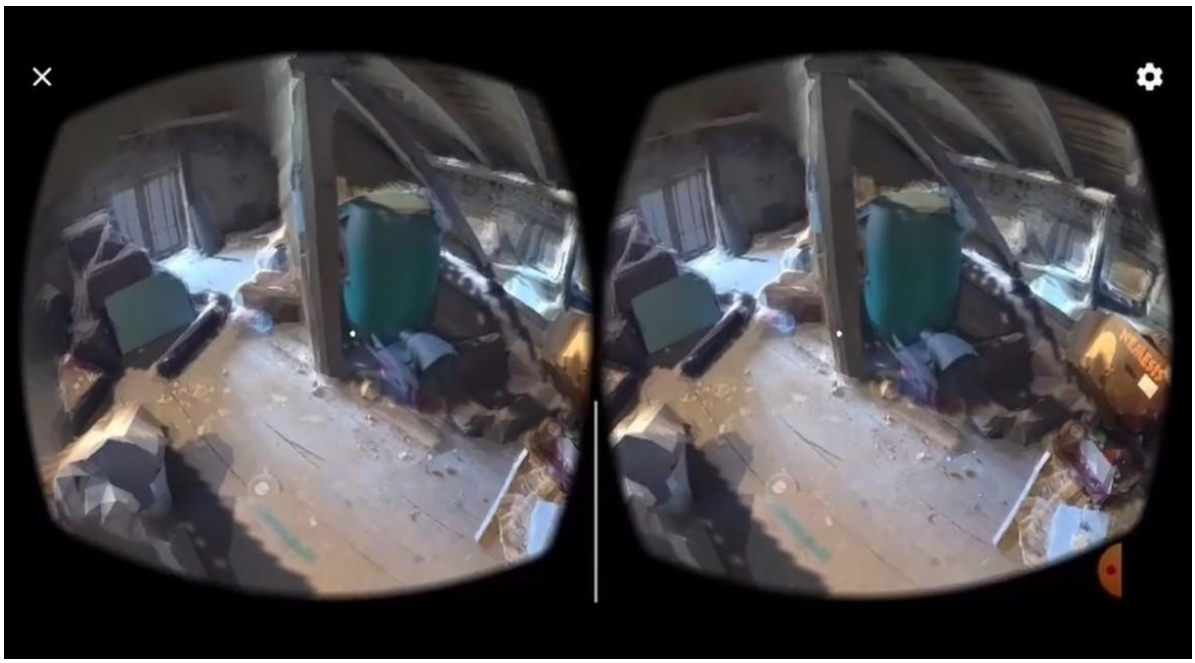

Figure 72: Photogrammetric model of the existing interior space of the attic floor

5.2.5 Web VR application: universal viewer for demo site Varna enriched with data from the sensors

The Web Application created via JavaScript and is hosted on a server via Node JS. The BIM models have been edited in Blender.

The below image is a screenshot from the web application, which displays model of the building and sensor data. Sensor six is located at the backside of the building. A table in the web application shows pressure(barometer), temperature and light intensity(lux) with a graph and maximum and minimum values.
The values for B(pressure) are in bar units. The values for T(temperature) are in degree Celsius(°C) units. The values for L1 and L2(light intensity) are presented in lux units.

The application is accessible on this link .

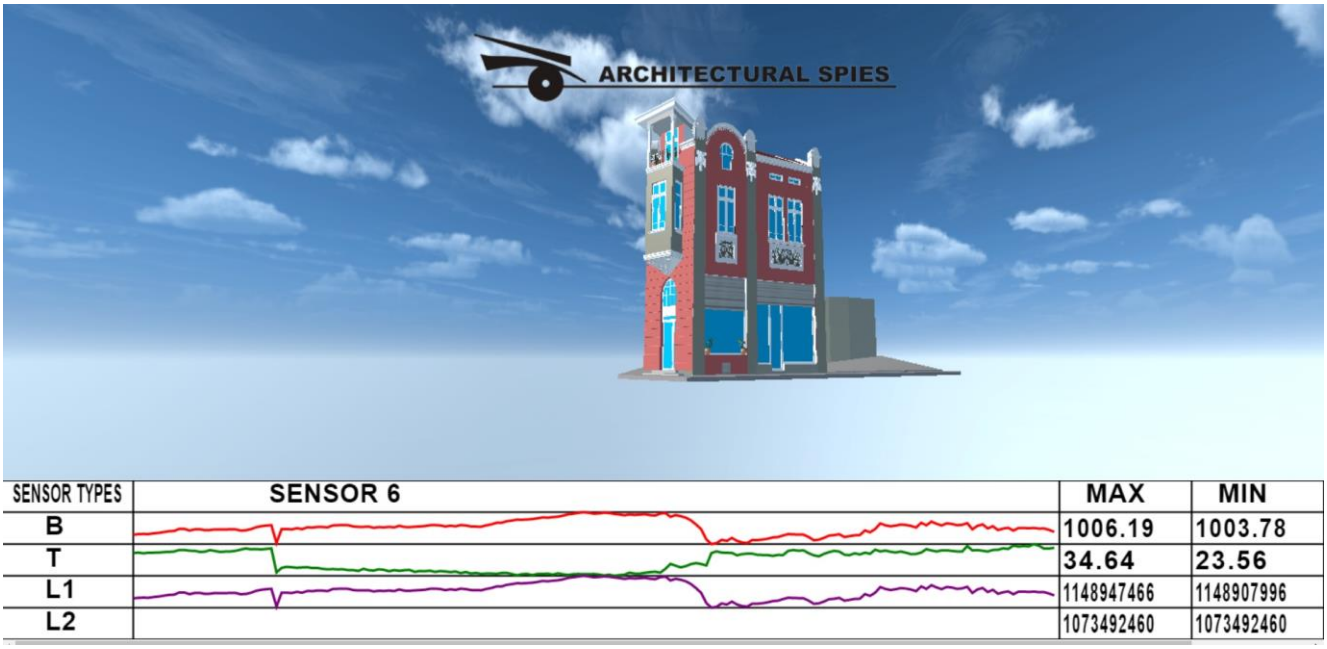

Figure 74: Web VR application displaying sensor data for demo side Varna

5.2.6 Web VR application, universal viewer for demo site Malko Tarnovo

The Web Application created via JavaScript and is hosted on a server via Node JS. The BIM models have been edited in Blender. This is the link to the application.

Figure 76: : Left – scanning the QR code, right – the poster from the demonstration in Varna

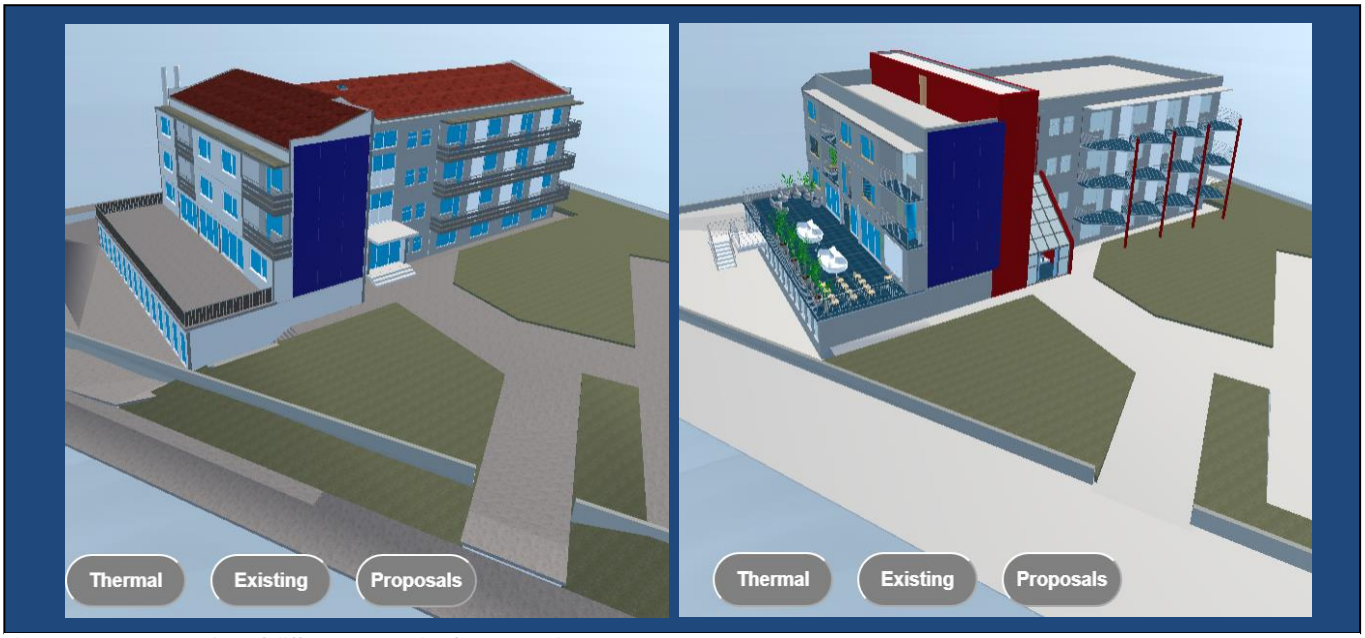

Figure 75: Demonstration of different scenarios for renovation

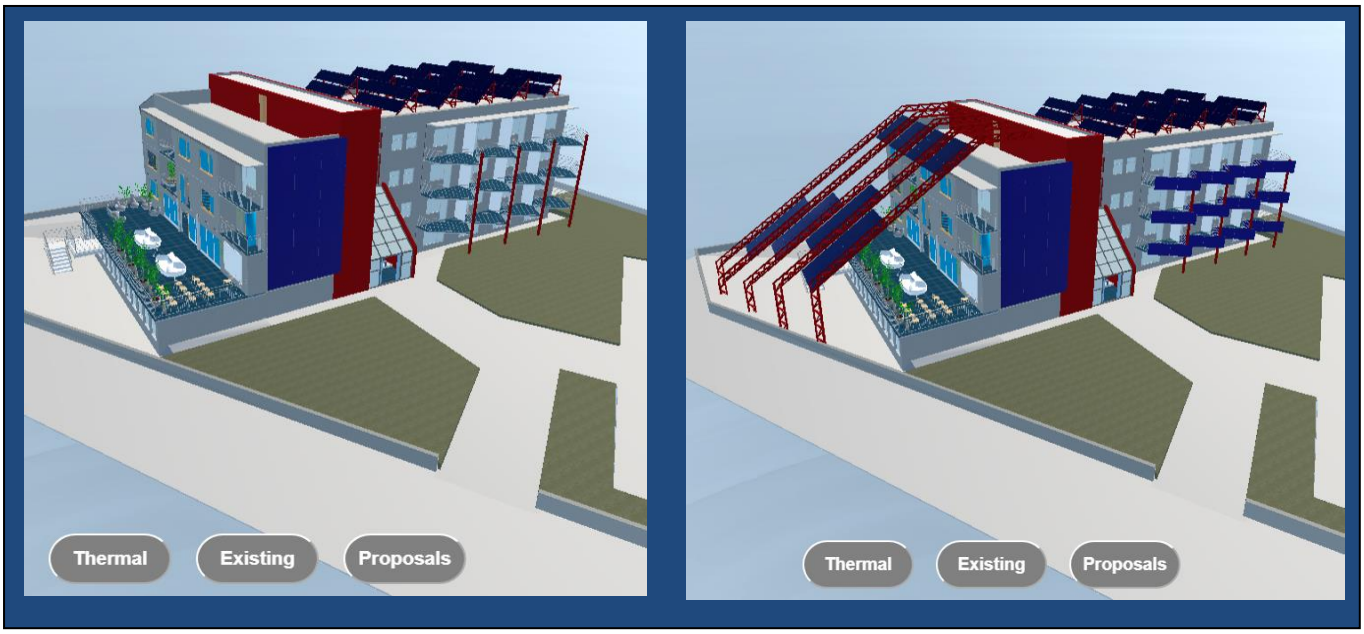

Figure 77: Demonstration of different scenarios for renovation

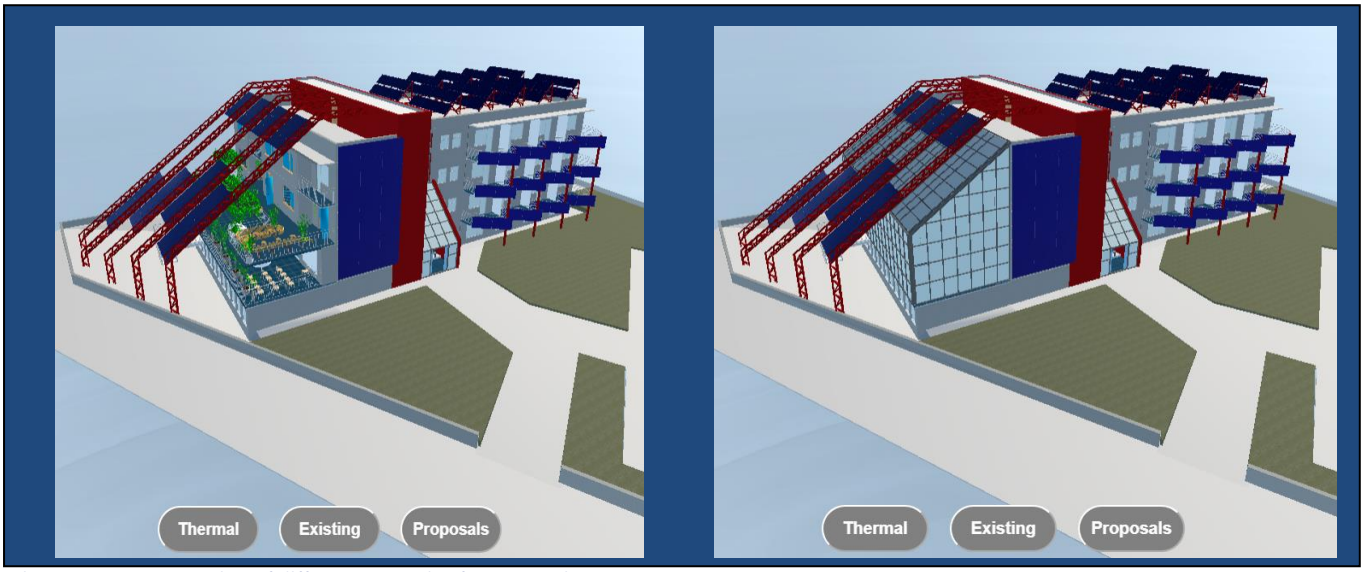

Figure 78: Demonstration of different scenarios for renovation

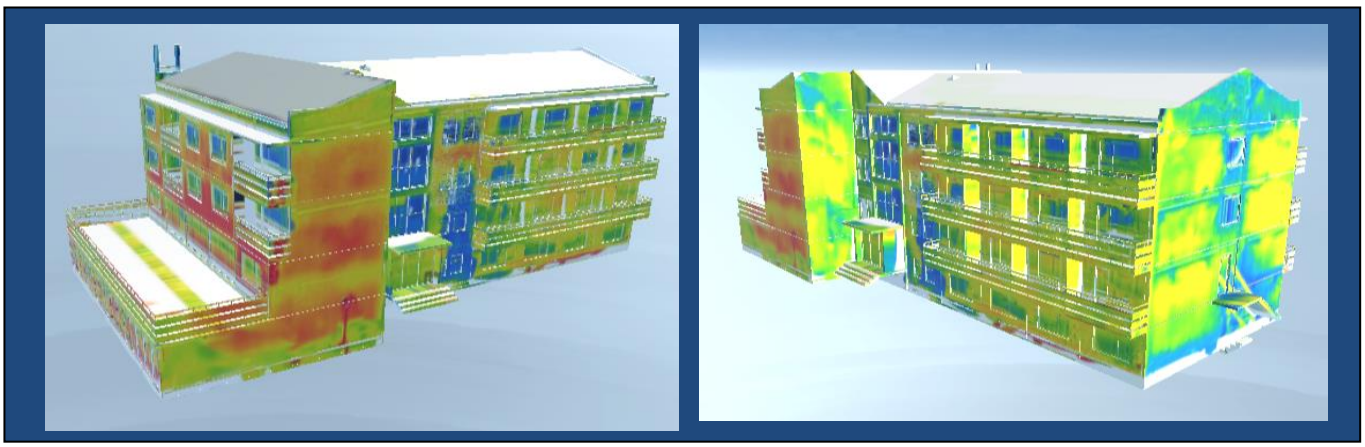

Figure 79: 3D thermal images based on 2D thermal scans

5.2.7 VR application for health and safety awareness for construction workers

Goal

The construction industry faces some of the highest worker injury and fatality rates in the European Union. Construction sites are full of potential dangers and one of the best ways to counter them is through awareness and training. Although many forms of training and certification already exist, the risks to workers are still too high and could always be improved. New technologies may be the solution, offering relatively low-cost and potentially high-impact improvements to worker safety. One such solution is the use of virtual reality for training construction workers to be aware of and react to these ever-present dangers. Training in virtual reality may prove to be more engaging compared to traditional training sessions, ensuring that its impact is greater, and that knowledge is retained for longer. Two safety training scenarios have been developed to test this solution in practice.

Scenario One: Personal Protective Equipment

One of the simplest and most important methods of ensuring worker safety on a construction site is to ensure that they are protected by the proper gear and to enforce the need to wear it at all times while on site. The first scenario that has been developed is to remind workers of the personal protective equipment (PPE) that they will need before entering the construction site. Workers will be placed directly into the construction site, where they will be immersed in a 360-degree photo. There will be a simple quiz that appears on screen where the trainee will be prompted to select the proper equipment corresponding to the question. The 360-degree photo includes a man, showing him before and after putting on his PPE. The trainee will have to complete all question to pass the test and complete the scenario. The layout of the first scenario can be seen in the image below.

Figure 80: Safety test scenario 1 demonstration using VR

Scenario Two: Securing technological openings

The second scenario guides the trainee on what to do if they find themselves in a situation where they find an unsecured technological opening on a construction site. Falling from heights is a danger on most construction sites, and in some cases, it is easily preventable. First and foremost, any unsecured opening must be fenced off so that others are aware of the danger and so that they could avoid it. Once fenced off, the next step is to secure it in such a way that it does not pose a threat anymore. Such a scenario was crafted as a step-by-step VR guide, where the trainee will learn how to proceed if and when such a danger is noticed by them.

The trainee will be placed in a 3D model of the construction site where an unsecured opening can be seen. They will then be asked to identify the danger, and then be prompted to inform the site manager of the situation, alerting any nearby workers. The following step is to fence off the danger zone, where the trainee will have to place barriers to block off the opening. The worker will then need to report the situation and obtain permission to secure the opening. They will be advised to ensure that they have the proper PPE and will then be instructed on mounting their harnesses to anchor points, which would allow them to perform their task of securing the opening according to the guidelines of the fall protection system. Below is an image of the corresponding real-world location that the scenario will take place in.

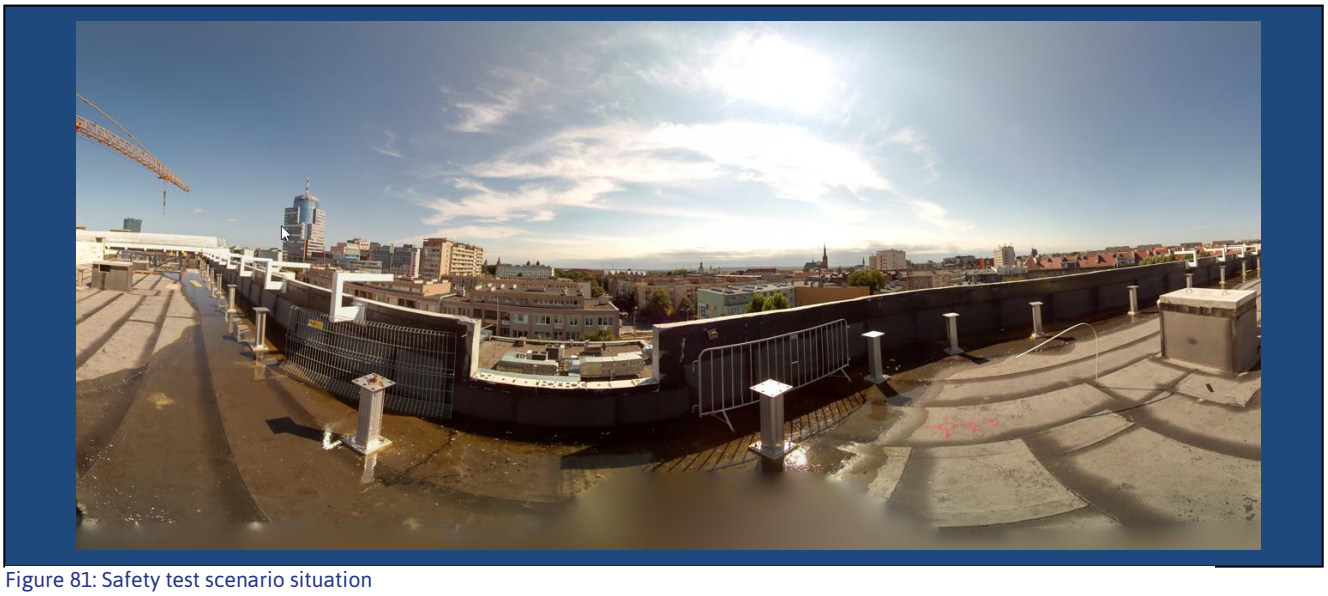

Figure 81: Safety test scenario situation

Figure 82: Main menu

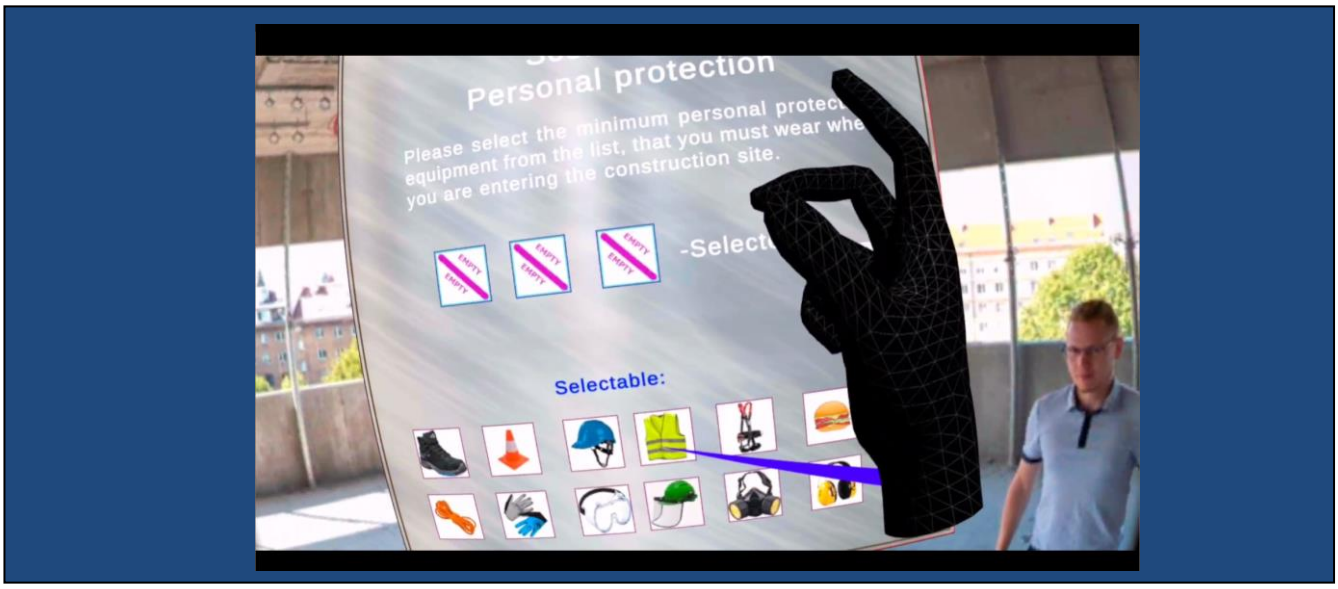

Figure 83: Scenario 2 - tests

Figure 84: Scenario 2 – tutorial walking

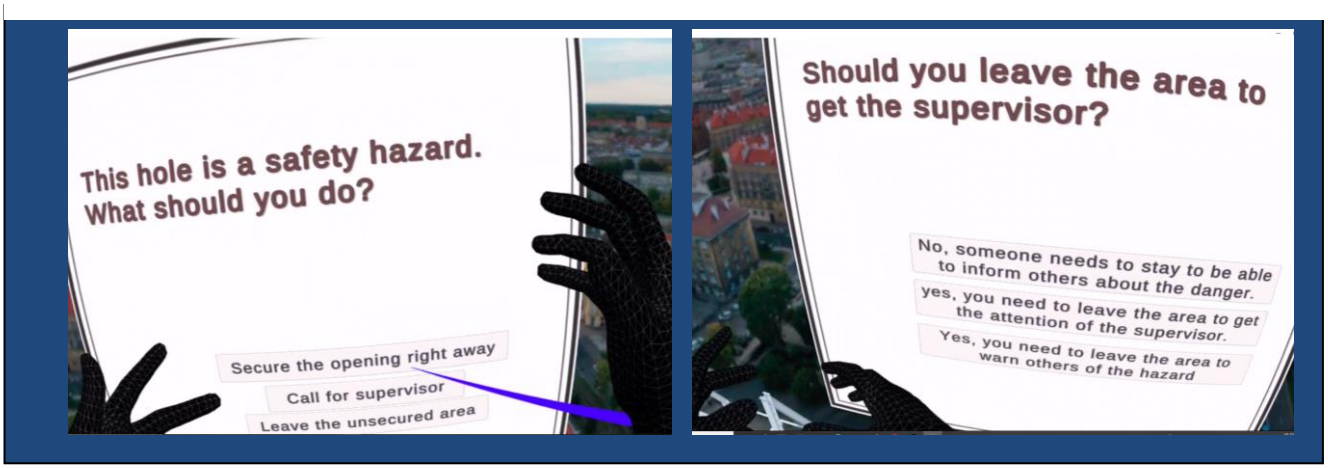

Figure 85: Scenario 2: tests(left) ; the questions(right)

Benefits

Using virtual reality for safety training has numerous benefits over traditional solutions. The workers will be more engaged during the training, making it both more entertaining for them and more valuable in terms of lessons learned and retained. Increased knowledge retention will lead to more awareness of the dangers on construction sites and provide workers with useful skills on how to deal with them. This should lead to lower accident rates on the construction site, which is beneficial to both the worker and the construction company, which will face fewer delays and experience a positive return on investment from using this technology.

This is the link to the video “Safety Training Simulation with Oculus Quest 2 Screen Recorded”.
This is the link to the video “Safety Training Simulation with Oculus Quest 2 by Trainee”.

6. Conclusion

There could be done the following conclusions of the work on T7.4:

- The state-of-the-art shows extremely fast development of the VR/AR hardware. This means that some of the devices could be old-fashioned only a year after their purchase. There could be found new ways of usage by development new software solutions. Such an example could be both VR applications for demo Malko Tarnovo. The old one uses the controllers, and the new one developed a solution replacing the hardware (controllers) with a virtual control panel using the function of hand tracking of the headset. It is one of the contributions of the project BIM-SPEED.
- The state-of-the-art shows also extremely fast development of VR/AR software. Relating to the functionality, the new software facilitates the work of the professionals, but from another point of view, some functions provided free by the older versions are not accessible free. Some of them are not affordable for freelancers and the small companies at the EU market. As it is known, the structure of the architectural market in the EU is composed of small studios. Such an example is the workflow of converting the BIM models for importing into the game engines for producing VR/AR.
- There is a lack of educational materials for VR/AR, especially for AEC professionals. BIM-SPEED provided such training materials in 2021 but because of the extremely fast development of the VR/AR hardware and software, it is recommendable they to be actualized annually after the end of the BIM-SPEED project.
- The mobile AR applications will become more accessible and friendly in the near future and it must be paid attention to develop more of this type of XR.
- The mobile AR for standalone buildings differs from the AR of buildings included in the street silhouettes. It could show façade walls, balconies and cantilevers at front of the common façade line but not able to show any spaces deeply of the façade wall if not have the 3D models of the neighbor buildings. The recognition of a facade in a row of houses connected continuously in a residential area, it is a challenge for mobile AR technology to identify the unique property of the building.
- The project BIM-SPEED has made a great contribution to the use of VR/AR in AEC industry. For example, the solution for off-site holographic simulation of a remote building was recognized as an achievement at a conference of the VR/AR Association. It is the first-time use of an interactive multi-floor remote simulation by holograms.

7. List of References

1. Stamatova N., Visualization and Simulation of the Bulgarian Demonstration Sites of the Project BIM-SPEED via Virtual and Augmented Reality, Annual Conference of the Union of Scientists Varna, 28 October 2022, Varna, Bulgaria. Preprint for: ИЗВЕСТИЯ на Съюза на учените – Варна. Серия Технически науки 2022, Варна: Съюз на учените, 2022 Серия Технически науки, ISSN 1310-5833

2. Angelov A., Perfanov O., Yazici S., Visualization and Analysis of Environmental Data Obtained via Sensors Installed on the Bulgarian Demonstration Sites for the Project BIM-SPEED, Annual Conference of the Union of Scientists Varna, 28 October 2022, Varna, Bulgaria. Preprint for: ИЗВЕСТИЯ на Съюза на учените – Варна. Серия Технически науки 2022, Варна: Съюз на учените, 2022 Серия Технически науки, ISSN 1310-5833

3. Angelov A., Perfanov O., Thermophotogrammetry as a Tool for Analyzing the Technical Condition of Buildings and Facilities I Youth Scientific Conference with International participation "Design and Construction of Buildings and Facilities" 4-5 November 2021, ISSN 2738-7887 (online); ISSN 2738-7879 (CD-ROM)

4. Dymarski P., Kowal C., Angelov A., Safety Training in Extended Reality (XR), Varna Union of Scientists ИЗВЕСТИЯ на Съюза на учените – Варна. Серия Технически науки 1'2021, Варна: Съюз на учените, 2021 Серия Технически науки, ISSN 1310-5833. pp. 36- 42

5. Stamatova N., Angelov A., Case Study: Demonstration of a Real Scale Hologram of a Remote Large Scale Object at the Space of Another Large Scale Object via Mixed Reality Application by Device MIcroosoft HoloLens 2, Varna Union of Scientists ИЗВЕСТИЯ на Съюза на учените – Варна. Серия Технически науки 1'2021, Варна: Съюз на учените, 2021 Серия Технически науки, ISSN 1310-5833 , pp.21-27

6. Stamatova N., Angelov.,A., Immersive Presentation Technologies XR (AR,VR,MR) of Cultural Heritage in the City of Varna, Bulgaria, conference Cultural Heritage of Varna and Black Sea Region, Union of Scientists Varna, September 30, 2021, Varna Union of Scientists ИЗВЕСТИЯ на Съюза на учените – Варна. Серия Културното наследство на Варна., Варна: Съюз на учените, 2021 Серия Културното наследство на Варна и Черноморския регион, ISSN 2738-7372 (Print) ISSN 2738-7380 (Online)

7. Stamatova N., Angelov.,A., Thermophotogrammetry in Use for Cultural Heritage in the City of Varna, Bulgaria, conference Cultural Heritage of Varna and Black Sea Region, Union of Scientists Varna, September 30, 2021, Varna Union of Scientists ИЗВЕСТИЯ на Съюза на учените –Варна. Серия Културното наследство на Варна., Варна: Съюзна учените, 2021 Серия Културното наследство на Варна и Черноморския регион, ISSN 2738-7372 (Print) ISSN 2738-7380 (Online)

8. Stamatova N., Angelov A., Volumetrization of 2D FLIR Thermo-scans, Xth International Scientific Conference on Architecture and Civil Engineering ArCivE 2021, Varna, Bulgaria, May 29, 2021, ISSN 2535-0781, Vol.3

9. Stamatova N., Vasilev V., Angelov A., Perfanov O., Building Information Modeling (BIM) of Cultural Heritage. Case Study: 28, Dragoman Str., Varna, Bulgaria, conference Cultural Heritage of Varna and Black Sea Region, Union of Scientists Varna, September 25, 2020,Varna Union of Scientists, ИЗВЕСТИЯ на Съюза на учените – Варна.Серия Културното наследство на Варна., Варна: Съюз на учените, 2020 Серия Културното наследство на Варна и Черноморския регион, ISSN 2738-7372 (Print) ISSN 2738-7380 (Online).

10. Squelch A.P., Virtual reality for mine safety training in South Africa (12.05.2022) As part of The Journal of The South African Institute of Mining and Metallurgy (2001) ISSN 2225-6253

11.https://architecturalspies.com/ Internet site of Architectural Spies(12.05.2022)

12. https://www.microsoft.com/en-us/hololens Internet site of Microsoft about Microsoft HoloLens 2, (12.05.2022)

13. https://www.bim-speed.eu/en Internet site of the H2020 project BIM-SPEED, (12.05.2022)

14. https://www.oculus.com/experiences/quest Oculus (Meta) Quest 2 (12.05.2022)

15. https://unity.com/learn Unity (12.05.2022)

16. https://www.pico-interactive.com/ Pico Neo (12.05.2022)

17. https://www.youtube.com/watch?v=7lBF-VLundY Virtual Reality Immersive Safety Trainings by VR. Consulting adding weight to the case of use of VR in training a workforce.

18. https://www.youtube.com/watch?v=S4CX_2Y0IMk&t=208s BIM-SPEED Extended Reality Tools Presentation Workshop 20th October 2021 (17.07.2022)

19. https://www.youtube.com/watch?v=wtkSCaYxY84&t=42s Augmented Reality - Mobile Video Tutorial (17.07.2022)

20. https://www.youtube.com/watch?v=k_UrezQL_EE&t=153s Augmented Reality - 3D Anaglyph Glasses Video Tutorial (17.07.2022)

21. https://www.youtube.com/watch?v=EADzZmLHVw4&t=103s Virtual Reality - VR Box and Android/iOS Video Tutorial (17.07.2022)

22. https://www.youtube.com/watch?v=rgRm59hIZS4&t=97s Virtual Reality - Oculus Quest 2 Video Tutorial (17.07.2022)

23. https://www.youtube.com/watch?v=akp2lI_0mAY&t=56s Extended Reality Video-tutorial, Microsoft HoloLens 2 (17.07.2022)

24. https://www.youtube.com/watch?v=s_-2HQJdOeg&t=46s Volumetrization Techniques Video-tutorial, part 1 (17.07.2022)

25. https://www.youtube.com/watch?v=5TPeTChrceU&t=51s Volumetrization Techniques Video-tutorial (part 2) (17.07.2022)

26. https://www.youtube.com/watch?v=qRyggv7P1H4&t=34s Cultural Heritage Digitization, Varna 2019 (17.07.2022)

Appendix 1: Applications and Projects

Table 8. Appendix 1- listing the applications and projects files for Augmented Reality

№	Augmented Reality (AR)		
	Demo Sites	**Applications**	**Projects**
1	**Malko Tarnovo**	Mobile with Vuforia	Mobile with Vuforia
		Mobile with Vuforia	Mobile with Vuforia
		Off-site with HoloLens 2	Off-site with HoloLens 2
		HoloLens 2 with Vuforia	HoloLens 2 with Vuforia
2	**Aldabe**	Mobile with Vuforia Version 1	Mobile with Vuforia version 1
		Mobile with Vuforia version 2	Mobile with Vuforia version 2
3	**Arkaya**	Mobile with Vuforia version 1	Mobile with Vuforia version 1
		Mobile with Vuforia version 2	Mobile with Vuforia version 2

Table 9. Appendix 1- listing the applications and project files for Virtual Reality

№	Virtual Reality (VR)		
	Demo Sites	**Applications**	**Projects**
1	**Malko Tarnovo**	Oculus Quest 2	Oculus Quest 2
		Oculus Quest 2	Oculus Quest 2
		Web 3D Viewer	Web 3D Viewer
2	**Varna**	VR Box with Mobile	VR Box with Mobile
		Oculus Quest 2	Oculus Quest 2
3	**Training For Construction Workers**	Training Tutorial	Training Tutorial

Appendix 2: Videos Recordings

Table 10. Appendix 2- listing the Augmented and Virtual Reality video recordings

№	Demo Sites		Augmented Reality (AR)	Virtual Reality (VR)
1	Malko Tarnovo		Mobile with Vuforia link	Oculus Quest 2 link
			Off-site with HoloLens 2 link	-
			Small to real scale with HoloLens 2 link	-
			On-site with HoloLens 2 link	-
2	Varna		Mobile with Vuforia link	VR Box link
			Small to real scale with HoloLens 2 link	Oculus Quest 2 link
3	Vitoria	01 Aldabe	Demo site Aldabe Mobile with Vuforia link	-
		02 Arkaya	Demo site Arkaya Mobile with Vuforia link	-
4	Safety Training		-	Oculus Quest 2 by Trainee link
			-	Oculus Quest 2 Screen Recorded link