NEXT GENERATION INTERNET

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Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment

Deliverable 3: Experiment Results and Final Report

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Deliverable 3: Part I

Analysis, results, and wider impact

1. Abstract

The vision of an augmented reality (AR) cloud is about an enhanced version of the real world extended by persistent, location-anchored digital objects. In this project, we adapted and advanced various components of the Open Spatial Computing Platform (OSCP) to become deployable at multiple testbeds. We deployed the platform at the COSMOS 5G testbed and produced tutorials and best practices for building and using maps of spaces in AR cloud experiences. We created a new OSCP reference client in Unity and built representative demo applications that allow virtual objects to persist throughout space and time. With this new client, users have the possibility to create and discover objects.

2. Project Vision

Spatial computing is a broad term for a suite of technologies that result in users being immersed, engaged, and interacting with spatial and temporal digital information that pertains to the physical space in, around, and near the user. It consists of a superset of technologies required for traditional Augmented Reality. Figure 1 introduces the concept and the most important terminology.

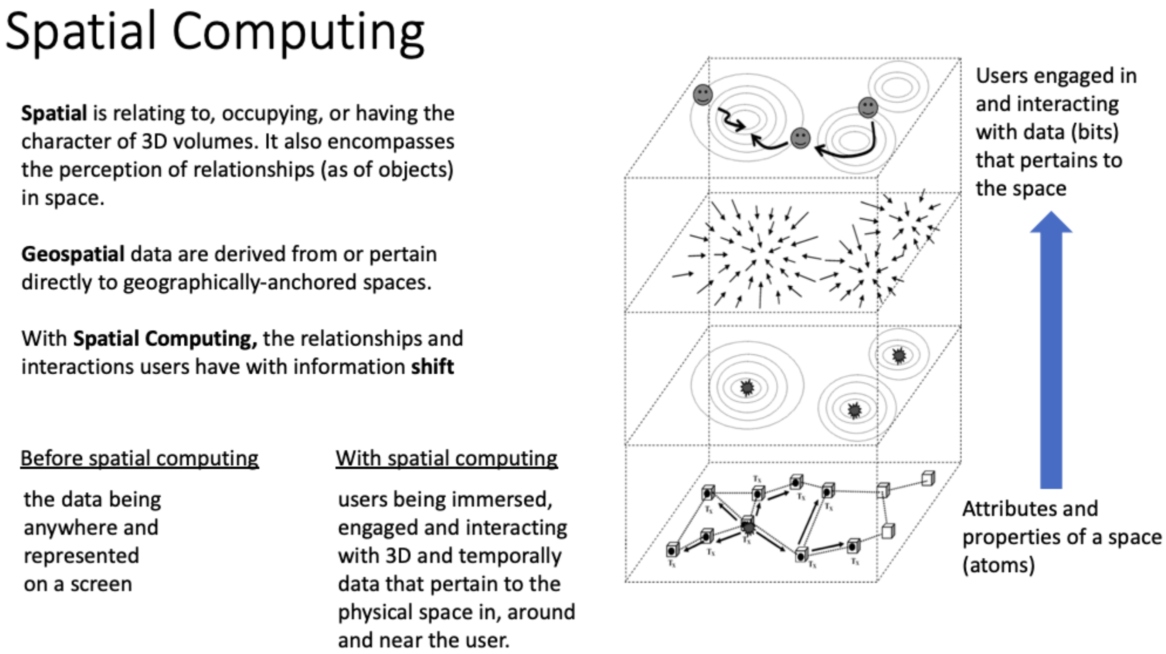

Figure 01: Spatial computing connects atoms with bits and allows users to directly interact with digital information at a relevant physical location

Spatial computing relies on a number of fundamental technologies such as real-world 3D capture (sparse and dense point cloud mapping), precise localization with six degrees of freedom, and discovery and delivery of personalized content to users. Today, these building blocks are only available from and controlled by a few major companies (Microsoft, Apple, Google, Meta, etc) in siloed platforms.

The Open AR Cloud (OARC) association is dedicated to the development of technologies and standards for open and interoperable spatial computing components on which an ecosystem of companies and their services can flourish. The OARC has already designed and implemented prototypes of important building blocks of an Open Spatial Computing Platform (OSCP), shown in Figure 2. The OARC has released the components as open-source code (see https://github.com/OpenArCloud) and these are already deployed in an OARC testbed in Bari, Italy. The existing OARC testbed has proven that the OSCP enables discovery of spatial services, localization of users based on images sent from the user's mobile camera, discovery of digital multimedia content attached to physical locations or smart objects and sensors, and display of content to test bed-connected users. Based on personalized user preferences, location, and other context information, the retrieved content can be dynamically filtered.

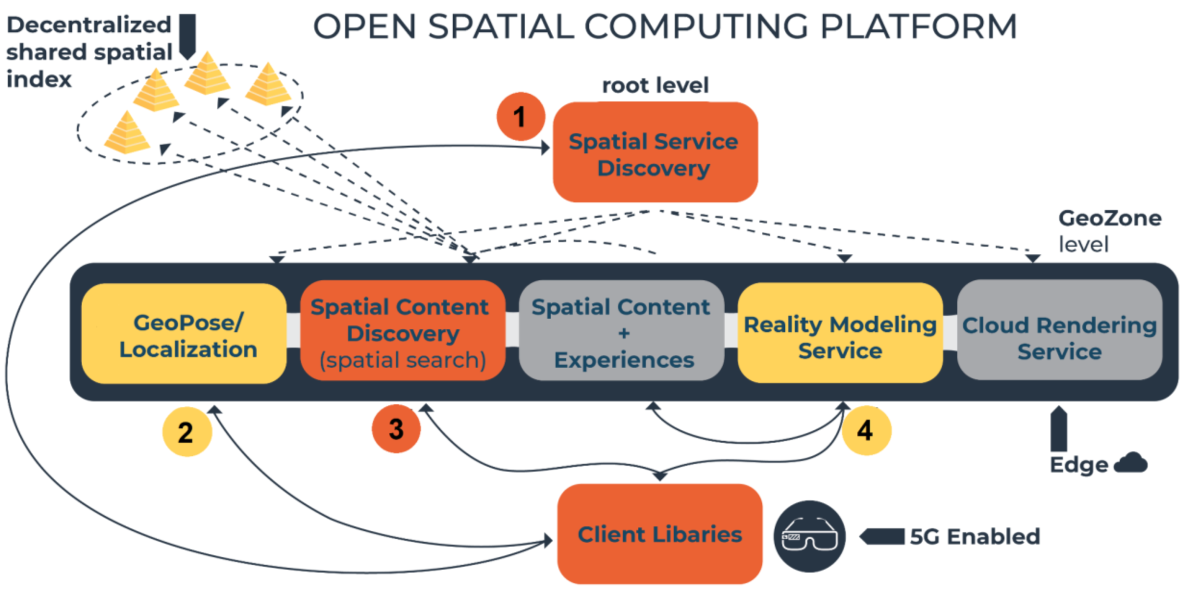

Figure 02: The building blocks and the services of the OSCP. (1) The mobile client first queries the SSD for spatial services in the vicinity. (2) The client sends a photo to a visual positioning service and receives back its estimated 6DoF GeoPose. (3) SCD helps to discover relevant spatial contents at the current location. (4) The client can download world models that allow features like occlusion and semantics (not yet implemented). Orange blocks are fully specified, yellow blocks are partially specified, gray blocks are not specified by OARC.

With support of the NGI Atlantic program, the Open AR Cloud (OARC) Europe team is adapting the reference implementation of the OSCP and deploying the components on the COSMOS 5G platform in Manhattan. In addition, the team creates a new Unity-based reference client application and two representative demo applications. The team is also working on integrating a new, open-source Visual Positioning Service developed by George Mason University.

The COSMOS 5G deployment of the OSCP will allow conducting experiments that will deepen understanding of limitations and opportunities of the OSCP, provide component and network performance metrics, and trigger development of new software to increase the capabilities and features of the OSCP. The integration with an open-source VPS will permit any provider to offer a vendor-neutral positioning service to any organisation seeking to use the OSCP.

3. Details on participants (both EU and US)

EU Participants

Alina Kadlubsky is a Product Designer, Art Director, and WebXR Developer by Day. By night she is the Lead Strategist of the Cyber XR Coalition, Managing Director Open AR Cloud Europe, as well as OARC Director of Communications and Lead of the Accessibility and Safety Working Group. In this role, Alina has led the charge in OARC's mission to drive the development of open and interoperable technology, data, and standards to connect the real and digital worlds for the benefit of all. Alina served as the general coordinator of this project, branding and communication

Dr. Gábor Sörös is a researcher and engineer focusing on mobile and wearable computer vision, interaction, and augmented reality for more than a decade. He works as a research scientist at Nokia Bell Labs. Previously, he was a researcher at ETH Zurich, interned at Qualcomm's Vuforia team, and he was also involved in several successful startups in mobile computer vision and augmented reality. He obtained MSc in electrical engineering from TU Budapest and PhD in computer science from ETH Zurich. Gábor served as the technical lead of this project, he did the adaptation and deployment of the backend components, contributed to client development, mapping, and a new image collector application.

John Nilsson is an experienced 3D developer and has deep knowledge of the game engine Unity, and has developed VR and AR experiences since 2015 at 3DInteractive Sthlm. His background is from game design and .Net development. John was the developer for Unity and implemented Authentication, MQTT, GUI, support for asset bundles and new functions.

Pär Nordenhjälm Linde is a Unity3D developer focusing on 3D content creation for AR/VR. He holds a bachelor degree in Computer science and a background in graphical communication. Pär has been developing AR & VR applications at 3D Interactive Sthlm since 2012. Pärs served as the UI designer for the Unity app and the 3D-content creation, including optimising point clouds.

Karthik S. Kumar is an experienced full stack developer with over 10 years of experience from Unity3D, web development, backend development and has been developing AR projects since 2012. Karthiks role in the project was to develop File storage service for digital contents.

Jonathan Tiedtke is the CTO at 3D Interactive and oversees the technical architecture and development of Augmented reality applications and systems, as well as implementing web standards and frameworks for XR since 2018. He has previously worked with several key technologies for delivering XR experiences via the web. This includes the use of Remote rendering services for streaming 3D content to mobile clients. He was also one of the co-founders of the first VR arcade in the Nordic region, where he arranged XR hackathons and VR events. Jonathan served as technical coordinator for the Unity client development and setting up and connecting the services related to that on the Orbit server. He also helped with designing the functionalities of the backend and frontend.

Mikael Spuhl is the founder and CEO of 3D Interactive Sthlm, a Spatial Computing company based in Stockholm, Sweden. He has for many years been promoting, selling and being project lead for hundreds of AR/VR projects in Sweden since 2011 for a vast type of industries and technologies. He has been on the board for HVE programmes within AR/VR. Mikael served as project manager for the 3D Interactive team in the project and securing the resources needed were allocated to the project.

Christine Perey is an industry analyst and independent researcher focusing solely on AR since 2006. She is on numerous boards, is a member of many standards groups and co-chairs the IEEE SA ARLEM WG and the OGC GeoPose SWG. She is a work item leader in the ETSI Industry Standards Group on AR Framework. She is the founder of the AR for Enterprise Alliance (AREA), chairs the Research Committee and leads the AREA Interoperability and Standards Program. Since 2018, she is a founder of the Open AR Cloud (OARC) association and serves on the governing board. She currently leads the research coordination initiative of the OARC. Christine served as an advisor in the application stage of this project.

US Participants

Ivan Seskar is the Chief Technologist at WINLAB, Rutgers University, responsible for experimental systems and prototyping projects. He is currently the program director for the COSMOS project responsible for the New York City NSF PAWR deployment, the PI for the NSF GENI Wireless project, which resulted in campus deployments of LTE/ WiMAX base stations at several US universities, and the PI for the NSF CloudLab deployment at Rutgers. He has also been the co-PI and project manager for all three phases of the NSF-supported ORBIT mid-scale testbed project at WINLAB, successfully leading technology development and operations since the testbed was released as a community resource in 2005 and for which the team received the 2008 NSF Alexander Schwarzkopf Prize for Technological Innovation. Ivan is a co-chair of the IEEE Future Networks Testbed Working Group, a Senior Member of the IEEE, a member of

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ACM and the cofounder and CTO of Upside Wireless Inc. In this project, Ivan served as the local coordinator of the testbed in the US.

Prof. Dr. Bo Han is an Associate Professor in the Department of Computer Science at George Mason University. His research interests are in the areas of networked systems, mobile computing, and wireless networking. His current research focuses on immersive video streaming, augmented, virtual, and mixed reality, and the Internet of Things. He enjoys building practical systems by leveraging innovations in machine learning, multimedia, computer vision, computer graphics, and human-computer interaction. Before joining George Mason University, he was a Principal Scientist at AT&T Labs Research. Along with his collaborators, he has built several immersive video streaming systems and mobile augmented reality systems and published research papers in these areas on top-notch international conferences. In this project, Prof. Han served as an advisor on visual positioning.

Prof. Dr. Songqing Chen is a Professor of Computer Science at George Mason University. His research interests mainly focus on design, analysis, and implementation of algorithms and experimental systems in the distributed and networking environment, particularly in the areas of Internet content delivery systems, mobile and cloud computing, network and system security, and distributed systems. Currently, he is actively working on different issues around 360-degree streaming, augmented reality (AR) and virtual reality (VR), software-defined networking, and Internet of Things (IoT). Currently, he serves as the chair of IEEE Technical Committee on the Internet (TCI), and on the editorial boards of IEEE TPDS, IEEE IC, IEEE IoT-J, and ACM TOIT. In this project, Prof. Chen also served as an advisor on visual positioning.

Jennifer Shane is a laboratory engineer at WINLAB at Rutgers University under the direction of Ivan Seskar. Her responsibilities include development and maintenance of wireless testbed infrastructure and supervision of student projects. She has a bachelor’s degree in electrical and computer engineering from Rutgers University. In this project, Jennifer performed the tests at the US site.

Nan Wu is currently a Ph.D. student in the Department of Computer Science at George Mason University, instructed by Prof. Bo Han. His interests include augmented reality and AR system design. He is researching network-friendly volumetric video analytics and privacy protection for SfM mapping and localization. In this project, Nan worked on integration of OSCP with their visual positioning system.

4. Results

Overview

The common vision of a “real-world metaverse” is to be able to place 3D digital information linked to any physical place, enhancing our ability to gather information at a glance. A fundamental condition to the creation of persistent AR experiences is to capture and create a detailed 3D map of the environment. In existing AR cloud solutions today, the images and 3D maps of the users personal environments are centralized at a few industry giants. Apart from not only storing very intimate data about users' surroundings, all the digital information displayed in AR is also hosted and filtered (“personalized”) by these providers. To address these privacy concerns, this project aims to advance and make publicly available all components of an end-to-end AR cloud solution, the Open Spatial Computing Platform (abbreviated OSCP).

In this project, we adapted the existing OSCP components to be deployable at new locations, and we demonstrated the complete system in action in the COSMOS testbed in Manhattan in two representative use cases.

Prior to this project, AR contents in OSCP had to be added manually to the content database, which was inconvenient and not user-friendly. To lower this usability burden, we created a new reference client in Unity (available on Android and iOS) with the ability to easily place content directly in augmented reality. Our ultimate goal is that any client that adheres to the OSCP protocols will be able to place new contents, which will be immediately discoverable by other clients, independently of their underlying device type, operating system, or AR engine. We tested and evaluated the platform and the new client with the help of two use cases.

In the first representative use case, a mobile device discovers a sensor node in a laboratory environment and shows its current sensor values floating above the real node. Beyond the discovery, this requires real-time streaming of IoT data from sensors to AR devices. In the second representative use case, our plan was to place an AR art piece at an outdoor location or implement a collaborative drawing application. This latter requires real-time sharing of users' poses and interactions with each other. Due to time and person shortage, we did not finish the drawing application. Instead, we showed another demonstration in which a new object is placed with our Unity client and is immediately retrieved at the same location with our WebXR client, highlighting the interoperability of our platform. We also extended the existing WebXR reference client application with new features required by these use cases, such as texturing.

Related to content creation and placement, we also had to implement user authentication and a new, open-source file storage solution that anyone can easily set up (note that the OSCP does not store but only references contents). New users can simply host their own contents and make it available in our client app, and can place them at real-world locations.

The project also required creating 3D maps of the selected experiment locations, as well as creating simplified digital twins of the locations to aid the artistic design of AR experiences. The 3D map was built by the US and EU partners jointly with two different technologies. The digital twin is created by the EU team using a series of photos taken by the US team at the Rutgers University lab. We will publish a detailed process description of generating a 3D map to be used as a reference in this project. We also did the first steps towards integration of OSCP with an open-source visual positioning system developed by our project partner GMU in a parallel project.

Testbed/Platform Setup

In the COSMOS testbed, Rutgers University provided the servers (virtual machines) for the installation of the OSCP components. The US team also provided other hardware (mobile devices, IoT sensors) for conducting the experiments. The virtual machines were remotely accessible online. The EU team deployed the OSCP components after freeing their code from all settings and dependencies on the first prototype deployment in Bari, and reconfiguring them for COSMOS. A detailed tutorial was created about the setup process so that it is easily repeatable at other testbeds.

The OSCP backend services and access libraries have been adjusted and upgraded to be able to be deployed at locations other than the default one. The following repositories have been improved: Spatial Service Discovery (SSD), SSD JavaScript client module, Spatial Content Discovery (SCD), SCD JavaScript client module. In addition, an old Web-based GUI for service and content administration has been upgraded. These repositories can be found at:

- https://github.com/OpenArCloud/oscp-spatial-service-discovery
- https://github.com/OpenArCloud/ssd-access
- https://github.com/OpenArCloud/oscp-spatial-content-discovery
- https://github.com/OpenArCloud/scd-access
- https://github.com/OpenArCloud/oscp-admin

All these OSCP services have been deployed on a new virtual machine in the ORBIT Lab at Rutgers University, which will also be easy to transfer to other locations in the future.

The team chose two locations for the experiments: a large laboratory space indoors, and a street intersection outdoors. These locations first needed to be mapped by a visual positioning service.

Visual Positioning Services

Global Positioning System (GPS) technology has since long been used to position devices, content and users. However, GPS does not work indoors and cannot provide the required accuracy to enable precise placement of 3D objects in space. Instead of GPS, another approach called Visual Positioning System (VPS) can be used to estimate a precise location and orientation of a device. VPS uses camera input and compares images taken by the device to a geo-referenced point cloud map or an image database and can determine the precise position and orientation of the camera with respect to those.

GeoPose and GeoPose Protocol

Prior to this project, the OARC proposed the GeoPose standard to describe the location and the orientation of an object. First, the protocol needed for information to be linked to a physical place. GeoPose expands the long-lat-alt coordinates with heading, tilt, roll to describe the orientation of an object or device. Furthermore, the OARC also proposed the GeoPoseProtocol, which is an application layer protocol for visual positioning. It aims to standardize the VPS queries encapsulating image and other sensor data, and VPS responses encapsulating 6DoF camera pose in the world as a GeoPose description (see https://github.com/OpenArCloud/oscp-geopose-protocol).

Visual positioning service by Augmented City

While the OSCP would support many different types of localization systems that adhere to the OSCP GeoPose Protocol , in this project we rely on visual localization technology provided by Augmented City (Italy). We collected several hundred images with the AC Mapper application, and the AC cloud service built a sparse point cloud map from the photos. The point cloud is automatically aligned with the world coordinate frame, but sometimes manual adjustments are needed. Localization of a mobile device is performed by sending a new photo to the cloud service, which registers the new photo to the point cloud and returns its pose in global coordinates.

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In this project, we have mapped the radio laboratory of Rutgers University in New Brunswick, NJ, the outdoor intersection of Amsterdam Ave and 120th street in Manhattan, NY, and multiple private areas for developer tests.

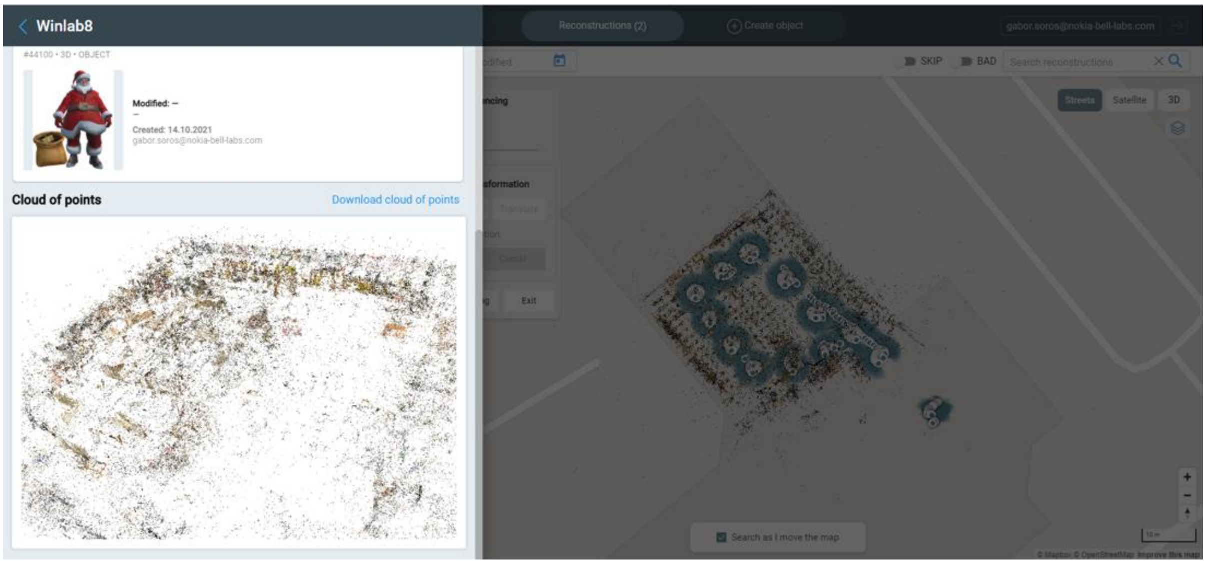

Figure 03: This figure depicts the reconstructed sparse point cloud of the Rutgers radio laboratory using proprietary technology from Augmented City. The blue circles represent the camera locations at the times when photos were taken with the proprietary AC Scanner image capture application. We have also added a test object (Santa Claus) which can be discovered by the proprietary AugmentedCity client (AC Objects). Note that the same object can be discovered but it cannot be drawn by our own clients due to its proprietary model format.

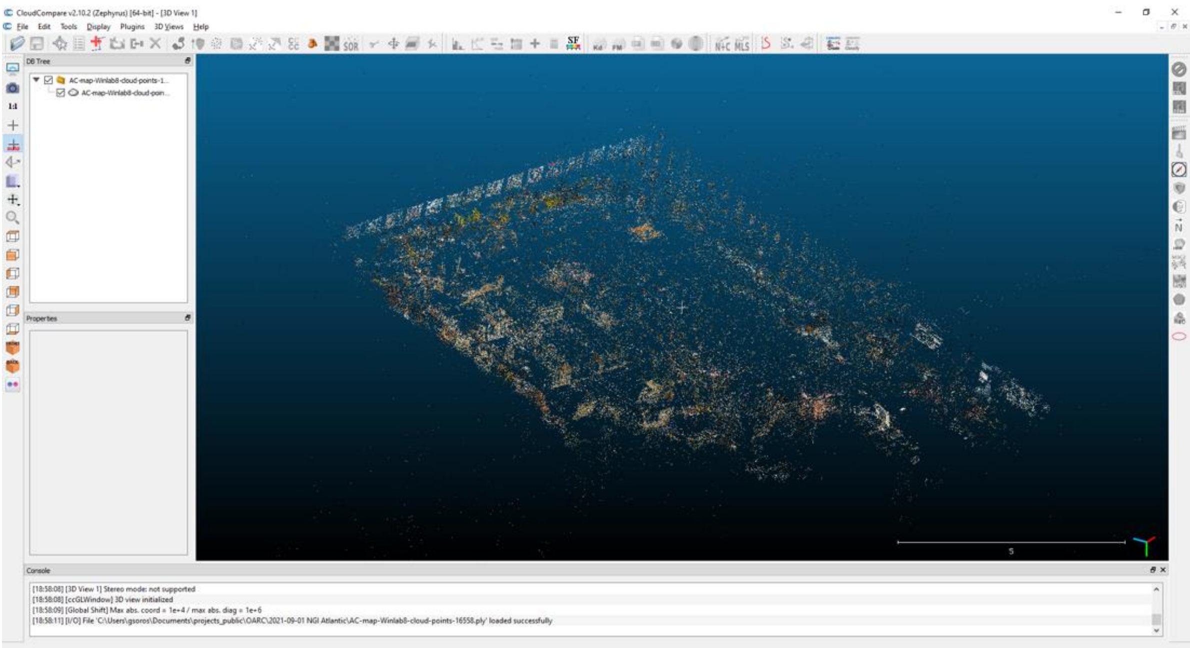

Figure 04: the exported localization point cloud visualized in CloudCompare, where distance measurements can be performed.

Figure 05: The point cloud map of the intersection of Amsterdam Ave and 120th street in Manhattan, created by the proprietary tools of Augmented City

Visual positioning service by George Mason University

Under the lead of Bo Han, the team at George Mason University (GMU) is developing an open-source visual positioning service (VPS). A spatial map consists of sparse 3D points (i.e., a point cloud) with visual feature descriptors, to store explicit geometric information and semantic knowledge of the surrounding environment in volumetric views. Widely used methods for spatial mapping include structure from motion (SfM) and visual SLAM (simultaneous localization and mapping), which processes images that capture the physical world. During localization, a mobile device extracts its camera image and uploads them to a server that matches them with the 3D features in the spatial map to estimate the device's 6DoF pose. This method is referred to as image-based localization. In order to protect user privacy, the device can also extract 2D features from the camera image for uploading, instead of directly sending the image.

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The GMU team is building the backend service of a VPS by leveraging existing open-source packages for structure from motion and hierarchical visual localization, including Colmap (https://github.com/colmap/colmap) and Hierarchical Localization (HLOC) (https://github.com/cvg/Hierarchical-Localization). The team has built the mapping and localization service's back-end service by leveraging Colmap.

The team created a Python wrapper for common functionality of the above tools and exposed them as a RESTFUL API on the Web (https://github.com/wunan96nj/3d-mapping-localization-GPS). Through this REST API, images can be supplied for reconstruction and other images can be supplied for localization. This RESTFUL API exposes the functions of the backend service on the Web. Its functions include uploading an image to the server under a user's specified workspace, building a 3D map with Colmap the server, and uploading an image to the server to localize the image under a specified workspace. The server also leverages the GPS provided with the uploaded images for reconstruction, scaling the reconstructed model to the actual size, and registering the map's origin to a GPS position. While for localization, once the server gets the pose of the query image in the map coordinate, it sends the pose and the GPS of the map's origin back to the client. The team has enhanced the RESTFUL API implementation to follow the GeoPose protocol defined by OARC. An intermediate API runs on the same server to process the incoming GoePose requests, calculates the GPS and quaternion in ENU coordinate based on the pose sent back from our service, and then sends the Geopose response to the client following the GeoPose Protocol.

The next step is to accelerate the localization performance with hierarchical localization (https://github.com/cvg/Hierarchical-Localization, https://github.com/naver/kapture-localization).

Image collection application for mapping

Visual positioning services like Augmented City or Immersal usually provide proprietary image collection applications to aid the mapping. These mobile apps are closed source and their capture formats are usually also closed. To support openness and interoperability, we created a new image collection Android app in this project. Our app stores images and GPS readings in the universal Kapture (https://github.com/naver/kapture/) format, which is widely used in academic research on visual positioning. Our capture app is built on top of an existing open-source camera application OpenCamera (https://opencamera.org.uk/), which provides full manual control over all camera parameters and comes with a user-friendly panorama capture interface, which we refurbished for our purpose. The app shows level lines and a compass on the screen and shows hints for directions where to look next (these features existed in the original version). Our app can export a Kapture dataset, which can be directly injected into 3D reconstruction software like Colmap, and is directly compatible with the mapping pipeline of our partner GMU. The source code is available at AndroidOpenCameraKapture (https://github.com/nokia/AndroidOpenCameraKapture), and screenshots are shown below.

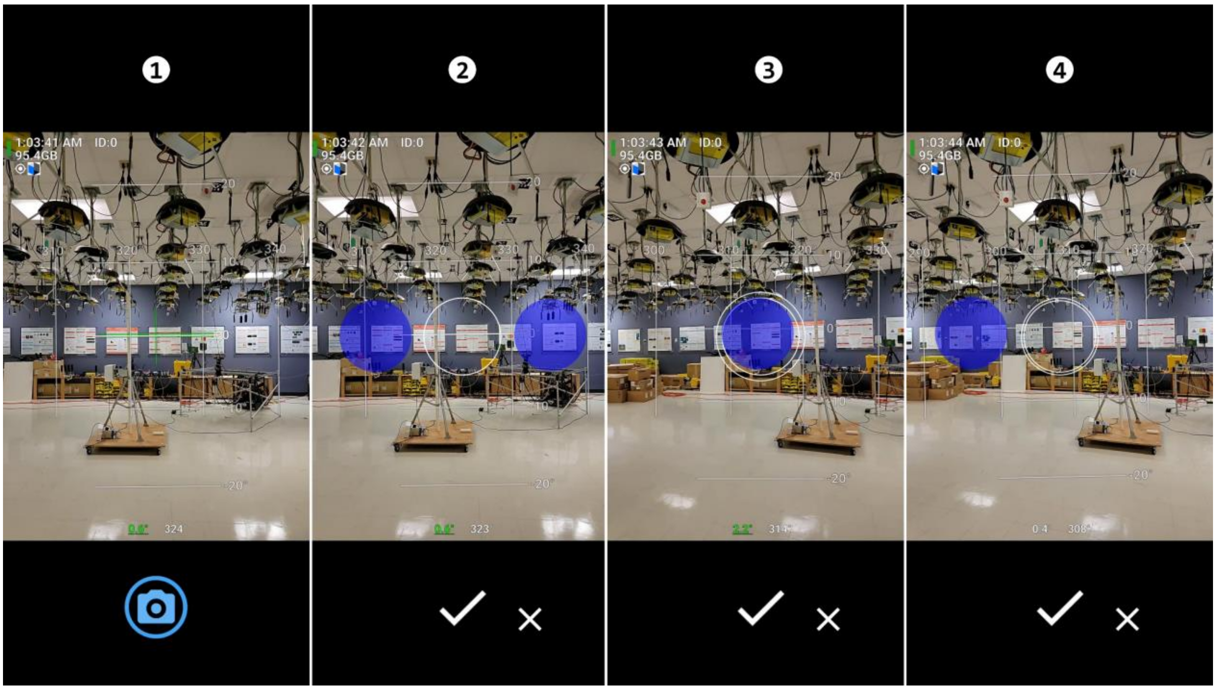

Figure 06: Screenshots of our Android image collector app built on OpenCamera. The user interface shows the compass direction, level lines, and hints about the next best view to capture. When the user rotates the device to align over the next blue spot, the next image is automatically captured. The images (along with GPS coordinates and other metadata) are stored in the universal Capture format.

Digital twin as 3D reference for experience design

The EU team did not have physical access to the place in the US where the experiments were carried out. Creating a digital twin of the lab enabled us to get accurate measurements of the location and remotely place content in the digital twin that then will be mirrored and displayed in AR view for local users. With the support of the team members at Rutgers University, we took around 500 images of a large laboratory space and 3D Interactive created a mesh and generated a dense point cloud reconstruction out of it. From the dense point cloud, we created a low-polygon mesh that could be used for example for occlusion handling in AR, but also for machine learning, navigation, and visualization purposes.

The polygon mesh approximation of the remote location allowed us to design the AR experiences in Unity. It served as a guiding grid for positioning different 3D models in a scene in Unity. The core idea is to anchor the entire scene in the Unity clients as a test. This process makes it easier for the user to add one anchor point, preferably in a corner or via a beam or something easily recognizable. By aligning the anchor in the real world with the anchor in Unity, we can geo-reference the digital twin with the real counterpart.

The steps of the digital twinning process are illustrated on the figure below. Approximately 500 photos were taken with a DSLR camera. The time to capture was about 1.5hr and the photos took 3.2 GB. Next, we generated a point cloud with Agisoft Metashape. The processing time on an 18-core machine took about ~1.5hr and resulted in 56 million points of about ~10 GB. With the same tool, we generated a mesh with 11 million triangles. The processing time on the same machine took about ~1hr, and the mesh is about 300 MB. Finally, with about 1 hr manual work, we created a highly optimised, low-polygon model which represents the 3D space with only 460 triangles (50 KB).

This room model along with 3D annotation are packed into a Unity Asset bundle which is ready to be used in AR applications. However, as it is not possible to ship every possible experience with the app, the location-specific asset bundles need to be downloaded on demand. As a next step, we investigated custom solutions for storing these assets.

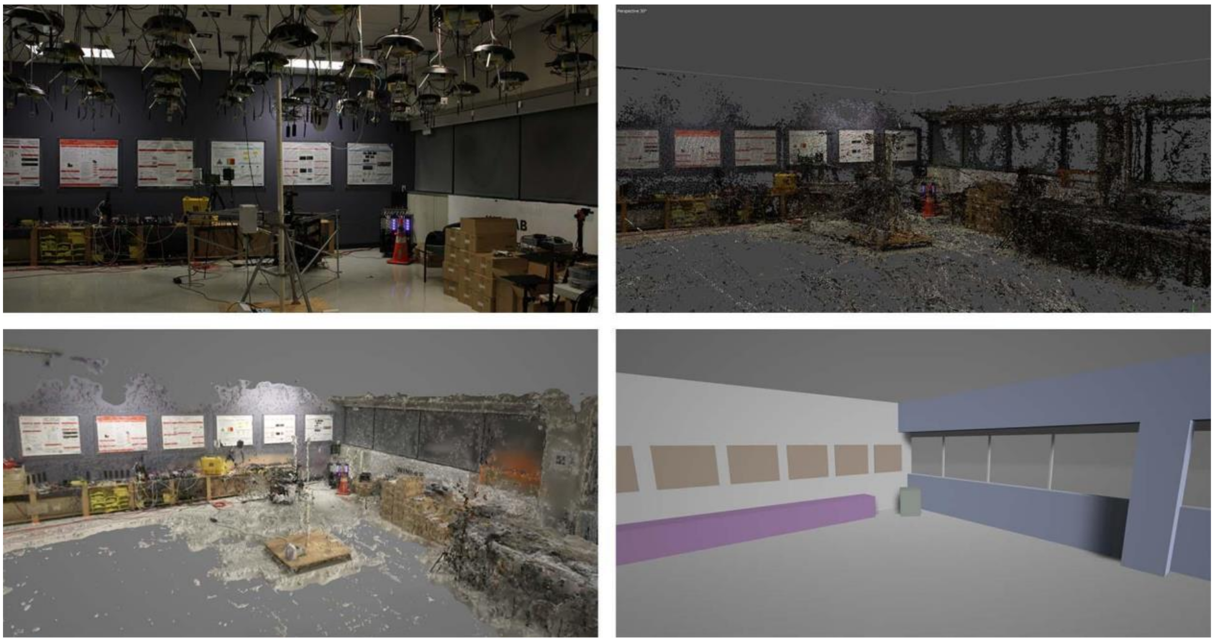

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Figure 07: top left: Image acquisition; top right: Point Cloud generation; Bottom left: Mesh generation; Bottom right: Low poly mesh

File storage service for digital contents

Note that the OSCP content discovery service only stores URLs to user-defined content. Our intention is that everyone can set up their own storage and populate it with their own content, which can be referenced from the spatial content discovery.

In order not to be dependent on any existing proprietary file storage solution, we created an own solution from open-source components within the frames of this project. Any organization or entity can host their own file storage for complete control over the content that will be served to the users. The approach we have implemented means content can be stored across a distributed network of File storage providers with no vendor lock-in.

The backend of the file storage uses the Amazon S3 services to host the files. Additionally, we're using the Amazon Cognito service to authenticate users through single sign on (SSO). The frontend of the file storage can be hosted on any standard Web server, and the code is made publicly available through Github (see https://github.com/3diab/simplecloudstorage, *Tutorial How to deploy the storage service: https://github.com/3diab/simplecloudstorage/blob/master/README.md*

will be merged to OpenArCloud soon). We deployed an instance in the COSMOS testbed.

We adopted a standard and interoperable file format, glTF developed by Khronos for all 3D content. GLTF (or its binary form GLB) allowed us to natively use and display the same file across platforms such as the desktop, web, iOS and android. This file format is often referred to as the *"JPEG of 3D".*

We also introduced a new content type in OSCP, namely asset bundles. An AssetBundle is an archive that contains platform-specific compiled assets, some of the types that are supported are 3D models, textures, audio and scripts. The scripts in asset bundles allowed us for example to store properties and MQTT topic names along with a model, and dynamically generate floating AR widgets in our demonstrator. There are, however, some limitations with AssetBundles: every asset bundle needs to be built for each supported platform. They are only able to use code that was compiled with the application. As soon as code needs to be changed inside a used class, the main application needs to be updated with the new code and new asset bundles need to be built and uploaded to function correctly. The rationale behind this is to prevent any malicious scripts in asset bundles.

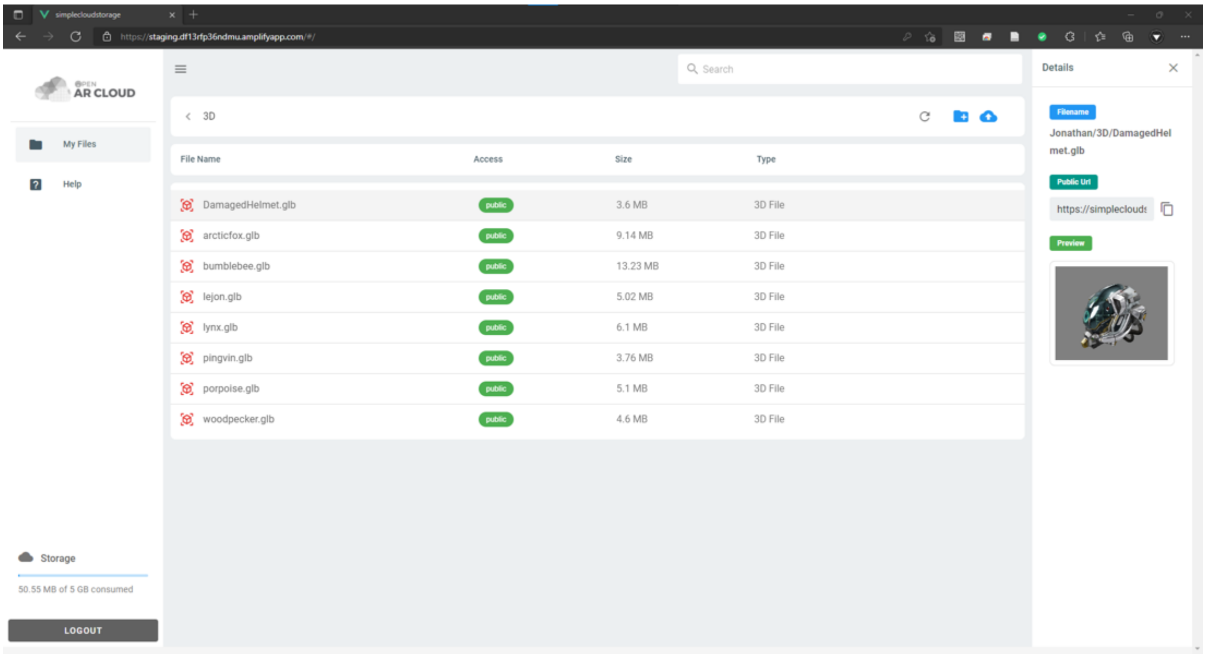

Figure 08: Web-based user interface of our newly created, self-hosted file storage solution with embedded 3D model viewer

The graphical user interface of the file storage allows users to upload 3D content that later can be accessed in the app to be placed at any location in the AR app with a simple click. This includes the creation of a new spatial content record that references the object in the file storage, and uploading the record to the SCD. A preview window showing the file selected to be used within the client has been added for selection of 3D models/Assets GLB files has been added to improve the user experience in this process. The files are managed and stored within a folder structure for easier management and organization of the contents. A JSON file can list all the files in a directory accordingly. The JSON file with the list of files within the user's library could be simply retrieved and displayed in the mobile application (we left the implementation for future work).

At the content discovery phase, the device queries the SCD for available content records in the user's vicinity, and the corresponding 3D assets that the user can interact with are automatically downloaded into our AR application.

The team is currently also investigating the possibility of integrating a geo-distributed data store. OSCP compatibility with such a service would allow distributing the storage layer of the digital services, supporting multi-cloud and on-premise deployments. For example, Garage (https://garagehq.deuxfleurs.fr/) is such a distributed datastore which is compatible with the S3 API and funded via the NGI open calls.

User authentication and signup

It is important that we can associate each piece of content with whoever created it (at least via an email address) to avoid spamming and to be able to trace back inappropriate contents on the platform.

A username/password-based authentication service on Auth0 (https://auth0.com/) has been configured for OSCP's SSD and SCD services independently (their intended user groups are different). We also extended the authentication options via Google or Facebook so that tutorial participants can be easily added in the future without the need to manually maintain a user database on Auth0. Unfortunately, the Amazon-Auth0 integration does not work out of the box so we could not yet integrate it, but it would be beneficial as it enabled seamless login to our file storage and to content records in SCD. We also tried Apple-Auth0 integration, but it was not supported by our version of the Auth0 client library. Querying contents requires no authentication, but creating objects requires at least an email address. Our SSD, SCD, oscp-admin already provided an Auth0 login screen, now we added a login screen to the new Unity app too. Due to limitations of the C# (Unity) Auth0 library, we redirect the user from the application to a Web browser to perform the login there and return the access token to the Unity app. First-time users can register very easily by just one click thanks to the integration of Google and Facebook OAuth into the Auth0 server (assuming they are already logged into Google or Facebook in their Web browser). The users who are not registered in the manually maintained database but log in with email instead, all get assigned to the "public" user which means they can edit each other's contents. We believe this approach is a good fit for workshops or university classes when a large number of new users would need to be added for only a short time of usage.

Separate from the rest of the OSCP, we created an authentication service for our exemplary content storage service, based on Amazon Cognito. Because the storage uses Amazon S3 AWS service, Cognito was the easiest integration for Authentication. Access to the Cognito service is available both in our file storage service as a JavaScript library and also in the Unity app as a C# library. It is also possible to add Auth0 as an identity provider, doing so removes the need for two logins. We plan to implement this in the future. A login screen with signup options allows users to sign up via email. The maximum uploadable file size per user was set to 500 MB, but this is upgradeable if needed.

Unity reference client

The main contribution of this project is a new, Unity-based reference client application for the OSCP which allows users to not only consume but also to create persistent 3D content in augmented reality. The code of the Unity app is developed in https://github.com/3diab/oscp-unity-client but will be merged to OpenArCloud soon.

Branding and user interface design

While developing the technical aspects of our project, we have in parallel developed and created the visual identity for our apps which will be gradually integrated into the project and will be an essential role for the communication process (see Section 6).

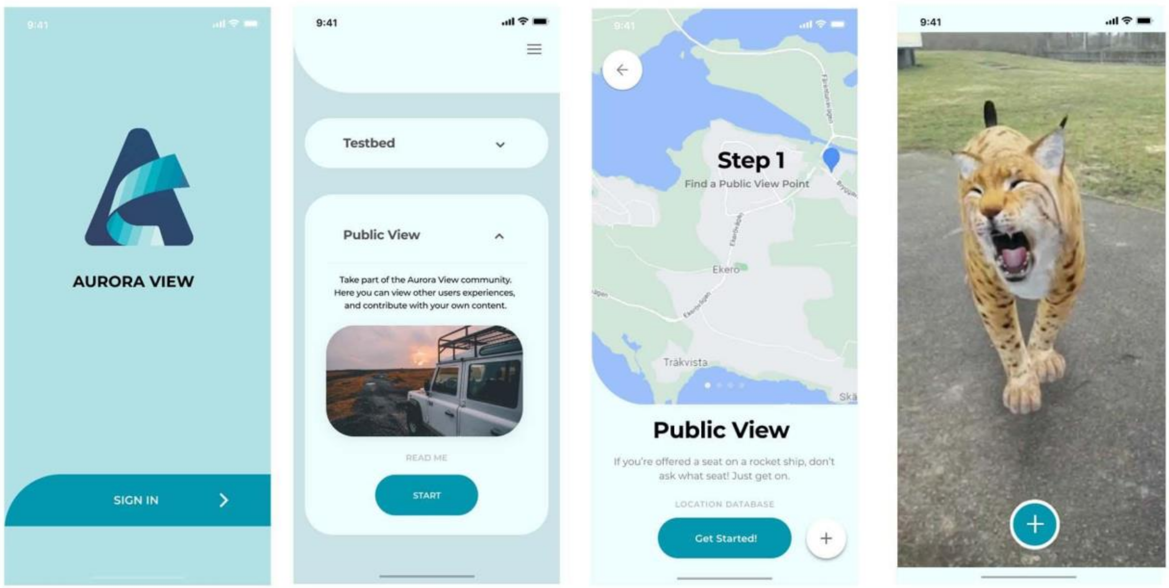

Figure 09: Our new UI (mockup) of placing geo-posed 3D content in augmented reality. After login, the user is displayed with a map on where to find 3D experiences or content that is persistent and anchored to a real-world location.

Authentication

We integrated the Auth0 authentication service into our client app. Some of the tested authentications inside Unity were AWS Cognito, OKTA and Google Firebase Auth. After testing and trying them out, we decided to not use them , so the application would be more open. Using the Authorization Code Flow with Proof Key for Code Exchange (PKCE) in Auth0, this is the recommended way for native applications to connect to Auth0 and other similar services. This enables a developer to use any authentication service that supports the PKCE flow just by changing the respective URLs and links inside the application.

Service discovery

At start, the app automatically connects to the Spatial Service Discovery and retrieves the available services at the current location. The application reads the user’s location based on a coarse GPS measurement, but to avoid sharing the exact GPS coordinates with the platform, we employ Uber’s hierarchical hexagonal spatial index, a coarser location information in all queries to OSCP. We integrated an existing C# re-implementation of the H3 library into our Unity app.

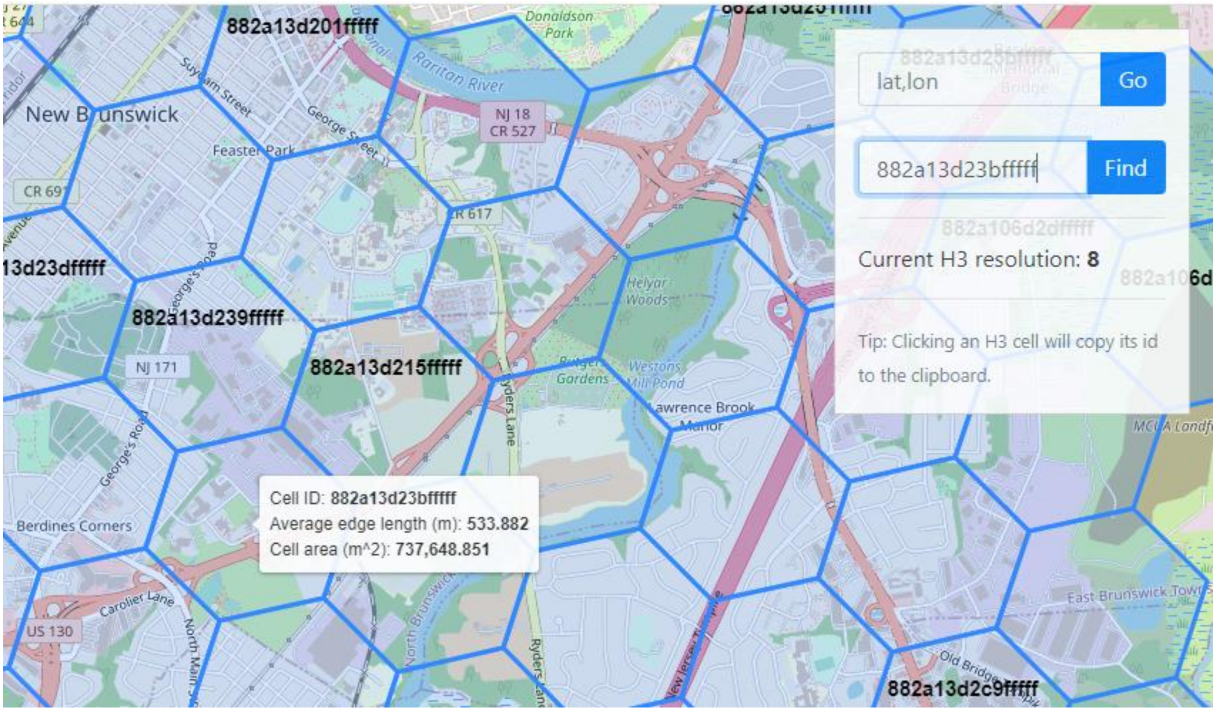

Figure 10: Visualization of the H3 hexagons (level 8) around the Rutgers WINLAB. The radio laboratory is located in the highlighted cell 882a113d23bfffff

Localization and content query

An image from the camera sensor is sent to the VPS server that aligns the current view of the user's smartphone with the world and sends back the current GeoPose of the device.

Depending on what content providers are available for the area (and in the future potentially also filtered based on the user's own preferences), the 3D contents are then downloaded into the App with each corresponding GeoPose for each 3D asset. The 3D assets are loaded in and placed in the world and can be revisited at any time.

Content creation

To create and place new content, the user can simply point the camera towards a location on the ground, and press the plus sign to browse and add 3D content from the file storage.

We have also implemented a very simple model editor in Unity which allows moving and rotating an object, and updates the spatial content records accordingly. This model editor is functional but not yet fully integrated with the rest of the system

WebXR reference client improvements

We have extended our existing OSCP reference client Web application with the capability to show textured models, and with the capability to query contents periodically instead of only at startup. Furthermore, we expose much more information (log messages) to the user about the inner workings of the system for teaching purposes. The code of the WebXR app is developed in, https://github.com/nokia/sparcl but will be merged to OpenArCloud soon.

While the WebXR client is primarily for content consumption, our new Unity client offers the content creation capabilities. We describe our interoperability test in the next section.

5. Monitoring and Data Collection

The main result of this project is several thousands of lines of new code in the form of the new Unity client, a new image capture application, the Authentication feature, the content creation feature, and several minor improvements to the existing components. In this section, we report our end-to-end tests we performed at the Rutgers WINLAB with all OSCP components running in the COSMOS testbed. We performed the end-user tests with a Samsung S21 smartphone connected to the lab's wireless network.

Experiment 1: Content creation and rediscovery with another client

We tested not only the functional readiness of the new Unity client but also the interoperability between different clients. The first screenshot below shows the opening screen (after login) of the Unity client. It lists all discovered services at the current location. The coarse location is determined by the client via GPS , but it is converted to a much coarser H3 index and only the H3 index is shared with the OSCP. The SSD (spatial service discovery) returned 3 available services: AugmentedCity for localization, and AugmentedCity and OrbitSCD for content discovery. The user selected AC for localization and OrbitSCD (spatial content discovery) for contents. Next, when the user pressed the “Localize” button, a photo was captured and uploaded to the AC VPS which returned the GeoPose of the user. With this GeoPose, after conversion to H3, the client app queried the available contents from OrbitSCD. The space already contained 3 models: a duck, a humanoid robot, and a sculpture consisting of a set of colorful ellipses. The user then pressed the Plus sign, indicating that a new object should be created. The client app offers four different models. This list is currently fixed, but it could be dynamically generated based on what is available in the user’s file storage. The user selects the fox model and after filling in the optional title and description, the model gets added to the scene, and the corresponding spatial content record (SCR) is written into the OrbitSCD.

Starting the Unity app on a different phone, another user can discover 4 pieces of content including the newly created fox, which all appear at the same locations as on the first client.

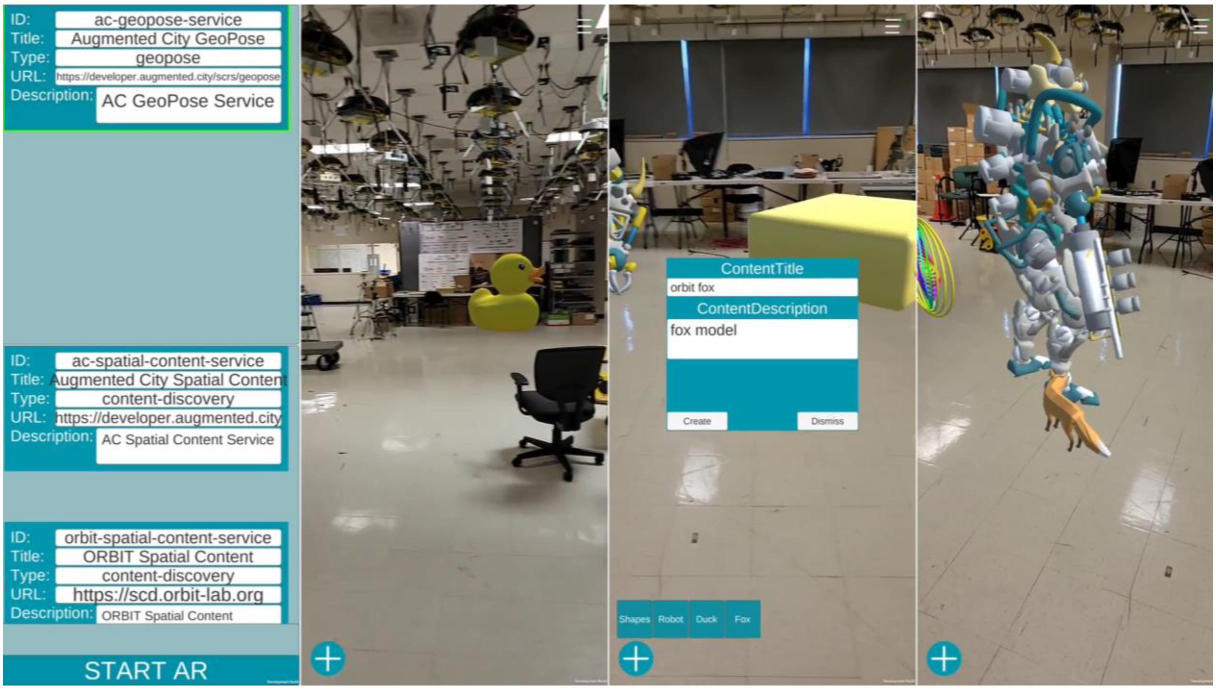

Figure 11: AuroraViewer (Unity client) in WINLAB, discovering services, discovering the existing contents, and creating a new fox.

To verify that the SCR was indeed added to the database in an interoperable manner, another user started the WebXR-based OSCP client (it runs in Android Chrome 92+). The opening dashboard shows similar information to what was seen in the Unity client: the H3 index of the device's location, the country code, and the available services. The user localized with the AC VPS and 4 content entries were automatically retrieved. The new fox appeared next to the robot model where it should be.

While the locations of the objects are correct, their orientations are not yet consistent between the creator session and the viewing session. The reason for this is that we currently write the identity orientation ([0,0,0,1] quaternion) into the spatial content record. In the future, we plan to implement user clicks on the floor to select the new object's position and our simple model editor to adjust the new object's orientation during the creator session.

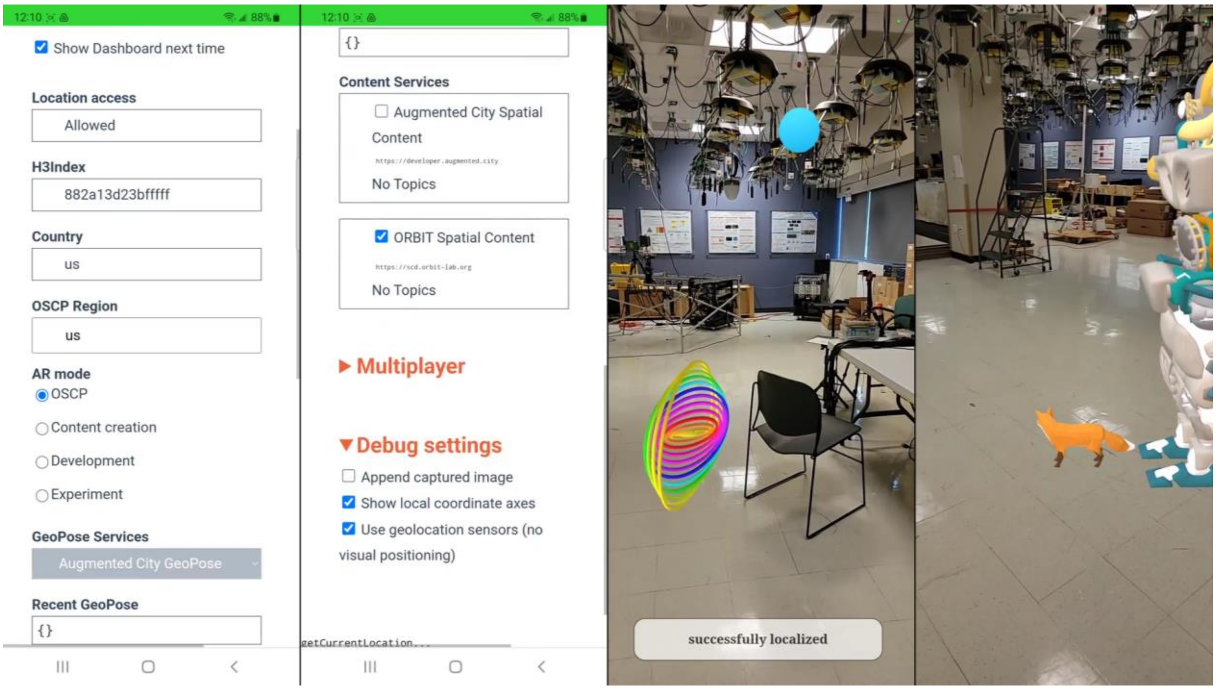

Figure 12: Sparcl (WebXR client) in the WINLAB, discovering the available service, discovering the existing contents, and discovering the newly created fox.

Experiment 2: Live IoT sensor stream visualization

In this project, we implemented live sensor stream visualization in augmented reality. In particular, we implemented a new content type in OSCP that links to a Unity AssetBundle, which may contain not only 3D models but also scripts and other metadata that allow for customization and dynamic generation of content. We used such an asset bundle to describe an MQTT pipe and to generate AR widgets on the fly that can connect to an MQTT topic, retrieve sensor values, and show them as floating bubbles above a physical object.

This use case requires real-time streaming of radio frequency data from software defined radios to AR applications. We implemented a floating display of received signal strength as a proof of concept, which demonstrates the utility of AR visualization for viewing and interpreting real-time RF experiment data. Our sample experiment consisted of one transmitter and four receiver nodes in the ORBIT wireless testbed.

In the experiment, the strength of the transmitter signal was varied over time by a controller running on the experimenter's computer, and the signal was received on four antennas in a spatial grid. The strength seen on each antenna was streamed to a publicly available MQTT broker. The records in the MQTT broker were then accessed by the Aurora Unity application

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and used to update the values in the AR overlay displayed next to the rack holding the antennas.

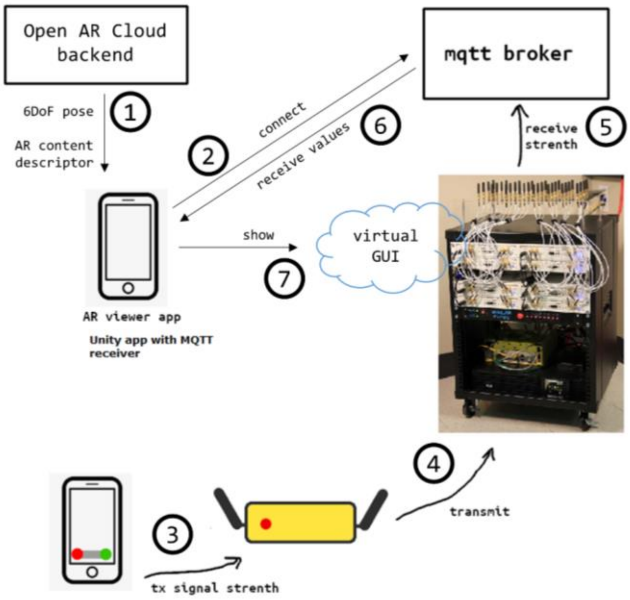

Figure 13: overview of the interaction flow in our live IoT data visualization scenario

Note that by simply changing the MQTT topic names in the asset bundle and switching the radio to any other MQTT source (such as https://play.google.com/store/apps/details?id=com.lapetov.mqtt), one could implement a whole line of compelling demonstrators.

We note here that we planned another collaborative drawing application in which multiple users can draw scribbles in the air in 3D by waving their client devices. This use case, in particular, requires real-time sharing of users' poses and interactions with each other, which would be shared between all participants via MQTT. However, due to time constraints we were not able to finish this application.

Experiment 3: Reconstruction from Kapture dataset

While the new visual positioning system of GMU is not finalized and therefore not fully integrated with our system, we performed partial reconstruction tests. In particular, we tested whether our new image and metadata collector app simplifies the map creation process. Indeed, we found that the output of our new Android kapture app can be directly used as input to GMU's mapping pipeline.

The SfM (Structure from motion) pipeline first extracts features from the images taken by the image collector, and then performs 2D feature matching among the images to get corresponding features from overlapped images. Finally, SfM triangulates the 2D matches to calculate the 3D coordinates of the features and pose of the images. The figure below shows the 3D reconstruction of the laboratory with the reconstruction tool Colmap, using our kapture dataset as input.

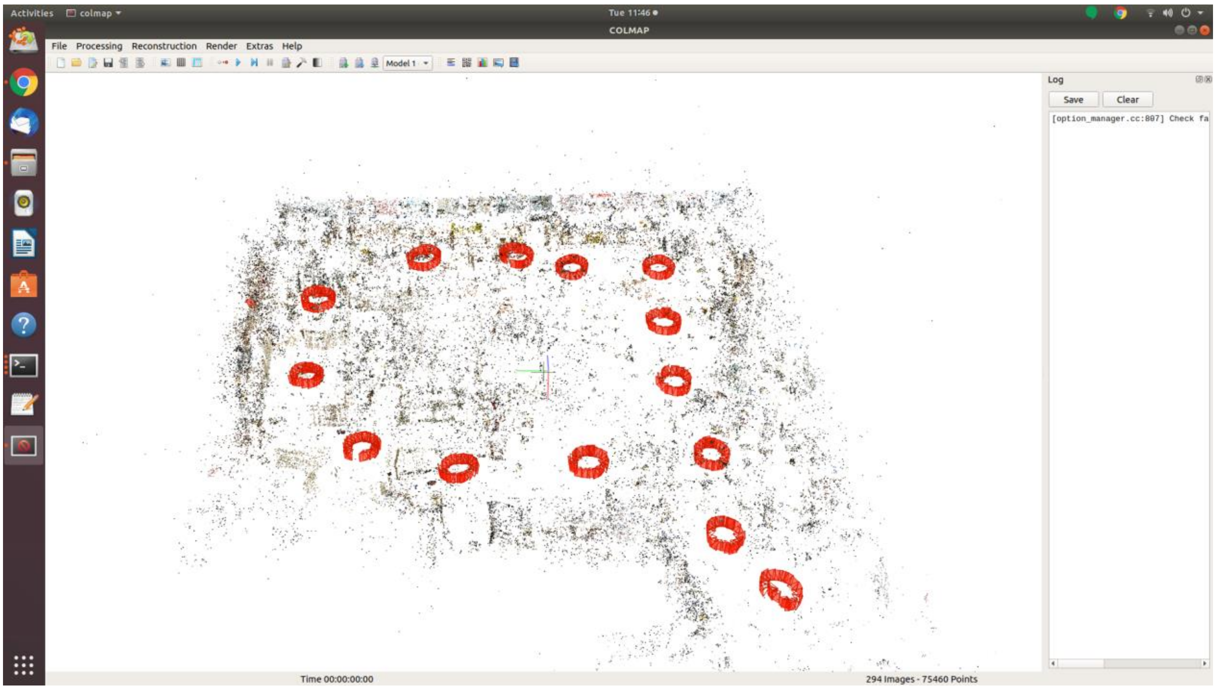

Figure 14: 3D reconstruction of the laboratory with open-source reconstruction tools, using as input the kapture dataset we collected with our app. The colored dots are the feature points of the room, and the red rectangles represent the individual images (captured in panorama circles).

Discussion and Analysis on Results

The goals of this project have slightly changed since the original application in February 2021 , but we have successfully presented end-to-end AR content creation, discovery, and consumption at the US partner with all components running in the COSMOS testbed.
Our initial goal setting was to conduct traffic measurements , but we realised that we need to make it significantly easier for users to create content in our system. We therefore shifted the focus of this project from traffic measurements to creating a new reference client that supports easy content creation and editing. We also implemented user authentication throughout the system. Furthermore, we created a new application that simplifies image

capture for map creation, and we started to integrate a new, open source visual positioning system (under development at project partner GMU) to aid developers with the freedom of choice. We conducted successful tests that validate the usability of our client application and the interoperability provided by the platform. We have shown content placement with our new Unity app, which was successfully discovered by our WebXR client. We have also shown live IoT data injected into floating AR widgets. We delivered detailed tutorial descriptions on how to deploy and how to use the components of our system, because we found this to be essential to facilitate adoption.

Due to the platform's heavy focus on user interaction, we realised that it would be difficult to record meaningful KPI measurements without a more representative set of reference applications. Thus, the focus of the project shifted toward development work on reference implementations such as Aurora and Sparcl. The overall system implementation and the two mobile phone applications were tested with a number of wireless access technologies (WiFi, 4G, and 5G with both research (in the COSMOS testbed) and commercial networks and no noticeable differences in the response times were observed (for a single user case). Unfortunately, due to time constraints and the re-focus on development of additional software components, the full performance measurement campaign had to be left as future work. The project team is considering performing at least some of those measurements even after the formal end of the project, as well as part of the (planned) future proposals. Additionally, the deployment of OCSP components in the COSMOS testbed will allow students and other testbed users to perform these measurements as part of their research into use cases of (5G) edge cloud environments. Some of this work is planned to take place this summer as a project in the summer internship program at Rutgers/WINLAB.

A comparison between originally proposed KPIs and achieved KPIs is shown in the table below.

#	Description	Target | Achievement
KPI-1	**Installation and configuration of all OSCP components on US testbed for use by the research team on the COSMOS network on the COSMOS network**	**Measuring mechanism: Confirm use by at least 10 concurrent AR devices connected to the OSCP and interacting with the services to produce AR experiences with user acceptance | The system is fully functional in COSMOS , but we tested with only 2 devices. We have upgraded and deployed the oscp-admin graphical user interface for user-friendly content management.**

KPI-2	**Heterogeneous urban environment of campus scale captured in 3D for testing with AR experiences and ready for development of future vision based localization services**	**Measuring mechanism: Successful return of GeoPose readings at multiple positions. | We mapped 2 US and 3 EU locations (1 outdoor and 4 indoor) with AC tools and verified the localization capability. We delivered a new image collector app, and we partially integrated an open-source VPS.**
KPI-3	**Measurement of AR over wireless network within expected performance parameters**	**Measuring mechanism: measurement of round-trip time, test device handover between zones while in motion, test simultaneous sensor streams, test maximum number of simultaneous localization requests | We have not performed traffic measurements but instead evaluated the end-to-end functionality and interoperability. We have decided to focus on creating compelling client app features for content authoring instead of the zone switching feature.**
KPI-4	**Two AR applications implemented on top of the Open Spatial Computing Platform**	**Measuring mechanism: AR applications using OSCP-services tested by students, faculty and visitors at Rutgers and at Columbia University campuses (in the captured zones). Visual and interactive components appear on user's AR display, comparison of Unity-based and Web-based AR experiences, user questionnaires | We have delivered a new OSCP reference client in Unity and implemented 2 use cases including content creation and MQTT stream visualization. We have done user tests but no questionnaire.**
KPI-5	**Discovery and filtering of AR assets for experiences using Spatial Content Discovery**	**Measuring mechanism: Logging data on server and client, measurements of device reception of personalized and location-relevant content for AR experiences under different loads. (Optional:prevention/prohibition of unauthorized access to personal/private data and/or personal/private map) | We have implemented authentication and authorization with Auth0, we have implemented content hosting and content**

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		creation in AR, we have verified location-based and user-specific content discovery with both reference clients.
KPI-6	**Release of project results in reports and publications**	**Measuring mechanism: report, videos, blog posts and other documentation of the project results tutorial for students and the research community (Optional:publication at conference or in journal) | We have delivered detailed tutorials on how to install and how to use the components of the system. We created a website showcasing our results. We will give workshops for students and aim for a publication in the near future.**

6. Present and Foreseen TRL

Aurora Viewer is in a TRL level 4, we've been testing the developed software in a lab environment throughout NGI through significant new code development in order of a more advanced demo product. We are aiming towards TRL 5 by testing it in real-life scenarios

Github links:
https://github.com/nokia/sparcl
https://github.com/3diab/oscp-unity-client
https://github.com/3diab/simplecloudstorage

7. Exploitation, Dissemination and Communication Status

Branding design

We have been focusing on designing and developing a project brand and visual identity (name, color-code, fonts, logo, icons) in order to reach out and start the external communication. The work made here is essential to drag interest and provides the needed cohesiveness for the communication, which needs to relate to the project and the delivered product.

Final logo:

A dummy of App with integrated project brand identity can be found at: https://xd.adobe.com/view/06b81ad3-f394-48ae-a5ac-97c031a057fa-53eb/

In addition to the documentation, we've set up a corresponding project website https://www.auroraviewer.org/ which we officially launch on international World Creativity and Innovation Day on April 21, 2022, webinar we've sent out press releases to tech and XR journalists, and it would be great to get promoted by NGI. In parallel, we are preparing collaborative blog posts with our US partners.
Until then each week we share a bit more about the project including, Tutorials, demos, to inspire the XR community and research community.

Tutorials, workshops, talks

We have created several tutorials on deploying the platform and using the client applications. The following documents are attached to this final report:

- OSCP deployment guide including SSD, SCD, oscp-admin, Sparcl (WebXR client)
- File service deployment and user guide
- Aurora Viewer (Unity client) user guide
- WebXR client user guide

Gabor Soros delivered a talk about this project on 12.01.2022 at a COSMOS 5G/Edge Testbed and COSM-IC International Interconnect Project meeting. Gabor will give a guest lecture at George Mason University for graduate students on 22.04.2022.

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Ivan Seskar delivered an overview of the project at the NSF COSMOS Project review meeting on 23.03.2022.

We will be submitting a short research paper (4-6 pages) to EuroXR 2022 Conference, which is due April 25th,2022, and will be presented during the EuroXR event in September in Stuttgart, Germany. Based on that research paper, we plan to resubmit another research paper to IEEE ISMAR 2022.

Additionally, the work will be presented within a presentation during the upcoming Augmented World Expo 2022 in Santa Clara which takes place from 1st-3rd of June 2022.

We will also host a summer workshop with Rutgers University during their summer intern programme. We are also planning something in the near future together with Bo Hans department and their student we have received interest from other universities too.

Target stakeholders	Purpose of dissemi natio n	Main channels of dissemination	Tools of dissemination
Researchers, Academia, Students Developers, Content creators / XR Spatial Computing Community NGI Stakeholder and Partners	Promote NGI Atlantic project advancement s (groundbreak ing project milestones through project mascot which builds engagement and breaks engagement barriers	Short snipet, live demo, recording published	e-Articles Blog Post, Newsletter, YouTube
		NGI Session to share outcome and advances with NGI Partners and Stakeholder	Video Session / Tutorial Video Material
		Social media Video material led by project mascot	Twitter / LinkedIn / YouTube session
Consumer Associations Civil			You-Tube, Hubs,

society organizations Creative Community *(media audiences, Creative local community / local research community, Students)*	Recruiting in engagement life demo / Testing local engagement	Virtual Session lifestreaming	
		NGI Atlantic Project Website	Newsfeed, e-newsletters
		Social media	Twitter
		Promote local engagement life testing connect with local community	Oral presentations in Science Communication and Researcher's Night
Innovation and Tech journalists / Media / NGI Stakeholders and Partners	Raise awareness and promotion of NGI Atlantic Project outcome	Press releases	e-Articles
		Downloadable material / Documentation GitHub Repository	
		NGI Atlantic Project Website	Newsfeed, e-newsletters
		Social media	Twitter, LinkedIn

8. Impacts

This is a consolidated and self-contained discussion of the achieved impacts of the project, in relation to the overall impacts of the NGI initiative and for **the entire duration of the project**, namely:

The primary goal of the project was to deploy and test the OSCP platform in a 5G edge cloud. Our experiments relate to the NGIatlantic.eu discovery and identification topic, methods to enhance personalized information retrieval and improve quality of experience through continuous contextual search using spatial discovery services of the OSCP.

The new Unity-based reference client application for the OSCP allows users to not only consume, but also to create persistent 3D content in augmented reality. This allows content creators and creatives to build up on our decentralized interoperable infrastructure.

During this project, we have also discovered some deficiencies in the original OSCP design, for example regarding discrete H3 cells that prevent continuous location-based fetching of content and make queries ambiguous at the border of two cells. We will address this problem in a follow-up project.

Impact 1: Enhanced EU – US cooperation in development of Next Generation Internet applications, including policy alignment and cooperation.

The costs for the GMU team will be covered by Dr. Chen's existing award from the U.S National Science Foundation (NSF) with award number 2007153, Dr. Han's start up funds, and other internal seed funds available from George Mason University and the state of Virginia.

George Mason University NSF Funded Project tied to NGI: Collaborative Research: CNS Core: Small: From Capture to Consumption: System Challenges in Pervasive 360-Degree Video Sharing.

Rutgers University NSF Funded Project tied to NGI: COSMOS - Next Generation Edge Testbed is a campus-wide platform designed to simplify the deployment of new and emerging edge technologies, while preserving the stability of the campus network. All Rutgers/ COSMOS team work on this project will be funded under the National Science Foundation PAWR COSMOS project (CNS-1827923). This project started on April 1, 2018 and will run for 4 years with $6.5M of total funding to date.

Impact 2: Reinforced collaboration and increased synergies between the Next Generation Internet and the Tomorrow's Internet programmes.

The OARC Europe has released the following NGI-related software components:

- 1. Spatial Service Discovery (SSD),
- 2. Spatial Content Discovery (SCD),
- 3. client libraries,
- 4. AR applications and experiences and

· 5. SDKs using open protocols for Positioning service Spatial Service Discovery (SSD) and Spatial Content Discovery (SCD) Reality Modeling Services Rutgers University

Impact 3: Developing interoperable solutions and joint demonstrators, contributions to standards.

Interoperability by default is at the core of our project approach; anyone who will use our solution doesn't have to install anything, as we're building upon the WebXR native browser solution. Everything we'll be working on within the scope of this research project will be provided to society and the community as open source.

Additionally, we have encountered a problem in Unity for the 3D files. We want one file to show on both iOS and Android devices and the spARcl. We needed a way to find an interoperable file format that works across all platforms. GLB is the file format of our choosing, as it works both for the web and the model view API. Additionally, it is supported equally on iOS and Android devices. (Include example of GLB.)

WebXR Our Web Client spARcl is built upon the WebXR standard, which gives us the advantage to be device and system agnostic and is interoperable due to its Browser-based nature, which means it works on most current devices.

The universal GeoPose Standard which is currently being developed within OGC a standard for geographically-anchored pose (GeoPose) is implemented throughout the whole project.
https://github.com/opengeospatial/GeoPose

This standard will also be integrated to the Open-Source Visual Positioning service that George Mason University is building

Impact 4: An EU - US ecosystem of top researchers, hi-tech start-ups / SMEs and Internet-related communities collaborating on the evolution of the Internet

During the development of support for dynamic generation of content, the Rutgers team identified a huge potential for use of the Aurora application for visualising the state of the testbed. The proof-of-concept experiment deployed in the COSMOS testbed demonstrated the viability and utility of AR-assisted diagnostic tools in a wireless testbed environment, and the OSCP infrastructure deployed in the testbed will allow for the rapid development of additional AR applications to be used for monitoring of testbed equipment and aggregated visualisation of testbed status information from various sources. The modularity and open-source nature of the OSCP, along with the availability of reference applications means that the testbed engineering team will be able to create and use these AR monitoring applications without needing expertise in AR programming.

This ease of application development will also be available to other experimenters using the COSMOS testbed: they will be able to develop applications using the OSCP to visualise live results from experiments. This is particularly useful in the context of wireless communications, where visualisation of complex measurements with many variables can be crucial to interpreting results of an experiment. The OSCP additionally provides a useful real-world example application for researchers focusing on the development of 5G edge cloud technologies. One such use case is a planned collaborative mural project based on OSCP which will allow artists around the world to work together in augmented reality to create a mural on a shared AR canvas and simultaneously deploy it in various locations around the world. This project is planned in collaboration with a number of cities on both sides of the Atlantic, and is expected to show the potential value of AR for creativity and cooperation, especially among users who don't have a technical background. The collaborative canvas will also provide an exciting technical challenge for edge-cloud and networking researchers who will be able to take advantage of the spatial information provided by OSCP to enable low latency collaboration.

We also anticipate that the reference applications and OSCP components deployed in the testbed will be a friendly starting point for students wanting to learn more about augmented reality. The fact that users will be able to create applications to run on commodity hardware, without any specialised equipment or expensive closed-source software makes this an excellent platform for educators wanting to design a curriculum around augmented reality.

When working on the Aurora project, the GMU team identified a few research challenges of vision-based positioning systems. One of them is the privacy of the constructed spatial maps and visual features extracted from localization images that may contain sensitive information about users' surrounding environment. For instance, once attackers or malicious users get access to the visual data, they can reconstruct the original images/ scenes with good quality (i.e., a high degree of accuracy). Thus, there will be security attacks when AR/MR applications get more popular and are used in life-critical situations (e.g., on a battlefield or in a surgical operating room). Moreover, an adversary can even modify the spatial maps and/or the uploaded features (e.g., man-in-the-middle attacks) and make the localization result significantly deviate from the ground truth. The above issues call for robust mechanisms to shield countless malicious attacks and protect user privacy. Thus, the GMU team is designing principled approaches to simultaneously preserve privacy and defend against security attacks for spatial mapping and localization in Cloud AR. The team also includes three undergraduate students who are supported by the additional NSF Research Experiences for Undergraduates (REU) funding that has been provided for this project.

The privacy concerns surrounding proprietary AR cloud solutions is of outstanding concern and this project aims to provide a publicly accessible and open source alternative of all required components, based on the Open Spatial Computing Platform (OSCP). This will allow citizens, organisations and companies to implement their own solutions that can perform the necessary steps for creating persistent AR experiences. Giving back the ownership and privacy of data to governments, companies and citizens to help to build out the next era of an open and transparent immersive Internet, often referred to as the Metaverse.

This project demonstrates that all the building blocks and infrastructure for creating persistent augmented reality experiences can be realized in a way accessible to everyone. The team hopes to inspire others to continue on this work and even further improve on the open-source code and resources that we have provided.

We are planning to continue our collaboration both with Rutgers University and George Mason University even after this project. There are some tasks left from the original plans (while other features have been implemented instead), and the development process also triggered several new research ideas. We have also received high interest from other universities who are willing to deploy and test our system, seeing components being implemented by partners of Open AR Cloud Europe and its mother organization Open AR Cloud Association. Open AR Cloud Europe will also A diverse consortium of 22 partners from Academia, organisations, and Industry, including Open Ireland and COSMOS, (University of South-Eastern Norway (USN), Fraunhofer Gesellschaft IAO (FhG-IAO), University of Stuttgart (USTUTT), Fontys University of Applied Sciences (Fontys), Karlsruhe Institute of Technology (KIT), Aalborg University (AaU), Delft University of Technology (TUDelft), XR Safety Initiative Europe (XRSI), 3D Interactive STHLM AB (3DI), Open AR Cloud Europe (OARC EU), CommonSpace (CS), XR4Europe (XR4E), Norwegian Computing Centre (NR)
The provost, fellows, foundation scholars & the other members of the board of the college of the holy & undivided Trinity of Queen Elizabeth near Dublin (TCD), Institute for Energy Technology (IFE), Innotrope SAS (Innotrope), Kongsberg Municipality (Kongsberg), Municipality of Halandri, Città di Pinerolo (Pinerolo), Kirchheim municipality (Kirchheim), Dublin city council (DCC) and Rutgers University (RUTGERS) submitted a Horizon Europe proposal on April 5th, 2022. The “CITIzen PARTicipation in European Municipality Affairs

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through the human-cantered and ethical use of XR technology" (CITIPART) project aims to utilize XR technologies for a societal application: the better involvement of citizens in their municipality's affairs. This project will therefore address two points in the HORIZON-CL4-2022-HUMAN-01-14 calls: "devising innovative digital interfaces that take advantage of spatial computing to allow users to interact with real-time contextual information activated by intuitive sensory triggers" and "developing novel multi-user virtual communication and collaboration solutions that provide coherent multisensory experiences and optimally convey relevant social cues."

The CITIPART project will design, develop, and demonstrate an XR environment that will allow citizens to interact with real-time contextual information activated by intuitive sensory triggers in their home municipality while tuning according to their preferences and abilities using commercially available personal devices. Examples of such applications include the possibility for citizens to visualize on their smartphone's digital augmentation of representations of building projects through filming physical spaces and the developed XR environment to provide their feedback or even co-design.
This proposal builds upon the building block of our recently funded XR4Human Horizon Europe proposal and is directly linked to the NGI I project as it builds up. In addition to the documentation, we've set up a corresponding project
website https://www.auroraviewer.org/
which we officially launch on international World Creativity and Innovation Day on April 21, 2022,
webinar we've sent out press releases to tech and XR journalists, and it would be great to get promoted by NGI.
In parallel, we are preparing collaborative blog posts with our US partners.

9. Conclusion and Future Work

The innovative elements introduced in this project will
include the seamless detection of spatial context and (through the use of the GeoPose standard) automatically provide the user the best 3D map and most relevant content as the user change's locations along a trajectory in a target rich environment including buildings and open spaces the project may further study aspects
of identity, privacy and personal data protection. Efficient and continuous 3D world capture, mapping and query technologies may, due to their invasive nature, introduce risks to private and public institutions and rights of users and entities. Control over sensitive/private data, privacy and security in a diverse range of contexts such as personal, on campus, in public, on-premises, in restricted facilities and under emergency settings are high on the OARC's roadmap for further developments.

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The 5G testbed will gain a service that enables mobile camera localization and real-time location aware content discovery on top of the existing platforms. The OSCP also serves as the spatial context layer for location- based and personalized information retrieval in smart environments. These features can enable further sensing research and (in case of public testbeds) may also serve as an incentive service for a large number of users to join gamified experiments on the testbed.

As the backbone of location-based applications for students and campus visitors, the deployed platform can further serve (even after the project is finished) as a learning and test environment. We envision location- anchored and community- created digital media content, interactive visual navigation, restaurant discovery, lecture discovery, ride-hailing, etc. application to name only a few

Outlook

(basically all the tests we wanted to conduct): The experiments to be conducted on the COSMOS implementation of the OSCP include:
Measurement

1. of performance of Spatial Service Discovery, Spatial Content Discovery and GeoPose service on sub-6GHz and mmWave 5G research network under different load Conditions

2. Comparison of OARC member Immersal and Augmented City SDKs for reality capture and
their support for interoperability through the OSCP platform components

3. Simulate and block attempts by unauthorized users to access private/personal data and/or maps

4. Testing ability to configure the OSCP platform components to publish and share geospatially anchored experiences with groups of authorized users

5. Evaluate, and if possible, quantify, the accuracy of OSCP- compliant visual localization
services under a range of conditions (indoor, outdoor, day, night)

10. References

Open AR Cloud https://www.openarcloud.org/, https://github.com/OpenArCloud

COSMOS 5G testbed https://www.cosmos-lab.org/

[Kapture] https://github.com/naver/kapture/
[OpenCamera] https://sourceforge.net/p/opencamera/code/ci/master/tree/
[AndroidOpenCameraKapture] (https://github.com/nokia/AndroidOpenCameraKapture)
[Colmap] https://github.com/colmap/colmap
[HLOC] https://github.com/cvg/Hierarchical-Localization

11. Glossary

5G	**Fifth Generation (mobile/cellular networks)**
NGI	**Next Generation Internet**
R&D	**Research and Development**
SDN	**Software Defined Networks**
VNF	**Virtual Network Function**
WIT	**Waterford Institute of Technology (Coordinating Partner)**
OSCP	**Open Spatial Computing Platform**

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Deliverable 3: Part II

Financial and cost information

This part is to be treated as a consortium confidential deliverable, and access is restricted to consortium partners and EU commission operatives.

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1 Workplan Progress and Travel Details 8.000 Euro

The person months provided here are estimates. The work hours are tracked in separate time sheets.

WP 1, Deployment	Start month	December	Duration	3 months	Total PM	0.20
Title	**Open Call 03-295** **Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment**					
Partners involved			Person months			
Partner 1	*Gábor Sörös*		0.20			
Partner 2						
Partner 3						
Partner 4						
Partner 5						
Partner 6						
Goal: ***deployment of all OSCP components in COSMOS testbed***						

Activities Description ***adaptations of existing OSCP components to be deployable at locations other than the default one*** ***service for user authentication*** ***deployment in COSMOS testbed***

WP 2, Client App	Start month	December	Duration	3 months	Total PM	6,1
Title	Open Call 03-295 **Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment**					
Partners involved			Person months			
Partner 1	*John Nilsson*		2			
Partner 2	*Jonathan Tiedtke*		1			
Partner 3	*Pär Linde*		1			
Partner 4	*Karthik S Kumar*		1			

Partner 5	*Mikael Spuhl*	1
Partner 6	*Gabor Soros*	0.1

Goal:

The task is to develop a Mobile application (Unity client) that works with the OSCP components

Activities Description

- ***Authentication to OSCP***
- ***Creation of a file storage solution with following sub tasks: Frontend, Backend, UI, Database, Authentication, 3D Viewer, API end points***
- ***Brand profile including logo design***
- ***Research***
- ***Loading and parsing external files***

WP 3, Mapping and Localization	Start month	December	Duration	3 months	Total PM	0.15

Title	**Open Call 03-295** **Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment**	
Partners involved		**Person months**
Partner 1	***Gábor Sörös***	**0.1**
Partner 2	***Jonathan Tiedtke***	**0.05**
Partner 3		
Partner 4		
Partner 5		
Partner 6		

Goal:

mapping the experiment locations

Activities Description

mapping the experiment area with existing proprietary tools

creating a simplified digital twin

open source application for image capture in an interoperable format for 3D reconstruction research

integrating new, open-source visual positioning system created by project partner GMU

WP 4, Experiences(Use Cases)	Start month	December	Duration	3 months	Total PM	3
Title	**Open Call 03-295** **Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment**					
Partners involved			Person months			

Partner 1	*Jonathan Tiedtke*	1
Partner 2	*Pär Linde*	1
Partner 3	*John Nilsson*	1
Partner 4		
Partner 5		
Partner 6		

Goal:

Designing and implementing use case 1 and use case 2

Activities Description

1. ***design and implement use case 1: indoor sensor steam visualization***
2. ***design and implement use case 2: outdoor mulituser art experience***

WP 5, Experiments and Data analysis	**Start month**	**December**	**Duration**	**0.25 months**	**Total PM**	**0.25**
Title						
Partners involved				**Person months**		
Partner 1						
Partner 2						
Partner 3						
Partner 4						
Partner 5						
Partner 6						
Goal: *User testing and Analysis from Data of experiments compiled by Open AR Cloud Europe and COSMOS (US Partner only)*						

Activities Description ***1. Use case tests:*** ***a) placing and discovering object*** ***b) sensor streams*** ***c) multi-user art use case*** ***The user will walk, using a planned route holding AR display device while also recording the screen (second COSMOS team member may be needed to hold separate camera/device to capture video) (user switching zones). AR experiences will be delivered to two or more user devices connected to the same OSCP services (multiuser)*** ***2. GMU: evaluation of positioning accuracy*** ***GMU evaluate hardware requirements and tradeoffs of Open-Source Visual Positioning*** ***Data from experiments compiled by Open AR Cloud Europe and COSMOS*** ***Open AR Cloud Europe and COSMOS will repeat experiments and data analysis until complete***

WP 6, Documentatio n	Start month	December	Duration	3 months	Total PM	0.4
Title						
Partners involved				Person months		

Partner 1	***Gábor Sörös***	**0.2**
Partner 2	***Alina Kadlubsky***	**0.2**
Partner 3	***Christine Perey***	**0.1**
Partner 4	***Jonathan Tiedtke***	**0.1**
Partner 5		
Partner 6		

Goal:

Preparation of results for reports and publications

Activities Description

project reports

tutorials

prepare publication of research as conference paper or technical report

WP 7, Communication and Dissemination	Start month	December	Duration	3 months	Total PM	0,15
Title						
Partners involved			Person months			
Partner 1	*Alina Kadlubsky*		0.1			
Partner 2	*Gabor Soros*		0.05			
Partner 3						
Partner 4						
Partner 5						
Partner 6						
Goal: ***Publish and promote final Project with Research and XR Community***						

Activities Description

Branding and Visual Identiy of project

Production and creation of tutorials for local users, students and research community

prepare Press Release material that can be shared with Tech Media and XR Community

Video capture and editing of Material

creation of Slide deck for webinar NGI event and COSMOS event

Blog Postl

WP8, Project Coordination	Start month	December	Duration	3 months	Total PM	0,15
Title	Open Call 03-295 Deployment and Evaluation of a 5G Open Spatial Computing Platform in a Dense Urban Environment					

Partners involved		Person months
Partner 1	*Alina Kadlubsky*	0,15

Goal:

Provide a continues update, internal communication, collaboration and make sure the tasks are done.

Primarily making sure that the project reaches its project goals.

Make sure there is a continues exchange and feedback between tasks and jobs as well as providing an outlet to discuss and find solution for potential problems that could emerge during the project development cycle

Activities Description

Providing Documentational draft work for the Developers and Engineers.

Scheduling weekly group update sync and taking care of Meeting recording and minutes

Taking care of Contract and legal work.

Provide ongoing communication with NGI

2 Funds Utilisation Report

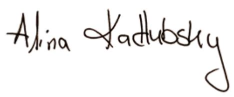
Cost Title	Amount	Description
Personnel cost(s)	**1.500€**	**WP 1 / Task number: Expert 1 (0,2 person months @ 1PM = €7.600**
	46.400€	**WP 2 / Task number: Expert 6 (6,1 person months @ 1PM = €7.600)**
	1.100€	**WP 3 / Task number: Expert 2 (0,15 person months @ 1PM = €7.600)**
		WP 4 / Task number: Expert 3 (3 person months @ 1PM = €7.600)
	22.800€	**WP 6/ Task number: Expert 2 (0,15 person months @ 1PM = €7.600)**
		WP 7 / Task number: Expert 1 (0,15 person months @ 1PM = €7.600)
	1.100€	**Continue for all personnel in project**
		integrating former 8.000€ travel costs
	1.100€	
	8.000€	
Other Direct Costs – Travel	**0.00€**	**Due to the ongoing Pandemic, the**

only		team will not be travelling as most of the events have been pushed to the Summer of 2022. (We've integrated the 8.000€ into the Personal costs)
Total Direct Costs	82.000€	(the former travelling costs have been added)
Indirect Costs	0	
Total Costs	82.000€	
Received Amount	83.000€	(the former travelling costs have been added to the total amount
Remaining Amount	1.000€	

On behalf of Open AR Cloud Europe gUG, I, Alina Kadlubsky confirm that this funds utilisation report is in accordance with the contract already in place between Open AR Cloud Europe gUG and Waterford Institute of Technology under financial support to third parties from Article 15 of Grant Agreement number 871582 — NGIatlantic.eu. I confirm that this report also includes all the expenditures (limited to PM and travel) incurred by all EU partners in this project and adhere to all instructions contained in H2020 Annotated Model Grant Agreement[1]. These are referenced in section 3 and 5 of the contract. I also confirm that any applicable VAT or tax payments on the amount due to the Grant Recipient shall be fully borne by the Grant Recipient.

Signed for and on behalf of

Open AR Cloud Europe gUG



……………………………………………

Alina Kadlubsky

Managing Director

Complete Address

06.04.2022

[1] http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/amga/h2020-amga_en.pdf

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