ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

DEMOS OF VIRTUAL REALITY ENVIRONMENTS

WP2 – FRAMEWORK AND TOOLS FOR EFFECTIVE IMPLEMENTATION AND ASSESSMENT OF CPCC

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[1] *ARV is a Norwegian word meaning "heritage" or "legacy". It reflects the emphasis on circularity, a key aspect in reaching the project's main goal of boosting the building renovation rate in Europe.*

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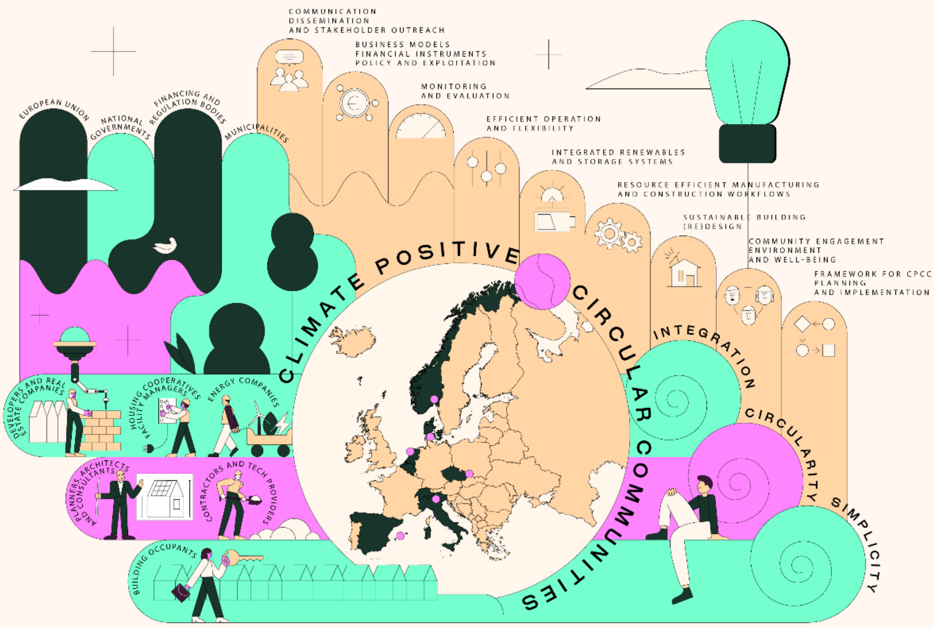
ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come. The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries. To achieve this, the ARV project will employ a novel concept relying on a combination of 3 conceptual pillars, 6 demonstration projects, and 9 thematic focus areas.

The 3 conceptual pillars are integration, circularity, and simplicity. **Integration** in ARV means the coupling of people, buildings, and energy systems, through multi-stakeholder co-creation and use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through integrated use of Life Cycle Assessment, digital logbooks, and material banks. **Simplicity** in ARV means to make the solutions easy to understand and use for all stakeholders, from manufacturers to end-users.

The 6 demonstration projects are urban regeneration projects in 6 locations around Europe. They have been carefully selected to represent the different European climates and contexts, and due to their high ambitions in environmental, social, and economic sustainability. Renovation of social housing and public buildings are specifically focused. Together, they will demonstrate more than 50 innovations in more than 150,000 m^2 of buildings.

The 9 thematic focus areas are 1) Effective planning and implementation of CPCCs, 2) Enhancing citizen engagement, environment, and well-being, 3) Sustainable building re(design) 4) Resource efficient manufacturing and construction workflows, 5) Smart integration of renewables and storage systems, 6) Effective management of energy and flexibility, 7) Continuous monitoring and evaluation, 8) New business models and financial mechanisms, policy instruments and exploitation, and 9) Effective communication, dissemination, and stakeholder outreach.



The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the Norwegian University of Science and Technology and involves 35 partners from 8 different European Countries.

EXECUTIVE SUMMARY

The work package 2 (WP2) of the ARV project has as a purpose to refine, deploy and test methods for effective design, implementation, and assessment of climate positive circular communities (CPCCs). As part of WP2, Task 2.5 focuses on developing and testing virtual reality (VR) and augmented reality (AR) tools to achieve an effective communication to the different stakeholders of the CPCCs. Additionally, the use of VR and AR tools are sought to be used in conjunction with the project Living Labs (LLs) from WP3, aiming to promote awareness and engagement of citizens in sustainability topics.

The purpose of T2.5 is thus to develop VR and AR tools that can inform both citizens and stakeholders about sustainable choices. This will, in turn, engage them in integrated design processes that can help decision-makers and will accelerate the adoption of CPCCs. As the VR and AR tools are part of the overall methodology of the LLs, they are implemented in both demos. According to the ARV project description, the VR/AR tools are demonstrators developed in the framework of the project, and as such a short report should summarise the activities that lead to the demonstrator.

The objectives of this report are:

- To report the purpose for each VR/AR tool in connection with their demo context.
- To document the design and technical development process for each of the tools.
- To report the level of information provided in each tool related to their purposes.
- To offer additional information that could serve for the planning of LL activities.

The information contained in this report will provide a general description of the VR and AR tools from a technical perspective. This will, in turn, provide an overview of the capabilities and possibilities of the tools to inform, educate, and engage citizens and stakeholders. As such, it will serve as a basis for the planning of the Living Lab activities for both the Oslo and Palma LLs. It is important to highlight that this deliverable focuses on the technical, informative, and visual aspects of the tools and does not report the activities carried out with these tools. Such LL activities will be reported under D3.4 'Analysis of citizen engagement tools and processes using a citizen design science approach', and D2.7 'Description and lessons learnt from training and awareness sessions using Virtual Environments', which will be delivered in months 40 and 48 of the project, respectively.

The target audience of this deliverable is thus professionals and researchers working on or planning social engagement activities in which VR and AR are used as innovative visual aids. Technical developers interested in the generation of virtual scenarios and modes of presentation are also a natural target group for this document.

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1. INTRODUCTION

The ARV project aims to establish Climate Positive Circular Communities (CPCCs). The project integrates advanced Virtual Reality (VR) and Augmented Reality (AR) technologies as key tools to facilitate the design, visualization, and stakeholder engagement processes essential for the successful implementation of sustainable urban developments. This document is dedicated to report the development and deployment of these immersive VR environments, which are intended to serve as critical platforms for demonstrating and refining the CPCC concept.

VR and AR technologies have emerged as transformative tools in urban planning and architecture, enabling the creation of immersive, interactive three-dimensional environments that can significantly enhance the understanding and evaluation of complex design proposals. These technologies allow users to experience digital models in a manner that closely mimics real-world interactions, thereby providing a more intuitive and comprehensive understanding of spatial relationships, environmental impacts, and functional aspects of proposed developments (Alp et al., 2023). In the context of the ARV project, VR and AR tools are utilized to visualize CPCCs, facilitating the integration of sustainable practices and circular economy principles into urban designs. The incorporation of VR/AR in urban planning is particularly advantageous in the case of CPCCs, where the convergence of various sustainability strategies—such as renewable energy integration, resource-efficient building materials, and waste minimization—requires careful consideration and coordination. Traditional two-dimensional plans and static models often fall short in conveying the dynamic and interconnected nature of these elements. In contrast, VR and AR tools allow stakeholders to visualise virtual representations of the communities, providing a more complete view of how different design elements interact and contribute to the overall sustainability goals (Van Leeuwen et al., 2018).

The role of VR and AR as tools for stakeholder engagement is emphasized within the ARV project's Living Lab framework. The Living Lab approach fosters co-creation and participatory design by involving stakeholders including urban planners, architects, local communities, and policymakers, throughout the development process. VR and AR tools enable these diverse stakeholders to engage with the CPCC designs more effectively by offering a shared virtual space where they can collaboratively explore, discuss, and refine proposed solutions. This collaborative interaction is crucial for aligning the community's needs and expectations with the project's sustainability objectives, ensuring that the final designs are both technically feasible and socially acceptable. Moreover, the use of VR and AR technologies extends beyond mere visualization; it serves as an educational and communicative tool that makes the concept of CPCCs accessible to a broader audience. By simulating and visualising different real-world design scenarios, VR and AR tools help to demystify complex sustainability concepts related to the environmental and economic aspects of buildings, enabling informed decision-making by stakeholders at all levels. This interactive and immersive approach is expected to enhance the project's outreach, fostering greater public understanding and support for the adoption of CPCCs across Europe.

Within the scope of the document and the project, two fully immersive VR and two AR applications were designed, developed, and evaluated. The applications were tailored to align closely with the planned renovations in the area and the target demographics, yet they follow a scalable and adaptable framework that can be implemented in similar scenarios. This approach ensures that the developed tools are not only specific to the current project but also transferable to other contexts, fostering broader applicability. Ultimately, these VR and AR applications aim to streamline the integration of sustainability strategies, promote stakeholder collaboration, and enhance public awareness, making them valuable assets for achieving Climate Positive Circular Communities. By leveraging these technologies, the project sets a precedent for how immersive tools can drive sustainable innovation.

2. OBJECTIVES

The developed applications use both VR and AR technology which is defined under the broad domain of Mixed Reality, or Extended Reality. VR provides a fully immersive environment where users can explore a completely virtual space, simulating real-world scenarios without any physical constraints, generally in a head-mounted display (HMD). In contrast, AR overlays digital elements onto the real world, allowing users to interact with virtual objects while still being aware of their physical surroundings. In the scope of the applications mentioned in the current document, AR is referred as AR implemented on a phone/ablet screen using the camera of the device to overlay the physical environment with the digital on-screen objects, while VR refers to a display through an HMD where the real-word is occluded. In an academic context, these technologies can be understood using Paul Miligram's Reality-Virtuality continuum, as shown in **Figure 1** (Milgram et al., 1994). VR can be classified under class 2 displays, while AR can be understood as a combination of class 1 and class 4 displays combining the "window-on-the world" and the "video see-through" concept.

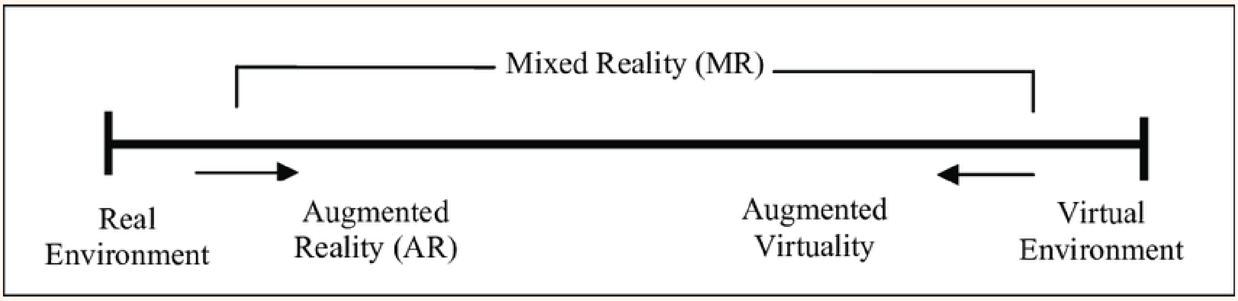

Figure 1. *Reality-Virtuality continuum (Milgram et al. 1994).*

As mentioned in Section 1, the primary objective of the AR/VR tools is to establish CPCCs through design, visualization, and stakeholder engagement processes. The objectives of the developed AR/VR applications in the ARV project are as follows:

- **Simulation of Scenarios:** Simulation of various environmental and urban planning alternative scenarios to assess the potential impacts and benefits of different design approaches in CPCCs.
- **Enhanced Visualization:** Enable users to experience immersive, detailed visualizations of Climate Positive Circular Communities (CPCCs), allowing for better comprehension of complex urban designs.
- **Iterative Design Process:** Support an iterative design process where feedback can be easily incorporated into the evolving designs, improving the quality and sustainability of the final outcome.
- **Stakeholder Engagement:** Facilitate interactive and collaborative environments where stakeholders can actively participate in the design and decision-making process, ensuring that all voices are considered.
- **Education:** Provide an accessible platform for educating the public and stakeholders about sustainability concepts and the impact of design choices on environmental outcomes.

Which are the differences between Augmented Reality (AR) and Virtual Reality (VR)?

AR superimposes digital objects over the real world which can be visualized and interacted through a screen. The real world is captured through the camera of the device while digital objects are built-in applications. On the other hand, VR is a completely virtual and immersive experience, generally in an HMD, in which the visualization does not include a direct view of the real world.

3. VIRTUAL REALITY (VR)

Two VR tools have been developed for the ARV project. One for the Oslo demo site and the other for the Palma demo site. Their intended use is somewhat targeted toward different stakeholders, and as such differs in functionality and scope.

3.1. VR TOOL FOR OSLO DEMO

The VR tool developed for use in the Oslo demo site is an experience/application mainly targeted toward stakeholder engagement and educational purposes. For stakeholder engagement, the VR application mostly considers citizen engagement starting at post-renovation, i.e. during the day-to-day usage part of a building's life cycle.

Figure 2. *From the VR application, 3D world of Voldsløkka School area - Oslo Demo site.*

During the phase of active use of the buildings, a local community with a feeling of ownership and pride in a building and its outdoor environment will indirectly or directly help maintaining the buildings/area, for instance through help with early detection and notification of e.g. maintenance needs. It is also argued that increased feeling of pride and increased social ownership will decrease chances for excessive wear and tear, littering, and even potential vandalism.

The demo site consists of a school building, a cultural school building, and an outside area directly connected to a public park. The design of the main school building, especially the facade and to some extent its placement in the landscape, has been sparking a discussion on aesthetic versus function through Norwegian press. Although humans tend to find some forms more pleasing than others, for instance the golden ratio, naturally occurring shapes, and some geometric shapes (such as inspired cubism), aesthetics are in the end individual. However, it is assumed that dissemination of design choices impacting the overall appearance, technical limitations, and especially technical innovations impacting design, can foster increased social ownership independent of individual preferences in aesthetics. The VR tool is therefore targeted toward dissemination to enhance engagement through awareness raising and learning, bridging the gap between the technical and social contexts.

GENERATION AND USE OF VR APPLICATION

The VR tool for the Oslo demo site was developed by SINTEF VR Lab, a part of SINTEF AS (SINTEF). The VR Lab's main focus is toward developing and testing of VR based interactive simulations and experiences for evaluation and impact assessment, where user feedback and user behaviour are in focus. The development was done in close collaboration with other parts of SINTEF and other ARV partners such as NTNU and OsloBygg KF (OBF). The partners supplied a range of knowledge and data to the development team, including, but not limited to Computer-aided design files, details on innovations, content, and input to movie scripts, ideas for usage, and suggestion on user groups to target dissemination.

Developing graphical applications, such as VR applications, involves two major approaches when considering hardware requirements, both aiming to achieve the best possible graphics quality. If the time to completion is low, the development can be largely based on present hardware at time of design. However, the longer the development cycle is, the more uncertainty must be considered. As the development of the Oslo demo VR application spanned years, with a goal of high degree of graphic fidelity and complex functionality such as dynamic lighting, the development targeted high end hardware. The present implementation has been compiled and tested for the following state-of-the-art hardware:

- HMD: Meta Quest 2 and Meta Quest 3 with hand controllers in link cable mode to a PC.
- PC with Intel Core i7-13700 or better processor.
- Nvidia 4090 or better (NVIDIA graphic cards only, as the application uses DLSS ai powered functionality).

Although it should be possible to run the application on lesser PC hardware (especially if reducing graphic settings in-application), this has not been tested and verified on hardware with lower specs. It is not possible to run the application directly on a Quest HMD without a link cable (or link over Wi-Fi).

Setup

Configuring the Quest 2 or 3 HMD for a "standing experience" is recommended for this application. This means that the space to move around in the real world is more limited than if a larger movement area was defined. The application itself is developed to run on a PC. This means that the visuals are streamed from the PC to the HMD to achieve as high as possible visual quality. As the application has only been tested for use with a USB link cable between a HMD and PC, and not with wireless link, it is recommended to use the application with a standing experience setup in the HMD. The link cable reduces the potential reach of a user and may entangle the user if not used carefully (it is highly recommended to have an operator helping to avoid that users get entangled in the cable if running the application at a public event).

Setting up a Meta HMD to use a standing experience and link cable is part of the documentation of the HMD and is considered out of scope for this introduction. It should be noted that for the present implementation of the VR application, the Quest HMD must be set up to be in developer/debug mode, allowing applications that are not part of the quest app shop to run. This requires registration as a developer on Meta's web site (presently at dashboard.oculus.com). This also makes it possible to further increase the quality of graphic streaming from PC over the link cable using the Oculus Debug Tool application. This is considered as an advice for expert users only and is not required for a good experience.

Navigation

The two main forms of interaction and navigation in the virtual world of the Oslo demo site VR application (Voldsløkka school area) are by navigating through the virtual world, and through a menu.

The user of the VR application can move through the virtual world using the VR hand controllers. Using the left-hand controller's joystick the user can move forward or backward by pushing the joystick forward or backward. Forward is defined here as the direction in which the user is looking inside the virtual world.

Using the right-hand controller's joystick the user can "snap" turn (in addition to turning in the real world). Snap turning means that the user rotates a set number of degrees (i.e. "snapping") each time they trigger the joystick. This is to avoid dizziness and potential simulation/VR sickness, that possible to induce if the turning is smooth (especially when moving forward or backward at the same time).

Also, any movement by the user inside a valid movement area in the real world will be performed in the virtual world also. Configuring the Quest HMD for a "standing experience" is recommended for this application. This means that the space to move around in the real world is more limited than if a movement area were defined. However, as the application has only been tested for use with a USB link cable between a HMD and PC, and not with wireless link, it is recommended to use the application with a standing experience setup in the HMD.

Menu

Pressing the X or A button on the controllers opens or closes a menu. This menu has three main areas, a side bar and a somewhat hidden second page. The menu is attached to the corresponding hand as the button that was triggered to open the menu. Any buttons on the menu can be pointed at with the other hand (controller). Pressing the main trigger button (index finger) while pointing at a button, presses/activates that button.

Figure 3. *Menu.*

The upper main area of the menu has buttons to "fast travel/teleport" to a specific point of interest.

The middle main area of the menu has buttons for setting specific times of day (sun location and intensity). It also has a small slider for more fine-tuning of the time of day. The sun's position at any given time of day is set to be correct for the 18th of October 2024.

The lower main area of the menu has buttons for selecting variations with different colours of the solar panels on the main school building.

The left part of the menu (expanding) has button for closing the application, restarting the application, using the camera see-through (disabled for the present version – used during debugging).

In the upper right corner is a small, somewhat hidden (grey) button to open a menu for optimization. This menu enables and disables a range of rendering features and was used for performance testing during development. It can potentially be used to tune performance on lower end hardware than used during development.

Keyboard shortcuts
Keyboard key 0: enable the application to use 4Gb more from the Graphics Processing Unit memory. Avoid error messages being displayed when observing the narrator Metahuman's character at an extremely close distance.

Keyboard key q: quit the application.
Keyboard key esc: quit the application.
Keyboard key 1-4: set rendering quality corresponding to Unreal Engine's in-editor rendering (0=performance, 4= epic quality).

DESCRIPTION OF THE VR APPLICATION

A VR application showing building and renovation design choices, different building elements, placement in the terrain, technical solutions, and so on and might be adequate when considering use of VR targeted for professional users and stakeholders. However, when targeting citizen engagement, it is often required to explain different technical or design aspects as part of the visualization. During the course of the ARV project, it became apparent that having such information included in the VR application was of high importance. This is due to the requirement to explain how the different design choices were impacted from the technical aspects of energy generation and use. Therefore, to make sure the VR application has as high usability potential as possible for use in citizen engagement, both the content conveyed, but also the method used for conveying the content inside the VR application is of high importance.

The 3D models of the buildings and the outdoor environment were generated from the "as built" Industry Foundation Classes (IFC) plans, early sketches from the architect, inspections of the building site during construction and outdoor environment as built. The IFC models were further refined using Sketchup to reduce number of objects, removing two-sided surfaces where not needed, optimization of objects' organization, and handling of materials. Final refinement and optimization of materials, and texture mapping was done in Unreal Engine.

For the VR application development for the Oslo Demo site, it was required to identify what CCPC concepts and aspects from the building at the Voldsløkka school area that should be included. The selection of concepts to convey was done during meetings with other Work Packages and with SINTEF and OBF, and input on the concepts were gathered from the relevant Work Packages in cooperation between SINTEF, OBF, and NTNU as text and still images.

The following concepts were selected as the most relevant and included:

- About the ARV Project.
- About the Voldsløkka School area/Oslo Demo Site.
- Low-ex GSHP.
- PV system.
- Smart building/energy control.
- On VR usage in ARV.
- Zero-emission construction sites.
- Storm water management.
- Pluss energy school.
- Living Lab and reuse of materials.

To convey information on the selected aspects of the Voldsløkka school area, several approaches were considered and used: a dynamically appearing *digital human* presenting the content (through speech), dynamically appearing Television (TV) screens playing *informative movies*, and static *posters*/signs. This range of different approaches instead of one approach were used to avoid monotony and to introduce an element of exploration to the users.

Points of Interest (POI)

To not overload the user of the VR application with forced information, ensuring the possibility for free roaming in the virtual word to encourage exploration, a set of Points of Interests (POI) were defined. Earlier works with virtual guides often used icons such as an "i" to indicate the presence of information (Skjermo et al., 2010). However, POIs location in the virtual world for this application was shown to the user using a 3D model of an exclamation mark. This iconography was chosen due to its prevalence use in modern gaming as a "quest" marker and is as such highly recognizable by a large portion of the population in Norway as a marker for interactive content. For users not experienced with such gaming concepts, an exclamation mark still conveys an emphasis on the area.

Figure 4. *Iconography: information (i) symbol from (Skjermo et al., 2010).*

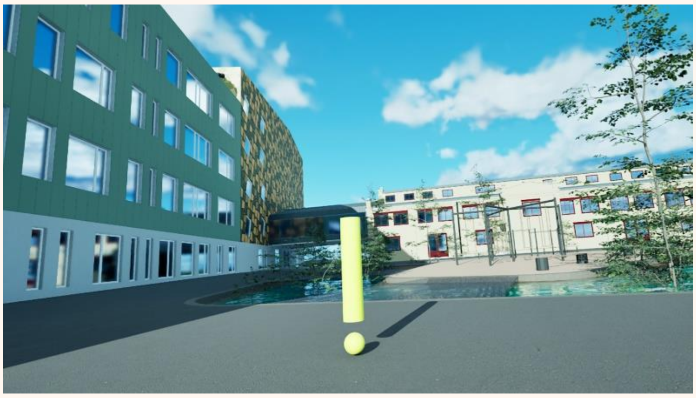

Figure 5*. Iconography: Quest (!) symbol used in Oslo Demo Site VR application.*

Each POI was further implemented as a trigger, that stated conveying its content when a user came within a defined invisible (box) volume from the 3D model of the exclamation mark. If the user exited the volume, the content stopped being conveyed. It should be noted that this applied to the dynamic (animated) content, and not to the static content/elements (i.e. 3D models of posters) that were always visible in the virtual world.

Dynamic content - Digital Human

One type of dynamic content used in the VR application is a talking 3D digital human explaining a given concept. The presence of this content type in the virtual world is, as with other dynamic content, indicated by a 3D model of an exclamation mark. This exclamation mark disappears when the user enters an invisible (box) volume centred on the exclamation mark. At the same time the digital human 3D model appears and starts talking (playing the animations and sound file defined for a given concept). The digital human always appears facing the user location when the user enters the trigger volume. The digital human model stops playing its animations and sound and disappears when the user exits the same volume. When the digital human disappears, the 3D model of the exclamation mark appears again. The user can then enter the volume and trigger the content from start again if wanted.

***Figure 6**. A 3D digital human placed in the virtual world.*

Dynamic content - Informative TV/Movie

A dynamic content type is a 3D model of a TV playing a video conveying a concept. The presence of this content type in the virtual world is, as with other dynamic content, indicated by a 3D model of an exclamation mark. This exclamation mark disappears when the user enters an invisible (box) volume centred on the exclamation mark. At the same time a 3D model of a TV appears and starts playing its movie. The TV object appears rotated toward the user and can be defined to also play a sound file (narration) or be silent. The 3D model of a TV stops playing its movie and disappears when the user exits the same volume. When the TV model disappears, the 3D model of the exclamation mark appears again. The user can then enter the volume and trigger the content from start again if wanted.

***Figure 7.** 3D model of a TV playing a movie about the PV system placed in the virtual world.*

Static content – Poster

A static poster or sign as a method is reminiscent of the information signs already used at Voldsløkka school area. The signs used in the real world is however designed to blend in with the area and the (future) greenery and have a limited size to contain information. As such, in the VR application, full poster size was used for the 3D models of information signs, and a content design of the posters were influenced from designs typically found at scientific conferences (with a typical size of A0-A1). Two posters were designed to be included in the virtual world. It should be noted that, although the 3D models of the posters themselves are considered as static content in the virtual world and therefore always visible, due to the reasons explained below, additional requirements made it possible that both posters' locations also included dynamic content. Content types at each POI implemented in the VR application: Static content (Poster) + Dynamic content (sound only):

***Figure 8.** 3D poster object placed in the virtual world.*

1. Static content (Poster) + Dynamic content (Digital Human): on Living Lab.
2. Dynamic content (Informative TV/Movie, with sound): on PV panels.
3. Dynamic content (Informative TV/Movie, without sound) + (Digital Human): on the building site.
4. Dynamic content (Digital Human).
5. Dynamic content (Digital Human).
6. Dynamic content (Digital Human).
7. Dynamic content (Digital Human).

POI 1: Static content (Poster) + Dynamic content (sound only).

Text can be hard to read in VR, depending on the VR hardware used (due to HMD resolution, lenses, display panels characteristics, antialiasing method used and so on). Also, for people using glasses, they might not be able to use them in a specific VR HMD. Therefore, a sound source was added playing a sound recording reading the main text on the poster out loud. This sound source was implemented as dynamic content, and as such the sound source was started or stopped depending on the user entering or exiting a trigger box placed at the poster. After exiting the volume, the user can then re-enter the volume and trigger the content from start again if wanted.

POI 2: Static content (Poster) + Dynamic content (Digital Human)

For the other poster, the aim was to convey associated information to what was conveyed through text and images on the poster. A talking digital human (dynamic content) was selected to convey this information. The talking digital human was defined as dynamic content, and as such appeared next to the poster and started talking, or stopped talking and disappeared, based on the user entering or exiting a trigger box placed next to the poster. It should be noted that this digital human did not only recite the information on the poster but talked about an associated concept. As such, the user was still required to read the poster text to access all the content. However, this poster was designed to convey its information using pictures more than text.

Figure 9. *POI with poster and digital human next to poster placed in the virtual world.*

POI 3: Dynamic content (Informative TV/Movie) + Dynamic content (Digital Human)

This POI contained two dynamic contents. It should be noted that both content types were triggered (appearing and start playing content or disappearing and stop playing content) based on one trigger (box) volume. Also, only one 3D model of an exclamation mark was shown. The content appearing at this POI was a Digital Human model talking about the specific concept, together with a TV playing a movie appearing behind the Digital Human. Basically, for the information on the concept being conveyed at this POI, the digital human was the narrator for the content/movie being displayed on the TV model.

Figure 10. *A TV playing a movie behind a digital human narrator placed in the virtual world.*

Additional POI: Indoor

An additional indoor POI was implemented. Selecting this POI from the menu, places a user in a meeting room setting, where the school area is displayed as a miniature model on a table/desk. The intended use is for users to strip away claddings, walls, and ceilings (by floor) of the main school building using buttons on the table. This is to enable visual investigation of the floor layouts for user groups for whom this is of interest.

On content generation

Several types of digital content needed to be generated for the Oslo Demo site VR application to convey the information and concepts gathered from the other work packages in the ARV project: videos, posters (text and images), sound (narration) and 3D digital human narrator animations and sound (speech).

Posters

Two posters were generated using MS Word based on the text and image content provided. They were saved in PDF format, and then converted to high resolution images (6144x8192 pixels). These images were then imported to Unreal Engine and used as textures in a material applied to a 3D model of a poster display placed in the virtual world.

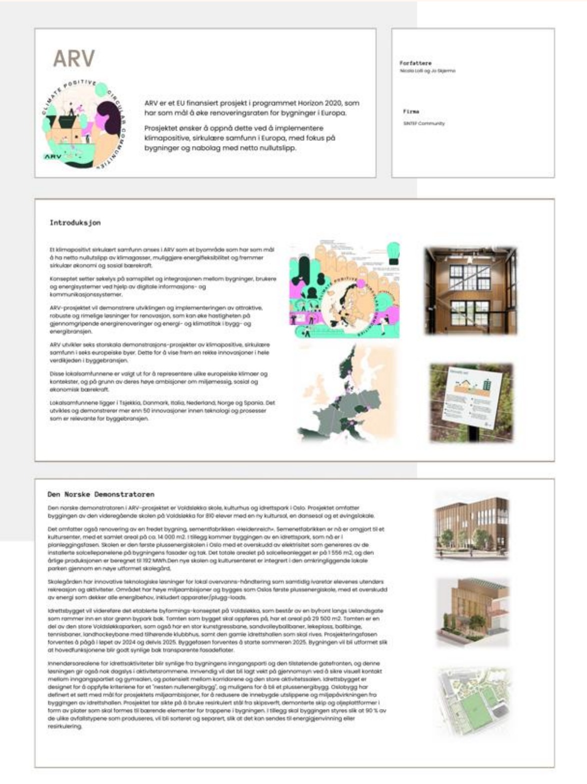

Figure 11*. Poster introducing and explaining the ARV project (low resolution).*

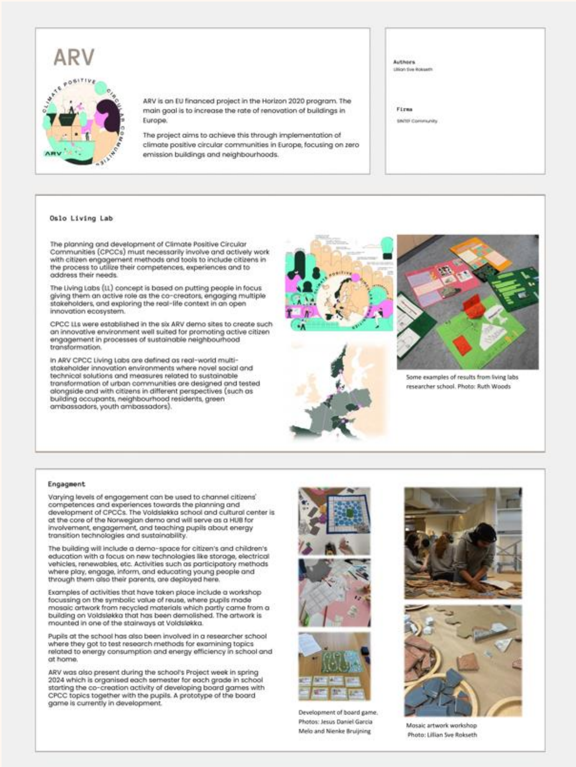

Figure 12*. Poster explaining Living Lab concept used in the ARV project at Voldsløkka school (low resolution).*

Movie Generation

Two short movies were made to be included in content of the virtual world. One movie was made in a slide show style, with images supplied from other work packages in the ARV project. The other movie was a mix of images in a slide show style and a moving sequence to help visualize information on placement of solar panels.

To visualize information about placement of solar panels at the side of the school building, it was required to show how the sun falls on the building sides during the day. To do this, a movie sequence showing the light (sun) during a day was made and rendered out using Unreal Engine. The sun's position was animated based on time of day on the 18th of November 2024. Time of day was then increased from 08:30 to 19:30, while the camera location was animated to circle the main school building.

Figure 13. *Frames from movie, from morning (upper left) to late afternoon (lower right).*

The final movies were put together and rendered out using the Window Photo application in Windows 11.

These movies were used as content on the TV models in the virtual world, together with playback of audio or when the presenters performed. Therefore, it is worth noting that neither of the generated movies are considered suitable for use in external dissemination without the extra narration.

Digital human content generation

A digital human (a 3D model representing a human, with animated motion and facial expressions during speech) was generated using the Metahuman capture pipeline in Unreal Engine (UE5.3).

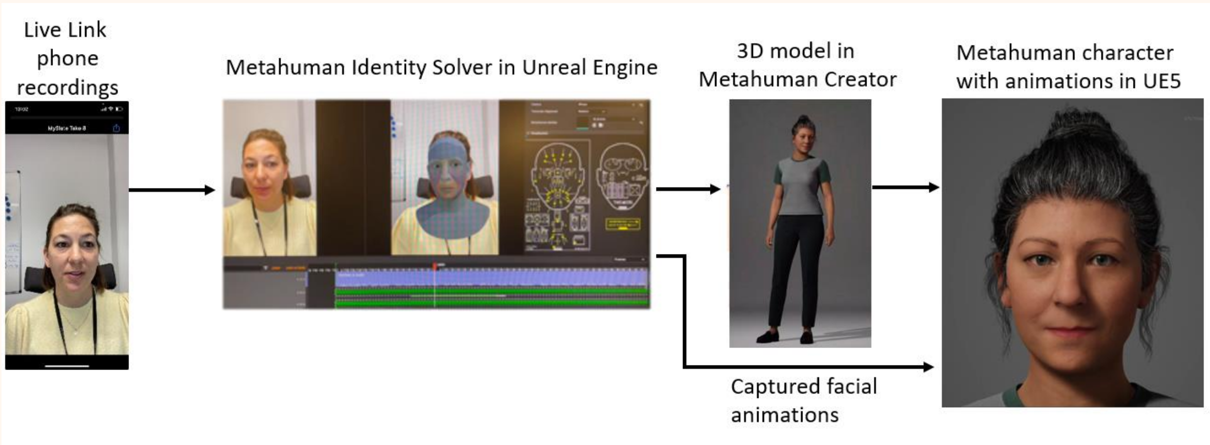

Figure 14. *Metahuman Live Link, Identity Solver and Creator pipeline.*

Recording speech and facial expressions – Live Link

The first step in the Metahuman capture pipeline was to record an actor narrating each concept being included in the VR application. The narration was based on the text supplied from the other work packages. It should be noted that some changes to the content were required to enable a more natural speech pattern, basically rewriting the text to flow more naturally when reading it out loud. Then each text was added to a free teleprompt display software that the actor could read from while her face was being recorded. The recording software used was the Metahuman Live Link application for iOS, and recordings were done using an iPhone 13 (set to record instead of injecting directly to Unreal Engine live). It should be noted that each performance began with the actor looking left, then right, then straight ahead before starting their narration from the teleprompt. This was to initialize the animation capture/generation in the Unreal Engine Metahuman plugin.

Metahuman Identity Solver

After recording the actor's performance, they were imported to Unreal Engine. The imported performances were then used in the Unreal Engine's Metahuman Identity Solver, which is part of the Metahuman plugin in Unreal. From the imported performances (videos), the actor's face was used to generate a Metahuman Identity (and initial facial mesh). This was exported to Metahuman Creator cloud service (https://metahuman.unrealengine.com), where the facial mesh was further refined, hair was added, and the face was attached to a body mesh of a type similar to the actor. This Metahuman model was then exported and imported back into Unreal Engine for use as a mesh and skeleton to use when playing back animations generated from the performances/movies.

Generating facial animations

The Metahuman Identity solver is further used to capture animations from each performance that are suitable for playback on the generated Metahuman skeleton/mesh model. This is done automatically, and no animation knowledge or experience is required. These animations are then exported as sequences and can then be played back inside Unreal Engine using the generated Metahuman.

Changes to the Metahuman asset

A Metahuman asset for Unreal Engine generated by Metahuman Create Cloud Service contains, in addition to a face and a body mesh and skeleton, an animation script and a state machine. These formed the starting point for the final implementation of an actor's 3D character. A final implementation uses a standard idle animation for the Metahuman model, while the captured facial animation of speech is used for the head mesh/skeleton when playing back the speech audio. Furthermore, this implementation enables the eyes of the virtual character to follow the user while still maintaining any blinking captured from the videos. This was done by, at each frame, overwriting the captured eye animation from the videos in the animation sequences, with a new animation pose calculated to point toward the location of the VR user (the scene camera's position). This was done to drastically increase the life-like quality of the model, as gaze usage is considered a powerful queue during interaction (Ho et al., 2015). A person looking directly toward a person when talking is typically considered talking specifically to that person, and as such, is a queue that is considered to be a good match for a personal teacher/narrator.

ADDITIONAL INFORMATION

The VR tool/experience was first presented and used at the "Architects as facilitators of the energy transition – ARV Workshop in Oslo" on the 18th of October 2024., which resulted in a great on-site feedback from the participants.

Further use of the application is currently being planned for 2025, including activities as part of the WP3 demo sites. Gathering feedback on preferences for dissemination approach (static content on posters vs dynamic/animated content with 3D characters and/or movies) is also being considered in this context.

Movies

Several movies from the VR experience are in the final stages of production. These are planned to be used for playback on 2D displays/TVs. The intended dissemination channels for these are at Voldsløkka school (info-TV), at dissemination events, as well as for publishing on the ARV YouTube channel.

Technical considerations

The “Additional POI: Internal” 3D environment is implemented as a separate “level” in the application. The generic office environment used in the present implementation is, based on feedback, under evaluation for an upgrade to a 3D environment based on the actual physical school. Using a photogrammetry approach from the actual physical school building is being considered for such an update before any major use of the application in 2025.

The application uses terrain data and satellite images for background terrain streamed using the Cesium service (https://cesium.com/). This requires an ongoing license and opens up for potentially additional costs of usage (especially after the ARV project ends). It also requires that the PC running the application have an internet connection. As such, a version of the application running the experience without the background terrain is being considered before the end of the project.

It should be noted that the pipeline for Metahumans used in the development of this application (in UE5.3/UE5.4), is not considered very stable and is not heavily optimized. In the recently released 5.5 version of Unreal Engine, Metahuman characters have been largely improved when it comes to the size optimization. For instance, a Metahuman model that used 800Mb has been reported to be reduced to 80Mb without a large reduction in Visual quality. In addition, facial animation for Metahuman models can now be generated directly from sound recordings only, simplifying content generation to a large degree. Also, two key technologies enabling dynamic lighting and automatic level of detail (Lumen and especially Nanite) have also been further optimized in UE5.5. It is therefore highly recommended to consider using UE5.5 or newer for the development of similar applications or content.

3.2. VR TOOL FOR PALMA DEMO

GENERATION OF THE VR APPLICATION

The task to generate the VR application in Palma has been led by IREC. The group of Climate Neutral and Resilient Buildings and Communities (formerly, Thermal Energy and Building Performance research group) wanted to test and demonstrate the hypothesis that VR tools can actively support the transformation of urban areas into Climate Circular Positive Communities. The final aim is to better communicate the results of different and potential future scenarios to different types of stakeholders and facilitate citizen engagement. The collaboration of a specialized partner working with VR/AR tools was needed to complete this task. IREC being a public body prepared a tender to select an entity to develop part of the works. The tender was released at the end of November 2021 (Exp. 21-1107) with the title "*Creació d'una aplicació basada en Realitat Virtual i experiències Virtual per la seva visualització 3D per la transició energètica del Districte innovació Llevant en Palma de Mallorca*", which can be translated as "Generation of a Virtual Reality based application for the 3D visualization of energy transition in the Llevant Innovation District in Palma de Mallorca". The main technical requirements for the service established in the tender were:

- Development of a 3D 360º virtual reality environment of the whole district where the ARV project aims to act.
- Development of at least three interactive user's experiences among the five defined in the project. Detailed 3D VR models should be used for that purpose.
- The application should be able to virtually showcase the transformation of the district in exhibitions and workshops.
- The application should be developed using the software engine UNREAL and be able to run with a Personal Computer (equipped with graphic cards for gaming) and VR glasses, as Oculus or similar ones.
- The application should be able to make virtual visits in real time using gaming joysticks and/or mouses. Those visits should be fluid with an adequate number of frames per second.
- When required, the application will be able to navigate for the current scenarios and visualize the potential future transformations.
- The design of the different sections of the tool should be done in a close collaboration with the Palma City Council and IREC.

Once the process was completed the company selected for carrying out the service was DUAL MULTIMEDIA 2007, SLU. The contract with the company was signed in January 2022. DUAL MULTIMEDIA (https://www.dualmultimedia.com/) is a company with more than 15 years of experience in the audiovisual sector, specialized in Virtual Reality, Animation, 3D Rendering and Virtual and interactive environments programming. Its goal is to offer their customers a simple and affordable access to the latest innovations in the area of image and new audiovisual technologies, so they can get the most benefit, both in their products and services, looking for the best solution to develop any type of project in the audiovisual world. The vision of the company is that not only the first impression has to be attractive but also need to be oriented to convey an idea a concept and communicate a clear objective, being creativity and video and high-quality 3D images essential tools to achieve it. DUAL MULTIMEDIA has been selected as they have proven experience using the Unreal engine for several applications, especially in the healthcare sector, but also has a proven experience in the building sector. In that sector, previous projects range from architecture and interior design 3D renderings, immersive VR tours of heritage protected buildings for exhibitions and 3D generation of historical areas.

Works started in March 2022, when DUAL MULTIMEDIA created a very simple proof of concept with available information facilitated by IREC. The aim of that example was to be shown in a kick-off meeting together with the ARV's representatives in the city of Palma. The purpose of this first meeting was for the group (Palma City Council, IREC, and DUAL MULTIMEDIA) to understand the different options that the technology can bring to the project and the potential use in Living Labs activities. That meeting defined the main objectives of the collaborative work while establishing the basis for future communication. During the development of the 3D applications, information has been shared, progress has been checked periodically, and details of the development have been discussed to drive the final result. Within the first months of the project, there has been a huge effort to collect as much as information available for the 3D modelling. As the project covers a large area and several detailed parts need to be modelled, a lot of information is needed which has required the collaboration of other partners in the ARV project. As a summary, the following entities have collaborated providing information and giving feedback as the 3D modelling and the VR tool were progressing:

- The City Council facilitates 2D blueprints of the GESA buildings and residential buildings to be retrofitted. They provide also blueprints of the public buildings (schools and others), which can potentially have PV on their roofs. They collaborated intensively in the selection of the buildings that will form the retrofitting and the Citizen Energy Communities sections. They facilitated information and blueprints of other public buildings in the area.
- Real estate company Metrovacesa provided 2D blueprints and available 3D models for three residential private buildings in the area.
- IBAVI provided information of the social housing in the area: 2D blueprints and renders by the architects.
- ENDESA provided information of the GESA building and potential future developments in its vicinity.
- IREC provided general 3D models for the whole area and was driving the whole process interconnecting the different teams, facilitating discussion when needed, testing and jointly approving the different parts.

DESCRIPTION OF THE VR APPLICATION

Two versions of the application were developed. The two versions should be able to run in a last-generation laptop equipped with a powerful graphic board as the gaming laptops. One version is thought for projection in PC/4K TV screens and controlled by a gyroscopic mouse. The other version is for immersive experience using VR glasses. Conceptually, there is no difference between the two versions, but adjustments that affect mainly the interactive menu were implemented. The application has been compiled and tested with the following hardware:

- VR glasses HMD: Meta Quest 2 128 Gb with hand controllers in Link cable mode to a PC.
- Laptop PC Portátil with Intel Core i7-13650HX,32GB or better processor.
- Graphical card NVIDIA GeForce RTX 4080 12GB GDDR6.
- RAM Memory 32GB SO-DIMM DDR5 4800MHz.
- 1TB Storage SSD M.2 NVMe PCIe.

The application starts with a general and realistic view of the whole district (**Figure 15** - top). There is a menu in the left side that shows the five sections that the user can select. When the user goes through the menu, the different parts are highlighted in the 3D map for the users to know where they are located. The five virtual experiences that the user can experience are:

- BIPV in GESA Building (**Figure 15**– #1). Users have a view of the current state of the building. The building was not in use for more than 15 years and is a heritage protected building that represents an example of modern office-architecture from the 60's-70's. Users can play with different option of BIPV systems with different colour finishing and can make a virtual tour around the building with an aerial or height-person perspective (**Figure 16**).

- Citizen Energy Communities (**Figure 15**- #2). Users can view how the visual aspect of some public and private roofs will potentially transform in case PV systems will be installed. As the area to be shown is large, users can have a look to two different areas and visualize with or without PV panels (**Figure 17**).

Figure 15*. General structure and parts of the VR application implemented for the Palma demo. (Graphics by Jesus Daniel Garcia Melo – NTNU).*

Figure 16. *Screenshots of the potential transformation of the GESA building with integrated BIPV. Current state (top image) vs. retrofitted scenario (bottom image).*

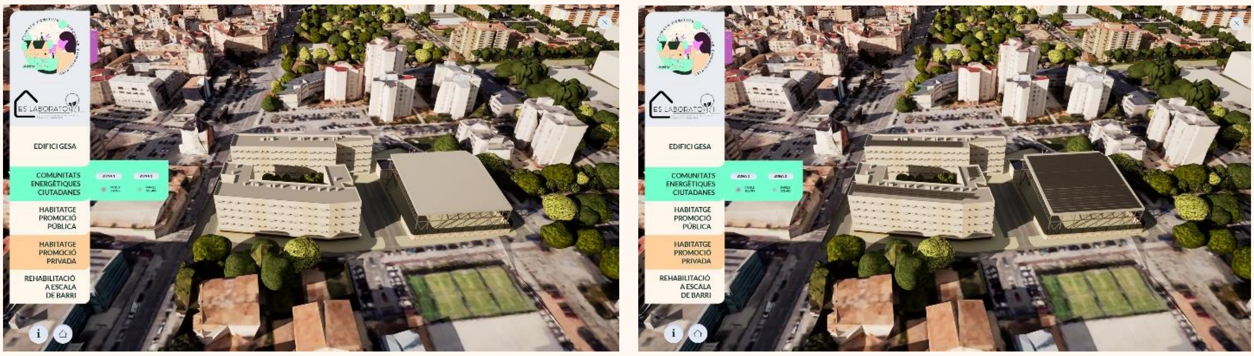

Figure 17. *The figure shows the part of the tool playing with potential Citizen Energy Communities, without (left image) and with PV systems (right image) in public and private roofs.*

- New social housing buildings (**Figure 15** - #3). Users are able to make a virtual tour in the area where two social housing buildings will be erected. These two buildings are promoted by IBAVI and the area covers also one square where a part of the ancient factory of Can Ribes will be retrofitted by the city council. Two points of interest have been created to initiate the virtual tour from different sites (**Figure 18**).

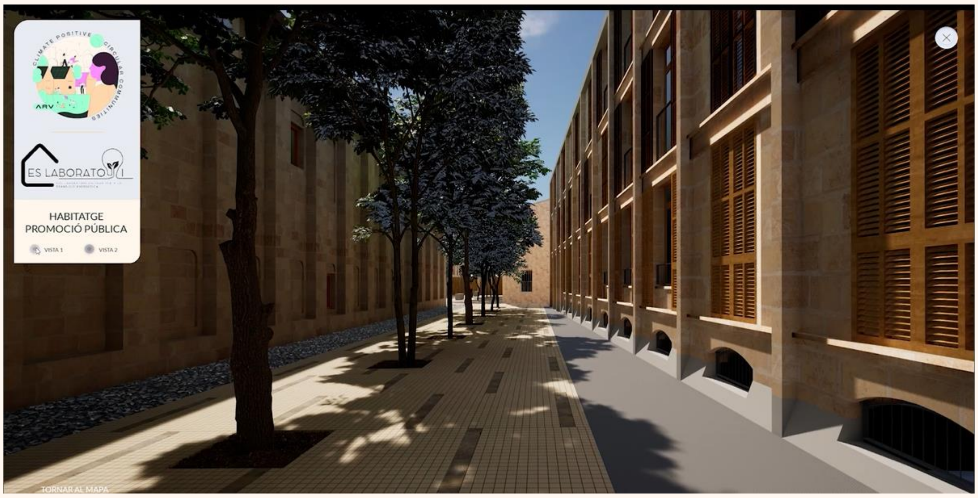

Figure 18. *Virtual tour around the social housing buildings promoted by IBAVI.*

- New private residential buildings (**Figure 15** - #4). Users can make virtual tours in the area where two new residential buildings by Metrovacesa have been built. The tour allows to have a look to the two buildings from the exterior, plus explore the common spaces and the roof terrace of one of them (**Figure 19**).

Figure 19. *Different screenshots of the virtual tour around the private promoted buildings by Metrovacesa. Jardins de Llevant building (top-left); Terrace with PV (top-right); Sol de Llevant building (bottom).*

- Large Scale Retrofitting (**Figure 15 - #5**): Detailed view of buildings to be retrofitted in two different streets of the district (Caracas and Bogotà). Users can experiment with the changes in the visual aspect of the zone and the building façades as they were retrofitted and compare with the current state. The features which the users can play in the buildings are: changes in the finishing colours of different opaque parts of the façade, change the colour of the blinds and window's frames, change the type of blinds, add commercial spaces to the ground floor in one of the cases and clear out additional elements in the façade (e.g., air conditioning external units) (**Figure 20**).

Figure 20. *Different views of the Large-Scale Retrofitting options in the VR app version for VR glasses: selection menu with the two areas (top); area of Bogotà street (bottom-left); area of the Caracas street (bottom-right).*

Users can navigate between the different sections in the app and visualize information about the developers of the application and the collaborators in the framework of the ARV project (**Figure 21**).

***Figure 21**. Credits of the VR tool.*

ADDITIONAL INFORMATION

A set of videos has been produced to show the main features of the VR tool developed in Palma. They have been uploaded to the official ARV YouTube channel (https://www.youtube.com/@arv7008) at the end of August 2024. Additionally, they have been posted in the IREC YouTube channel. The set of videos are:

- **ARV VR tool for the visualisation of the Spanish demo progress** (23/08/2024). A general video to show how the developed virtual reality tool facilitates the visualisation of all the improvements to be carried out in the Nou Llevant and La Soledad neighbourhoods. In this short extract, its main functionalities and features can be visualised. Two versions:
    - Voice in English with subtitles in English.
      Link: https://youtu.be/6qM7hPN0e_A?si=8c1BoHw2SgUd3ph-.
    - Voice in Catalan with subtitles in English.
      Link: https://youtu.be/2fhRHaR6XG0?si=C9Ks7MCwDy7SSYyo.
- **ARV VR tool to assist in selecting finishes during the refurbishment process** (23/08/2024). In this video, it can be seen how the virtual reality tool will facilitate the process of selecting finishes in the process of refurbishment of the intervention buildings of the ARV project, which includes the Nou Llevant and La Soledad neighbourhoods. Voice in Catalan; subtitles in English.
  Link: https://youtu.be/bI17Das8uoc?si=Agcvh28Yi1t5c9Wo.
- **ARV VR tour of the public and private developments in the Spanish demo** (23/08/2024). In this video, a tour of different public and private developments can be seen. These developments were formulated in ARV project's action district in the context of Palma de Mallorca demo. On one hand, there were private developments promoted by Metrovacesa, and on the other hand, the public ones promoted by IBAVI. Voice in Catalan; subtitles in English.
  Link: https://youtu.be/1jg1ixZqGr4?si=xpGvIkh6oal_6Q3T.
- **ARV VR tool to visualise how photovoltaic systems will look after installations** (23/08/2024). The virtual reality tool allows users to visualize how potential photovoltaic installations on the roofs of public and private buildings within the ARV project's action district would appear. Voice in Catalan; subtitles in English. Link: https://youtu.be/cw5NSReUPAs?si=yG8_a4n28C5r9kEW.

- **ARV VR tool to visualise different solutions for the solar photovoltaic windows of the GESA building** (23/08/2024). This is a visual example of how the virtual reality tool developed by the Catalonia Institute for Energy Research (IREC) together with DUAL MULTIMEDIA can facilitate the vision of the different constructive solutions for the solar photovoltaic windows of the historic building of GESA, giving the opportunity to choose between different alternatives and finishes. Voice in Catalan; subtitles in English. Link: https://youtu.be/iOSRDJn_Cyc?si=MIE78B45mgt9_VKa.

Videos also have been disseminated, once per week, through the ARV social networks in September-October 2024. These are the links to the posts in social network X.

- https://x.com/GreenDealARV/status/1830904647420088699 (3/09/2024).
- https://x.com/GreenDealARV/status/1833424350680138232 (10/09/2024).
- https://x.com/GreenDealARV/status/1835971772501369170 (17/09/2024).
- https://x.com/GreenDealARV/status/1838489519462469746 (24/09/2024).
- https://x.com/GreenDealARV/status/1841017069174706203 (1/10/2024).

IREC, as a lead partner of the development of the VR tool application in Palma, made a final press-release to recapitalise the series of videos and disseminate about the objectives of implementing VR technologies to favour user engagement.

- Press-release: https://www.irec.cat/press-society/news/innovative-virtual-reality-tool-to-engage-users-in-urban-regeneration/.
- Post in LinkedIn: https://www.linkedin.com/posts/institut-de-recerca-en-energia-de-catalunya_irecprojects-arv-vr-activity-7249340710796087298-5CzA?utm_source=share&utm_medium=member_desktop.
- Post on X: https://x.com/IREC_Energia/status/1843577497746849918.

4. AUGMENTED REALITY (AR)

4.1. AR TOOL FOR OSLO DEMO

The AR tool for the Oslo demo had as focus to test whether it could increase environmental awareness and citizen engagement in sustainable architecture. To this end, the tool was developed to provide information to citizens about the CO_2 emissions that different building elements may produce. The interface of the AR application was thus designed to offer information about the characteristics of different building elements and how the choice of these can either increase or decrease the CO_2 emissions which impact the natural environment.

The tool was tested on-site in the Voldsløkka School and Cultural area. The tool was tested using a Sports Hall that has not yet been built but is planned for construction adjacent to the school. The Sports Hall was then used as a case and was simulated in the AR application. The positioning of the Sports Hall in the actual area in which it will be built allowed a better visual information acquired from the real urban background. This ensured the understanding of the building in its context. An experimental user test was carried out to explore how the technical properties of the AR tool were evaluated by the users (both experts and non-experts) and whether its use could increase the understanding and interest in sustainable topics. Experimental sessions were carried out at the football field next to the Voldsløkka School in Oslo, Norway, in March 2023, **Figure 22**.

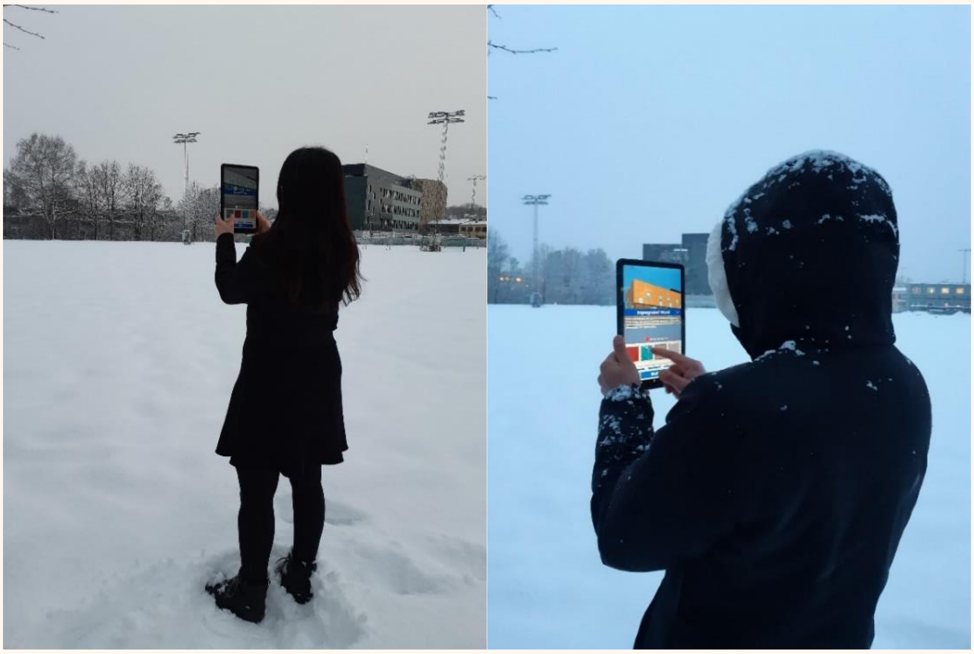

Figure 22. *Participants using the AR tool in the Oslo demo.*

GENERATION OF AR APPLICATION

The mobile AR application was developed using the Unity engine. To generate the AR tool, the developer of the Sports Hall (i.e. the manager of the design and construction of the Sports Hall building) provided a reference 3D model, which was later simplified using the modelling software Blender 3.2. The simplification of the 3D model allowed to improve the application performance. The adjusted model had 11,342 vertices and 19,630 edges. Terrain modelling was not needed as the building model was simulated assuming a level ground surface. The additional 3D models of the different materials shown in the AR tool were also developed using Blender and subsequently imported into Unity. The AR tool's image recognition functionality was built using ARFoundation in combination with Google ARCore. A single QR code was used for the initial image detection. This allows the spawning and correct localization of the 3D building model of the Sports Hall.

From a user interaction perspective, the AR interface was conceptualized to allow participants to securely hold the tablet (Galaxy Tab S8 5G) with one hand while interacting using the other. The device has an 11.0-inch LCD display with 1600 x 2560 pixels resolution and a 274 ppi density, providing a large, high-resolution display for viewing. Its LCD can achieve up to 420 units of brightness, addressing viewability limitations observed in many OLED screens for well-lit outside environments. With a weight of 507 g, the tablet was practical for handheld AR interactions, as the one developed for this study. The camera system's main backwards facing 13MP sensor was also suitable for the AR task. The device's 1080p video recording, ARCore depth API support, accelerometer, and gyroscope further enhanced its AR capabilities. This configuration was informed by preliminary tests of a previous version (Dimmen and Oksvold, 2022), which results showed that users prefer uncomplicated and user-friendly technological methods, deemed as satisfactory in this developed AR tool. A couple of screenshots of the user interface of the AR tool can be seen in **Figure 23**.

INFORMATION PROVIDED IN THE AR APPLICATION

Given that the visualisation of the building was set from an outside point of view, different façade elements were selected to be simulated. Three categories were selected for the façade elements:

i. Wall, presenting different wall materials.
ii. Glass, presenting two types of glazing for the building openings.
iii. Power, representing the use of photovoltaic (PV) panels in either the façade or the roof of the building.

Each category of façade element presented more than one alternative, which allowed the comparison between the different options regarding their CO_2 emissions. Each alternative was visualised containing a brief informative text about the material characteristics, and information regarding the CO_2 emissions of the material per square meter (CO_2 eq/m^2). This included considerations for the material volume and encompassed a maintenance timeline of 60 years. The three categories with their respective alternatives and the provided information about CO_2 emissions are listed in **Table 1**.

Table 1. *Categories and alternatives of façade elements presented in the AR application.*

Category	Alternative	Emissions (kg CO2 eq/m^2)
Wall	Burned wood	2.29
	Coated wood	2.34
	Composite panel	17.7
	Impregnated wood	4.9
	Concrete blocks	63
Glass	Tempered glass	54.6
	Stained glass	54.6
Power	East-wall PVs	-608.18
	Roof PVs	-1483.94

Figure 23 shows screenshots of the interface of the AR tool, showing examples of alternatives for wall materials and photovoltaic panels. This shows that for each alternative, written text was shown together with the CO_2 emissions per square meter of material. It is important to note that the screenshots of the AR tool were not taken where the user test was carried out. This means that the figure does not depict the building in its context (Voldsløkka school in Oslo) as visualised by the test participants.

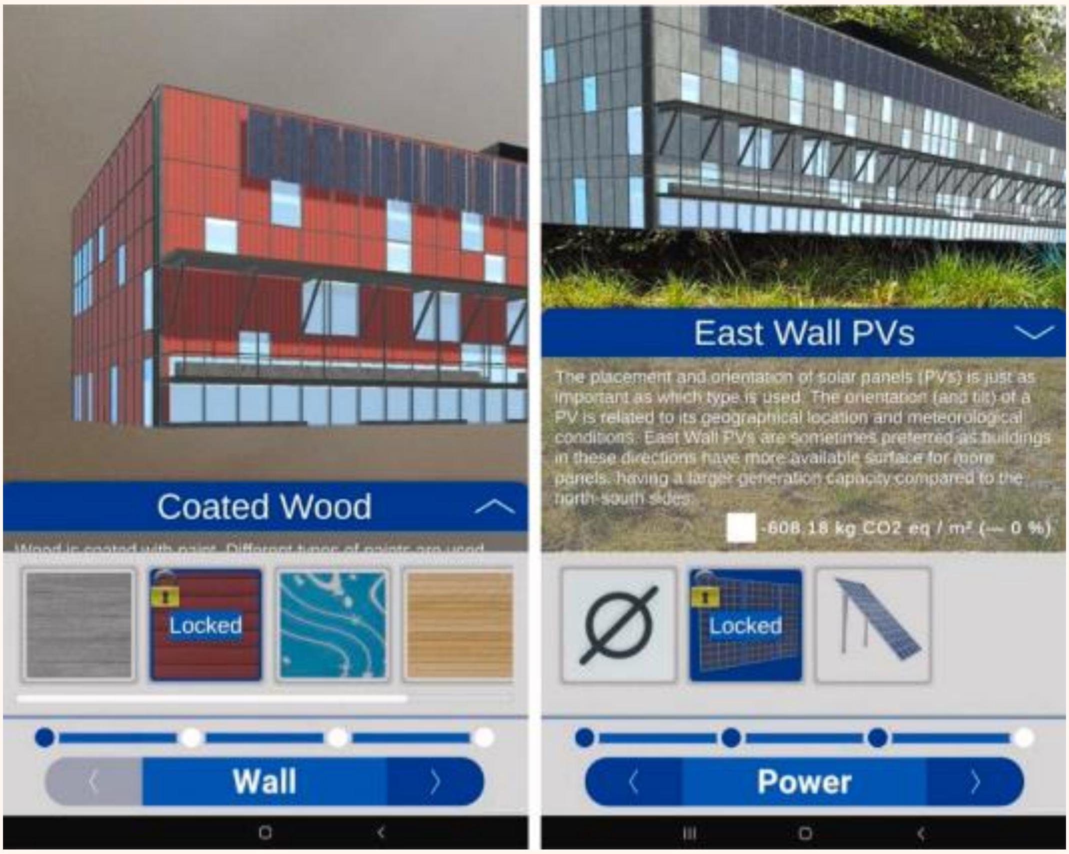

Figure 23. *Screenshots of the interface of the AR tool.*

PILOT STUDY

The AR tool was tested in a pilot experimental study to evaluate whether the tool serves to increase the interest, understanding and engagement of citizens in sustainable architecture, as described in Section 4.1. The findings of the study suggest that AR was found to be a valuable tool to increase the understanding, interest and engagement of citizens in sustainable architecture. A complete description of the background, method and results of the pilot study can be found at Moscoso et al. (2024). The lessons learned from the user test will also be described in the deliverable D2.7 of the project.

ADDITIONAL INFORMATION

Two YouTube videos show the initial version of the AR tool, as evaluated in the preliminary tests conducted by Dimmen and Oksvold (2022). These videos can be found at:

- https://www.youtube.com/watch?v=PwI8EpY0Q3Q.
- https://www.youtube.com/watch?v=YX-P66lm28U.

Moreover, a research article was produced describing the user test conducted in Voldsløkka School with the AR tool, as mentioned in Section 4.1. This article was published in the journal *Computers in Human Behaviour Reports* in the present year, and can be found via the following link: https://doi.org/10.1016/j.chbr.2024.100498.

Based on the scientific research article, two other articles were published in the Norwegian research magazines Gemini.no and Forskning.no. Both articles can be found at:

- "Denne teknologien lar deg sanse og oppleve arkitektur – som ikke finnes" (Eng: This technology allows you to sense and experience architecture – that does not exist). URL: https://gemini.no/2024/10/denne-teknologien-lar-deg-sanse-og-oppleve-arkitektur-som-ikke-finnes/.
- "Kan en app få oss mer engasjert i miljøvennlig arkitektur?" (Eng: Can an app get us more engaged in environmentally friendly architecture?). URL: https://www.forskning.no/app-arkitektur-baerekraft/kan-en-app-fa-oss-mer-engasjert-i-miljovennlig-arkitektur/2422704.

The article from Forskning.no was presented at the LinkedIn channel for SINTEF Community (the research partner responsible for the development and testing of the AR tool), and can be found via the following link: https://www.linkedin.com/posts/sintefcommunity_kan-en-app-f%C3%A5-oss-mer-engasjert-i-milj%C3%B8vennlig-activity-7257735748873842689-b2od?utm_source=share&utm_medium=member_desktop.

A similar popular article was also published at SINTEF's site: https://www.sintef.no/siste-nytt/2024/denne-teknologien-lar-deg-sanse-og-oppleve-arkitektur-som-ikke-finnes/.

Finally, the European Commission via the Green Deal Projects Support Office has included the study of AR tool of the ARV project as part of their success stories. The article is called "Using augmented reality models to engage stakeholders on retrofitting buildings" and can be found at the following link: https://projects.research-and-innovation.ec.europa.eu/en/strategy/strategy-2020-2024/environment-and-climate/european-green-deal/green-deal-projects-support/green-deal-success-stories/using-augmented-reality-models-engage-stakeholders-retrofitting-buildings.

4.2. AR TOOL FOR PALMA DEMO

In line with the aims and objectives of the AR application for Oslo, the application was further developed and modified for the Palma case. Under the umbrella of citizen engagement, the application focused on disseminating the impact of different renovation approaches on CO_2 emissions, energy savings and costs. Attributes from both the ARV VR applications and the Oslo AR app were used to conceptualize the application. The app is centred around the building Carrer de Caracas, 4, Llevant, 07007 Palma, Illes Balears, Spain. The application was designed such that it provides information about possible alternatives for renovation of the building and presents an interactive way for users to see and understand its impact.

Figure 24. *Participants using the AR app in the Palma Demo.*

The tool was tested on-site in Palma de Mallorca, Spain. The testing used the building mentioned earlier as a case study as different alternatives were being considered for its renovation. Input and acceptance from all the stakeholders including citizens and the neighbourhood were crucial to this renovation since it involves approvals from the local housing associations and the municipality. Here, the AR tool was used firstly, as a means to engage citizens to foster support and cooperation for the planned renovations. And secondly, to better communicate the different dynamics of the project. This also included visualizing the aesthetic impact on the building with renovations such as the integration of photovoltaic cells. As in the Oslo case, the user test was carried out to evaluate the AR tool with the target users regarding their perception of the tool and methodology of communication, hence facilitating stakeholder engagement, enhancing communication clarity, and gathering actionable feedback to refine both the tool and the renovation approach. The tests were carried out on a sidewalk in front of the building in November 2024; see **Figure 24**.

GENERATION OF AR APPLICATION

The AR application was developed using Unity engine (ver 2021.3.5f1), with the help of supporting tools such as the Android Software Development Kit, Blender, Visual Studio, etc. The interactions and functionalities were programmed using C# and Visual Studio. Both the Oslo app and the Palma app were designed to be consistent with each other. Hence, the Oslo app was taken as the reference for the Palma app. The app used the same UI components and the same tools, such as Google ARCore for the detection and tracking of QR codes. The development and modification of the app comprised the steps shown in **Figure 25**.

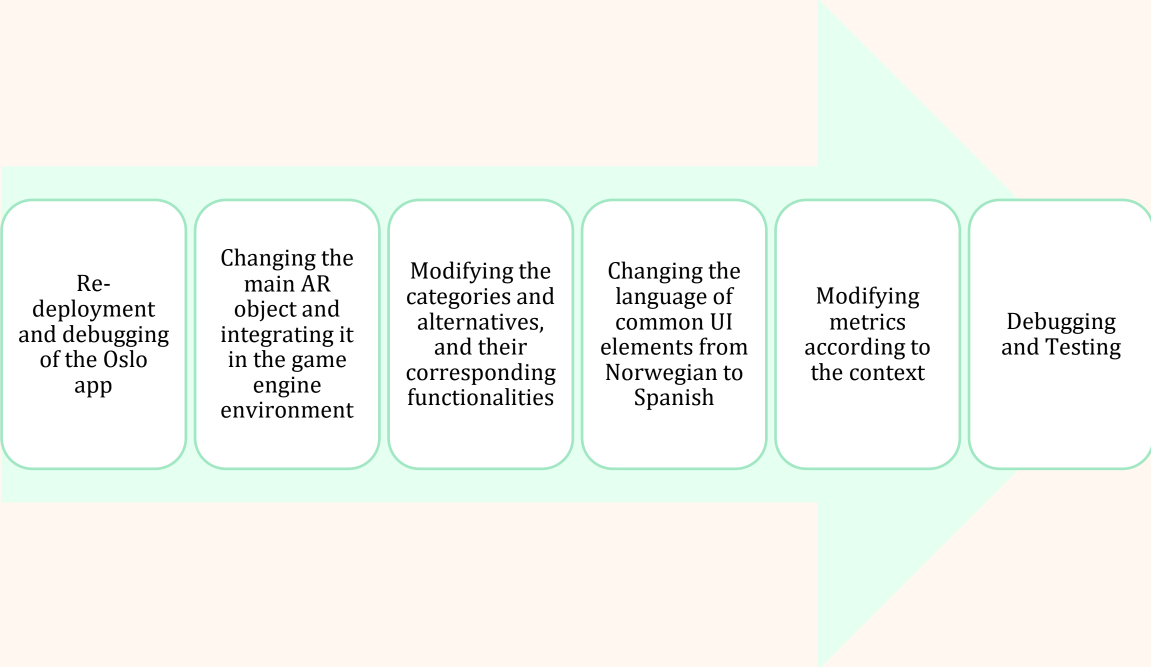

Figure 25. *Development pipeline for the Palma AR App.*

In addition to the steps mentioned in **Figure 25**, the development included fixing and improving some aspects of the application related to the user interface and interactions. After deploying and debugging the project from the Oslo application, Unity package 'FBX Exporter' and Blender were used to process and merge the different components of the 3D representation of the Palma building. Using Blender, the object was exported as a wavefront (.obj) with 167,826 vertices and 233,925 faces.

Figure 26. *The building in Palma (left). The 3D model of the building (right).*

The 3D object was imported into the Unity environment and placed to be activated and aligned with the trackable QR code. The program detects the QR code in real life, and places objects in the digital environment based on the distances between the QR code and the object in the Unity environment. For example, if the QR code is placed at (0,0,0) and the 3D object is placed at (5,0,0) in the environment, the object will appear 5 units away from the QR code on the x-axis. One Unity unit is roughly interpreted as one meter.

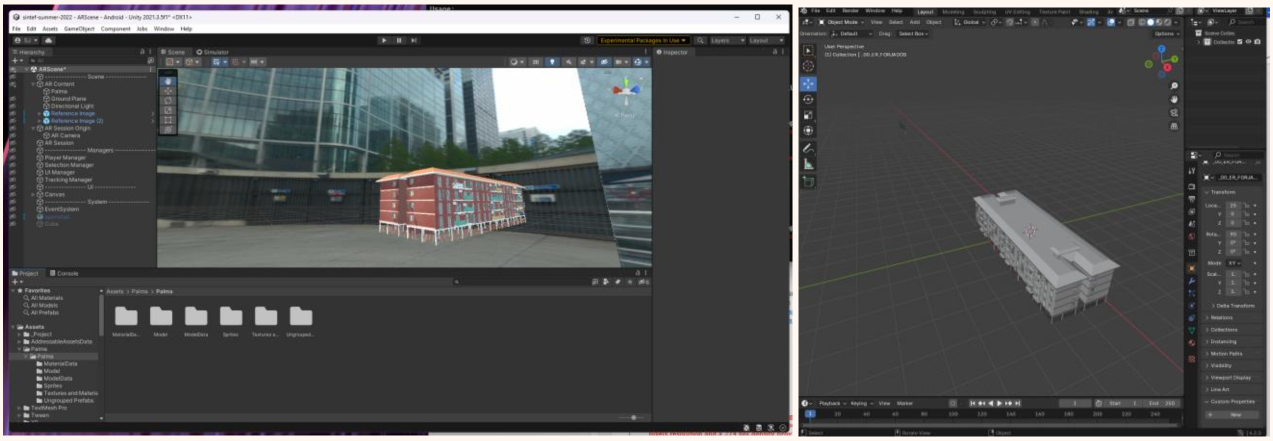

Figure 27. *Unity (left) and Blender (right) Environment for AR Palma Tool.*

INFORMATION PROVIDED IN THE AR APPLICATION

As in the Oslo demo, three categories with three different alternatives were selected:

i. Facade, presenting different retrofitting approaches.
ii. Energy, representing the use of heat pumps with or without PV panels.
iii. Window frames, presenting three alternatives for window frames.

Users could select any combination of these alternatives to see how such a combination would perform in terms of the chosen metrics. The metrics were reduction in carbon emissions, energy savings, and cost. The three categories with their respective alternatives are listed in **Table 2**.

Table 2. *Categories and alternatives of façade elements presented in the AR application.*

Category	Alternative	Reduction in Carbon Emissions (%)	Energy Savings (%)	Cost (EUR)
Facade	No Retrofitting (Current)	-	-	-
	Conventional Retrofitting	30	35	287072
	ECO Retrofitting	33	35	344487
Energy	Gas Boiler (Current)	-	-	-
	Heat Pumps	35	30	134400
	PV Panels (with heat pump)	38	37	18800
Window Frames	Aluminium (Current)	-	-	-
	PVC	7	5	341538
	Wood	8	5	443999

The functionalities of MaterialData and ModelData in Unity were used to switch between visualizations of different alternatives. A MaterialData or ModelData was created for each alternative, and a script stored the information about which MaterialData/ModelData to activate for different alternatives. ModelData(s) pointed to a prefab, while MaterialData pointed to a material. In order to communicate the retrofitting visually, a creative approach was taken where users could see the underlying layers of the possible retrofitting. This was done by creating a 3D model in Blender using the original 3D model of the building. The base texture of the façade was edited in Adobe Photoshop to depict the inner-most layer of the retrofitting. The category 'energy' showcases a series of 15 solar panels for the alternative 'solar panels (with heat pump)' on the roof of the building, while no changes were implemented on the façade for 'heat pumps' since installations of heat pumps had no visual changes on the building. This series of solar panels was created using Blender, and then the program implemented them using its corresponding ModelData. Window frames were changed according to the alternatives using their corresponding MaterialData changing the texture for the window frames in the original 3D model.

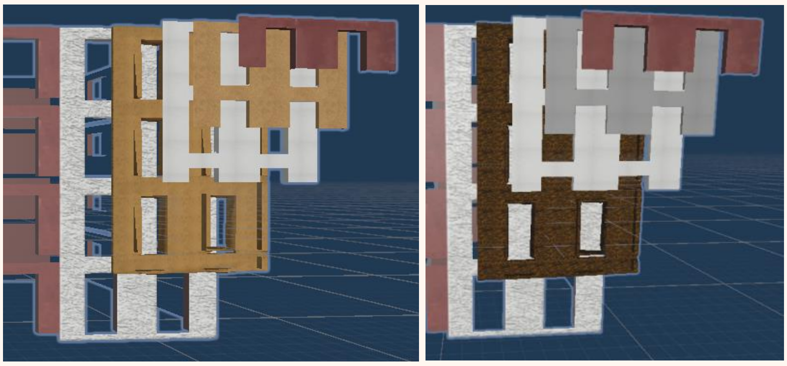

Figure 28. *Prefabs corresponding to the alternative: Conventional Retrofitting (left). ECO Retrofitting (right).*

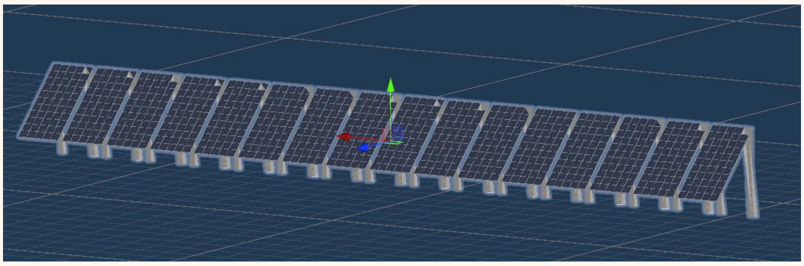

Figure 29. *Prefab for the alternative Solar Panels (with heat pump).*

Figure 30. *The three alternatives for the category: Window Frames.*

While keeping the primary components of the UI same, some changes were made to simplify the application based on the feedback in the Oslo demo, and to better fit the Palma demo. Most importantly, the language of the application was changed to Spanish. The main screen that prompts the user to scan the QR code was simplified, as shown in **Figure 31**. Then, AR object appears, and the app presents user with the option to explore different renovation alternatives. The categories and alternatives are accessed through a textured button on the screen, which was put alongside a camera button in the middle, as shown in **Figure 32** (left). Since the option to take a screenshot was obsolete due to the in-built capability of the device to take screenshots, the camera button was removed, and the primary button was moved to the middle. A more indicative graphic was used to further direct the user towards using the functionality of the application, as shown in **Figure 32** (right).

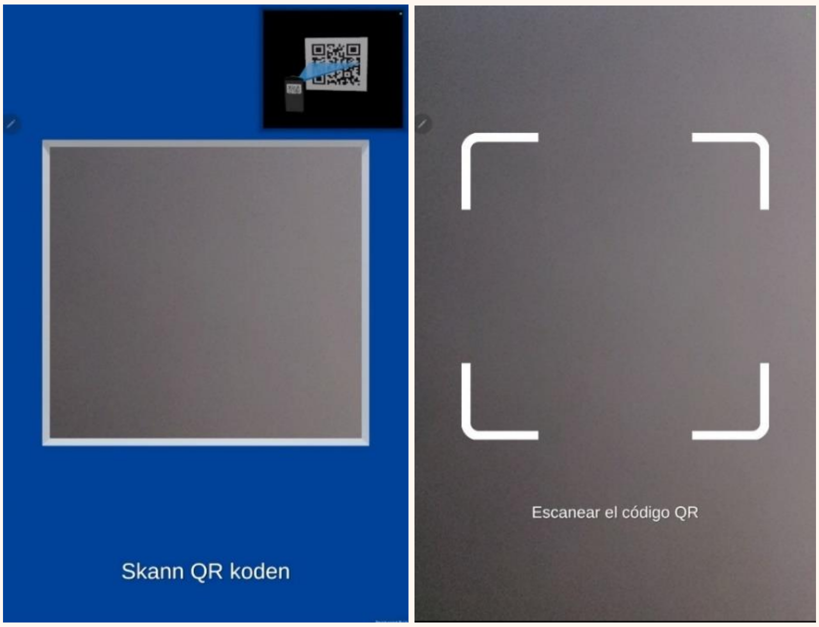

Figure 31. *QR Code scan interface (Left: Oslo Demo, Right: Palma Demo).*

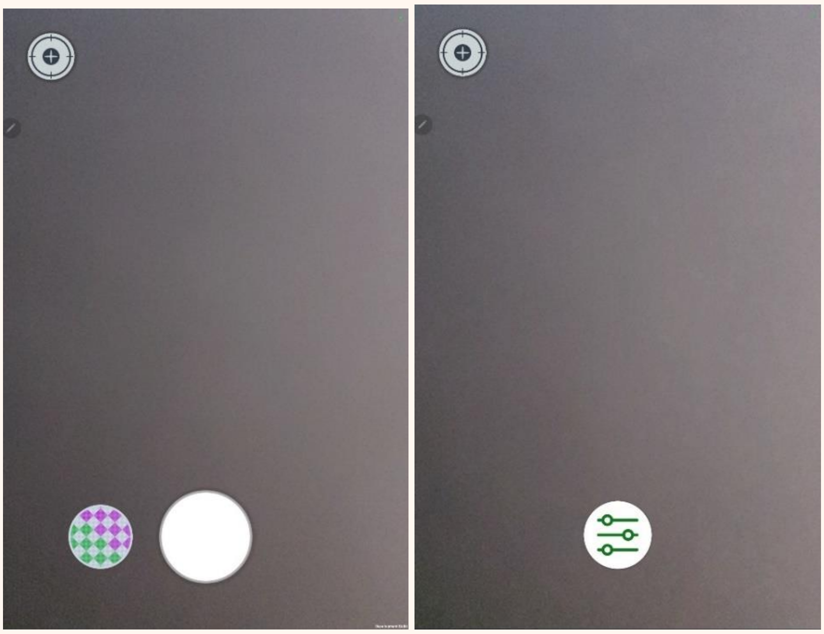

Figure 32. *Interface (Left: Oslo Demo, Right: Palma Demo).*

Users could compare different alternatives from each category since the application shows the increment and decrement in terms of metrics between the alternative that is locked (*bloqueado* in Spanish) and the alternative that is currently being evaluated. The users can change the alternative by clicking 'Lock' (*bloquea* in Spanish) option on the alternative, as shown in **Figure 30**. Based on the alternatives that are locked in each category, the app shows a summary screen with total reductions in emissions, saved energy and costs.

5. CONCLUSIONS

The ARV project demonstrates the potential of Virtual Reality (VR) and Augmented Reality (AR) technologies to foster Climate Positive Circular Communities (CPCCs). These tools are integral to enhance urban planning, stakeholder engagement, and public education on sustainable practices. By providing immersive, interactive experiences, they help bridge the gap between technical concepts and public understanding, ensuring that CPCC initiatives are not only technically sound but also socially inclusive.

Central to the project is the implementation of VR and AR applications at demonstration sites in Oslo and Palma. These tools offer immersive environments to visualize design choices, sustainability strategies, and renovation impacts while raising citizen awareness about environmental effects such as CO_2 emissions from different building materials and renovation techniques. Together, these technologies support informed decision-making and encourage active participation from diverse stakeholders. The use of these tools extends beyond visualization to foster deep engagement with communities and stakeholders (European Commission, 2024). By simplifying complex sustainability concepts, VR and AR applications ensure accessibility for non-experts, making it easier to convey the benefits and trade-offs of urban renovation projects.

The document focuses on the technical development of VR and AR applications. High hardware requirements and intricate software functionalities were tackled to ensure high-quality, user-friendly simulations. Moreover, the iterative refinement of these tools highlights the importance of user-centric design and usability testing in enhancing engagement and effectiveness. In summary, the ARV project exemplifies how immersive technologies can change urban planning, making it collaborative, transparent, and accessible. By integrating VR and AR into the planning process, the project not only advances sustainability goals but also sets a precedent for the broader application of such tools in building resilient, inclusive communities.

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APPENDIX A – GLOSSARY OF TERMS

Table A.1 *Abbreviations used in the report.*

Abbreviation	Description
AR	Augmented Reality
CPCC	Climate Positive Circular Communities
HMD	Head-Mounted display
IFC	Industry Foundation Classes
LL	Living Lab
POI	Point of Interest
PV	Photovoltaic Cells
PVC	Polyvinyl Chloride plastic
TV	Television
UE	Unreal Engine
VR	Virtual Reality
WP	Work Package

PARTNER LOGOS

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