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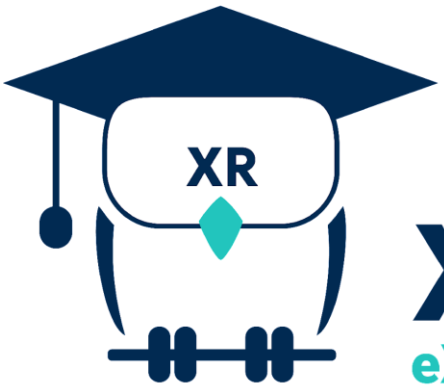

XR4ED
eXtended Reality for EDucation

D4.6
XR4ED platform prototypes

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XR4ED Project Profile

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Partners

CYENS CENTRE OF EXCELLENCE	CYENS	RESEARCH	CYPRUS
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eXtended Reality for EDucation

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List of acronyms

Acronym	Description
XR4ED	Extended Reality for Education
XR	Extended Reality
VR	Virtual Reality
API	Application Programming Interface
DRM/CRM	Digital/Content Rights Management
FSTP	Financial Support to Third Parties
HMD	Head-Mounted Display
UI/UX	User Interface / User Experience
GA	Grant Agreement

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Executive summary

The XR4ED project aims to transform education by providing an extended reality (XR) platform that enables educators, learners and developers to design, share and experience immersive 3D learning environments. Building on the initial platform prototypes reported in D4.3, Deliverable D4.6 documents the updated and consolidated XR4ED platform at a stable stage, focusing on the XR Module (World Builder and Portal Hopper) and its integration with the XR4ED Marketplace and platform backbone.

The XR Module constitutes the core authoring and delivery environment of XR4ED. The World Builder offers an intuitive, feature-rich editor for creating interactive 3D worlds, supporting a wide range of asset types (3D models, images, audio, video, documents and scripts), advanced logic editing, templates, plug-ins and publishing workflows. It has been refined to support different user profiles, from non-technical educators to expert developers, through configurable interfaces, reusable templates and an extensible plug-in architecture. The Portal Hopper complements this by enabling cross-platform exploration of the created environments in first-person, third-person and VR modes, with multi-user capabilities, flexible navigation, avatar support and mechanisms for linking and "hopping" across locations and worlds.

In parallel, the XR4ED Marketplace has evolved from a conceptual offer–demand space into an operational, web-based access point to XR4ED tools, services and content. The final version exposed in this deliverable acts as a one-stop-shop where XR solutions, assets, avatars, templates and services can be discovered, described and accessed through a structured catalogue and Marketspace. It is underpinned by a microservice-based architecture that manages products, files and licences and embeds core governance elements such as authentication, access control, digital rights management and basic transaction flows. This enables the Marketplace to surface XR4ED's own components (including the XR Module, DevOps environment and assets library) alongside solutions and services emerging from open calls and mini-pilots.

Overall, D4.6 provides a consolidated view of the XR4ED platform prototypes at maturity. It demonstrates how the World Builder, Portal Hopper and Marketplace have been implemented, integrated and aligned with the project's technical architecture, user requirements and ecosystem-building activities. By lowering technical barriers, supporting open standards and offering a coherent entry point for XR in education, the updated platform lays the groundwork for continued validation, exploitation and sustainability beyond the project's lifetime.

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Also, the platform has been successfully validated by 10 real-world pilot projects across Europe, which used the XR Module and Marketplace in classroom, vocational and higher education contexts.

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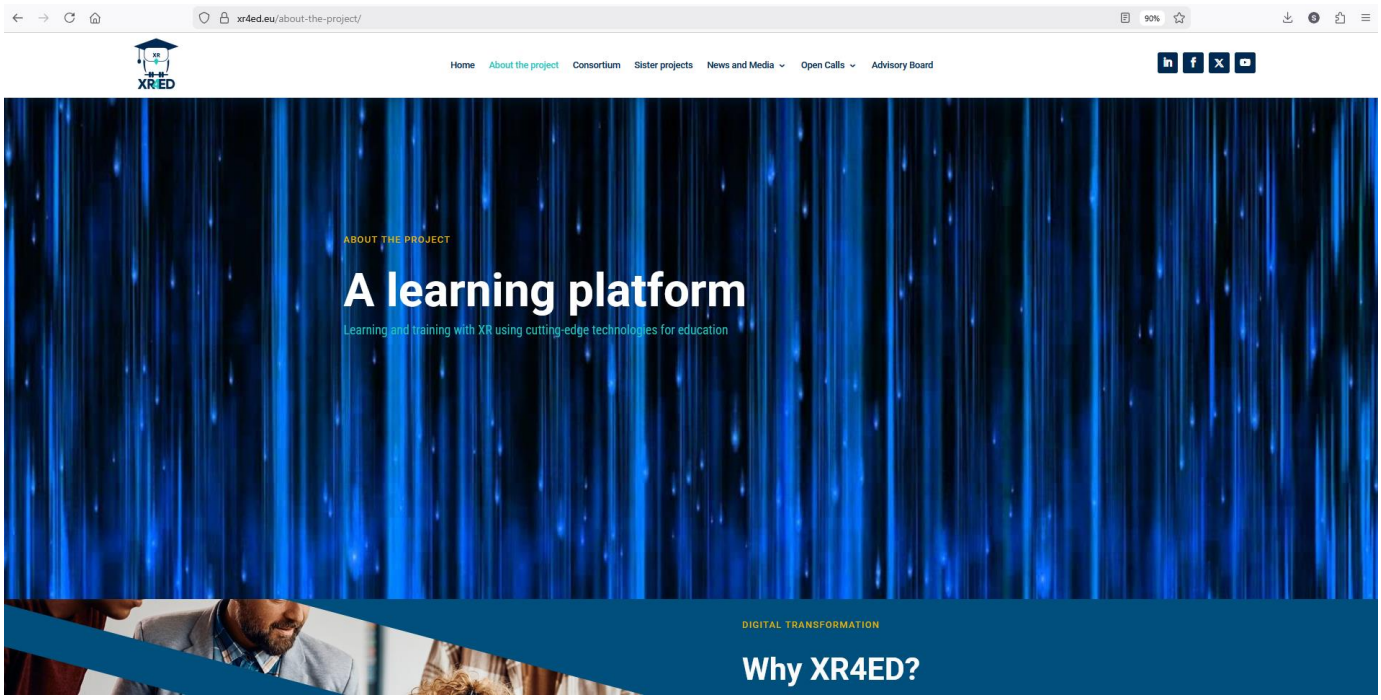
1. Introduction

2.1 Overview

The XR4ED project brings together the European EdTech and educational XR communities to create a common access point to XR content, tools and services for learning, training and education within a trusted European framework. Within this context, WP4 focuses on the development of the XR4ED platform backbone, the authoring tools, the XR glasses components and the associated DevOps environment that enable the delivery and maintenance of XR solutions at scale.

Deliverable D4.3 documented the first set of XR4ED platform prototypes, namely the World Builder, the Portal Hopper and the Marketplace, which together demonstrated how educators and learners can create, manage and experience immersive XR environments for educational purposes. These prototypes provided an initial implementation of the XR Module and the associated services that underpin the XR4ED platform.



This deliverable, D4.6, provides an updated view of those platform prototypes at a later stage of the project. It revisits the World Builder and the Portal Hopper as the core elements of the XR Module and updates their description in line with the current implementation and integration status. It also aligns the

description of the Marketplace, avatars and templates with the Marketplace versions delivered in WP4 and positions these components within the overall platform backbone.

D4.6 is closely related to the other WP4 deliverables. D4.1 describes the XR4ED platform backbone and integration layer, including the architecture and common services that support the XR Module and the Marketplace. D4.2 presents the first version of the XR4ED Marketplace, focusing on its initial architecture, user experience and feature set. D4.3 and D4.4 address the integration and validation of the XR modules. D4.5 then updates the Marketplace to Version 2, documenting its final implementation, role and evolution within the XR4ED ecosystem. D4.6 complements these deliverables by presenting the updated status of the XR4ED platform prototypes so that the XR Module and related components are described consistently with the platform backbone and the Marketplace.

2.2 Structure of the Document

The document is structured as follows:

- **Executive summary:** Provides a concise overview of the purpose, scope and key outcomes of the deliverable, highlighting how the XR4ED platform prototypes have been updated compared with D4.3.
- **Introduction:** Presents the background, objectives and positioning of D4.6 within WP4 and the broader XR4ED deliverable set.
- **XR4ED Main Components:** Describes the main components of the XR4ED platform at this stage of the project, focusing on the XR Module (World Builder and Portal Hopper), the Marketplace, avatars and templates and how they relate to the platform backbone.
- **XR4ED Demos and Features:** Details the available demonstrations and core features of the World Builder, Portal Hopper and Marketplace, illustrating how these components operate in practice and how they support XR4ED use cases.
- **Conclusion:** Summarises the updated status of the XR4ED platform prototypes, their relationship with the rest of the XR4ED architecture and the main implications for subsequent validation, exploitation and sustainability activities.
- **References:** Lists the key project documents and external sources that are relevant for understanding the work reported in this deliverable.

2. XR4ED Main Components

The XR4ED platform is organised around three main components that together support the creation, delivery and circulation of XR experiences for education:

- the XR Module, comprising the World Builder, the Portal Hopper and supporting tools
- the Marketplace, which acts as the central hub for XR solutions, assets and services
- the avatars and templates, which provide reusable personalisation and world-building elements.

These components were first introduced as platform prototypes in D4.3 and are further detailed and updated in this deliverable in line with the current implementation status and with the Marketplace evolution described in D4.2 and D4.5.

3.1 XR Module

The XR Module is a core component of XR4ED that enables users to create, visualize and interact with immersive 3D content for education and related domains. It provides an end-to-end pipeline from authoring to playback, targeting both non-technical educators and advanced developers.

Purpose: A core component of XR4ED, enabling users to create, visualize and interact with immersive 3D content for education and other applications.

Key Features:

- **World Builder:** A user-friendly editor for creating 3D environments, enabling the import of assets (e.g., models, audio, textures) and setting up interactive behaviors.

  The World Builder is a graphical editor used to design interactive 3D environments. Users can import and manage a wide range of assets (for example 3D models, audio, textures and other media), arrange them within locations and configure their properties. It supports typical scene-editing operations such as positioning, rotating and scaling objects, setting lighting and skyboxes and managing project-level settings.

- **Portal Hopper:** A visualization tool that allows users to explore the created environments in VR, 3rd-person, or 1st-person perspectives across multiple platforms.

  The Portal Hopper is the companion application used to explore the 3D environments created in the

World Builder. It enables users to navigate these worlds on different platforms in first-person, third-person and VR modes, including support for keyboard/mouse and VR headsets. In addition to basic movement, it offers interaction with objects in the scene and the ability to move ("hop") between locations and worlds.

- **Interaction Editor:** A tool for defining user interaction rules, goals and sequences within the 3D world.

  The Interaction Editor allows authors to define interaction rules, goals and sequences inside a 3D world. Using a logic-oriented approach, users can specify how objects react to user actions, how signals are passed between components and how more complex behaviours unfold during an experience.

- **Templates and Plug-ins:** Predefined environments like classrooms or labs and extendable functionalities for specialized needs.

  The XR Module includes support for predefined environments, such as typical classroom or laboratory settings, which authors can reuse and adapt. Its plug-in mechanisms make it possible to extend the editor and the runtime with additional functionality, for instance via custom scripts, camera controllers or publishing wizards.

- **Test Environment:** Verifies and tests the functionality and visuals of the created worlds.

  Before publishing, authors can validate the functionality and visual quality of their worlds using integrated testing facilities. Worlds can be exercised in different modes to verify interactions, navigation and performance prior to deployment through the XR4ED ecosystem.

Collectively, these tools implement the XR authoring and playback workflow foreseen in the XR4ED proposal, enabling educators and developers to configure rich XR learning experiences without building all components from scratch.

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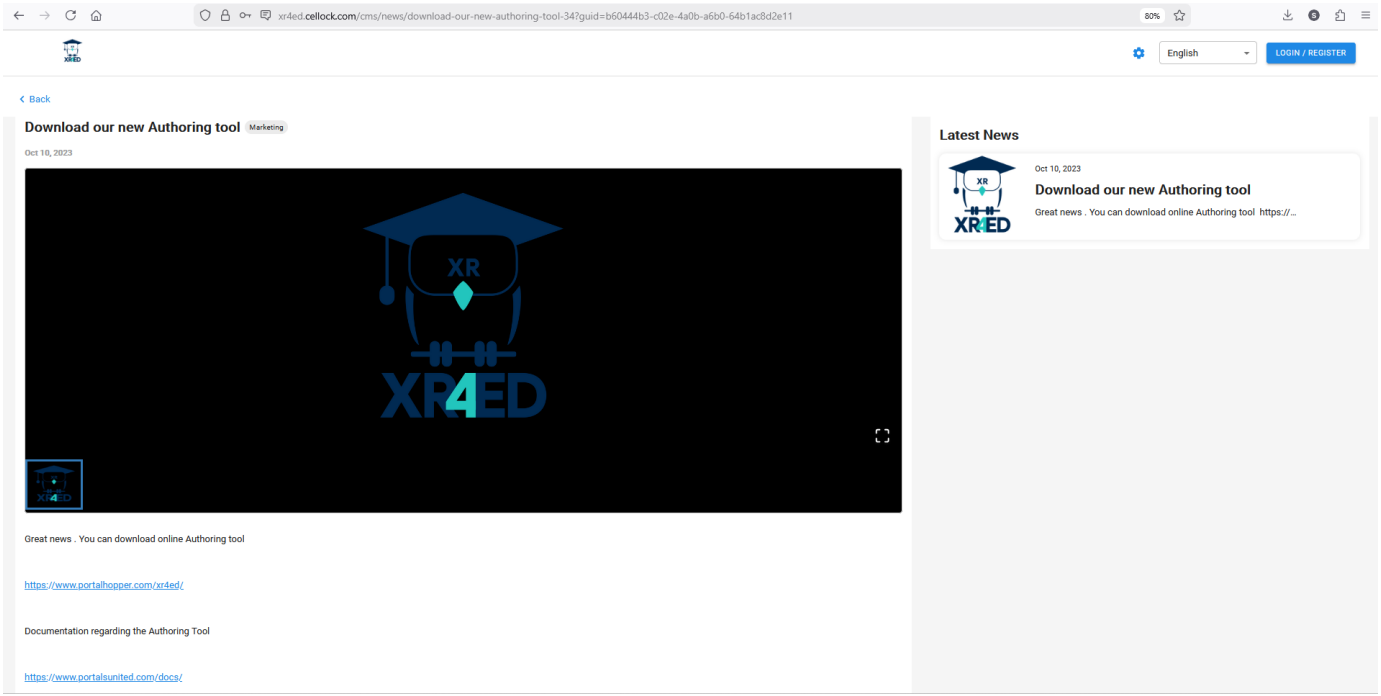
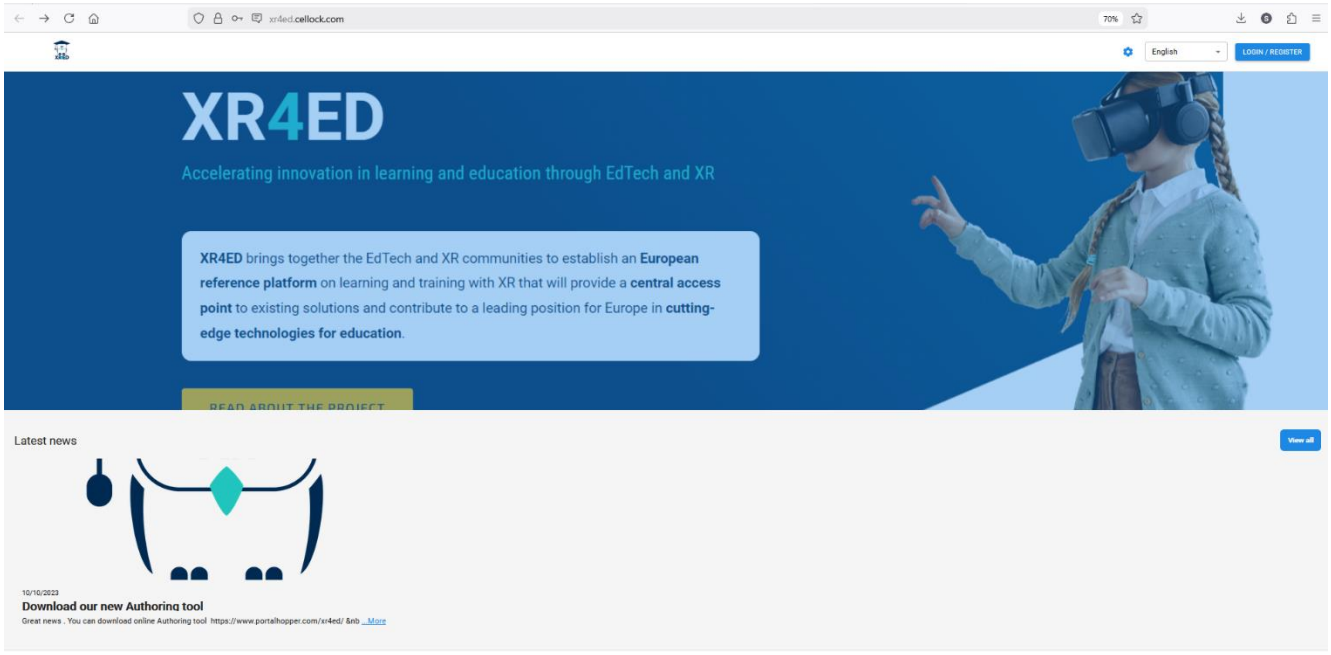


3.2 Marketplace

The XR4ED Marketplace is the central hub for managing and accessing XR content, applications and assets in the project. It acts as a one-stop shop and user-facing portal for XR solutions for learning, training and education, built on top of the XR4ED platform backbone and services.



Purpose: A centralized hub for managing and accessing XR content and assets.

From a conceptual perspective, the Marketplace combines:

- **a curated XR Solutions Catalogue,** where XR applications, content and tools for education are listed with rich metadata and can be discovered by educators and learners; and
- **a Marketspace (offer–demand space),** where stakeholders can advertise or request XR-related services and collaborations, supporting the wider XR4ED ecosystem.

Key Features:

- **Product and content management**

  The Marketplace supports the upload and management of XR-related products and assets, including descriptive information and categorisation. Entries can be organised into meaningful categories, such as 3D models, immersive environments or educational resources and are presented through a web interface.

- **Content discovery and distribution**

  Users can browse XR content including assets, avatars and interactive modules and use search and filtering tools to locate relevant resources quickly. Visual previews support inspection of assets and environments before download or access.

- **Shopping and transactions**

  The Marketplace implements a shopping-cart and checkout flow to streamline acquisition where transactions are applicable. It is designed to work with multiple payment gateways and institutional models, supporting both free and potentially monetised offerings in line with the project's exploitation framework.

- **Digital rights management and licensing**

  Licensing control mechanisms ensure that content is accessed and used under the appropriate agreements. Licence management includes automated generation and tracking of licence keys and their validity, aligning with the governance model presented in D4.5.

- **User accessibility and roles**

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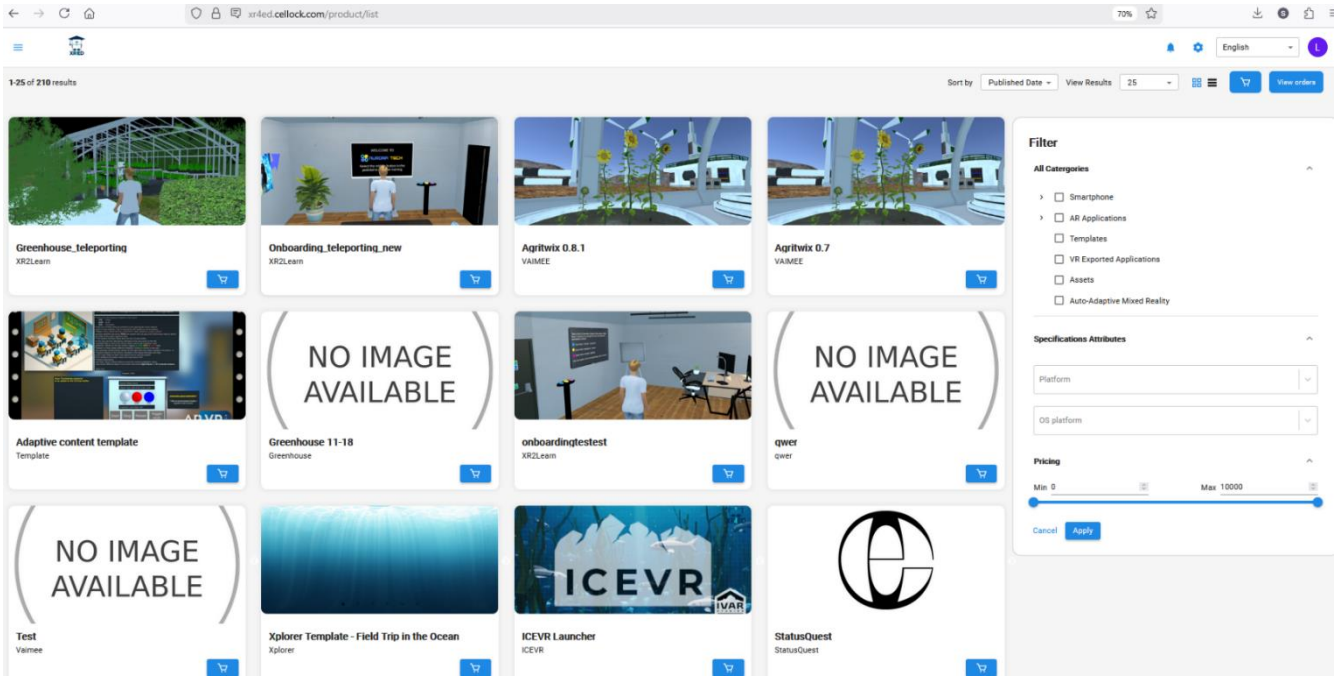
The Marketplace interface is designed for educators, students, developers and other stakeholders to access XR resources easily. It provides intuitive navigation and role-based access, including dedicated areas for content providers and administrators as described in D4.5, while end-users interact primarily with the catalogue and Marketspace views.



Through these features, the Marketplace exposes XR4ED's own components (including the XR Module outputs and associated assets) and, where applicable, third-party XR solutions contributed via open calls and pilots, within a unified catalogue and service space.

Integration of Open-Call Solutions

The final XR4ED Marketplace not only hosts the project's native components but also serves as the dissemination hub for third-party outputs. Notably, the winners of XR4ED's open calls have utilized the Marketplace to deploy and share their XR learning solutions. By design, all funded pilot and developer teams were required to publish their outcomes in the XR4ED Solutions Catalogue (the Marketplace's repository). This means that educators and learners can discover the new XR applications, lessons and assets produced by these external projects directly via the Marketplace. For example, several pilot-developed experiences – virtual field trips, science simulations, training scenarios, etc. – were packaged as reusable modules on the platform. A case in point is SURE–VFT's surveying field trips, which are listed

in the catalogue for any interested university to adopt. On the developer side, the Marketplace now also offers novel components like AI-driven virtual teacher avatars and a mobile 3D-scanning tool contributed by open-call winners, alongside XR4ED's own tools. By exposing these third-party solutions within a unified catalogue, the Marketplace accelerates community uptake and growth of the ecosystem. It validates the one-stop-shop concept: educators can not only find XR4ED's World Builder and Portal Hopper here, but also access a growing library of XR content and plug-ins from external innovators. This open, federated approach to populating the Marketplace has been key to demonstrating scalability and relevance across diverse educational domains."

3.2.1 Platform Validation Through Pilot Implementations

The XR4ED platform and its components have been rigorously validated in real-world educational pilots during the project. Through the open-call programme, ten pilot projects in schools, universities and training centres across Europe deployed XR4ED's World Builder and Portal Hopper in everyday learning scenarios. These implementations provided invaluable feedback and proof-points. In total, the pilot experiences engaged several hundred end-users – including students, teachers and vocational trainees – demonstrating the platform's usability and impact at scale. Critically, outcomes from the pilots indicate enhanced learning effectiveness and engagement. For example, one science pilot reported a ~94% improvement in student test scores after using an XR lesson, while another pilot saw XR training modules receive 8.7/10 average satisfaction ratings from learners. Across the board, educators noted increased motivation and hands-on skills acquisition when using XR4ED in the classroom. These successful trials confirm that the XR4ED ecosystem is technically robust and pedagogically beneficial. By meeting user requirements in diverse contexts – from inclusive music therapy for ASD students to construction safety training – the platform has proven its versatility. The pilots also helped refine features (e.g. interface adjustments from teacher feedback, added templates for common lesson types), ensuring the final prototype addresses real user needs. In conclusion, XR4ED exits its prototyping phase with a strong evidence base: the platform has been battle-tested in authentic educational environments, validating its concept and readying it for wider adoption and sustainable impact beyond the project."

3.3 Avatars and Templates

Avatars:

Avatars provide user representation inside XR4ED virtual worlds and play a key role in collaborative and

immersive scenarios. They:

- enable personalisation and presence in virtual environments
- support interaction and non-verbal communication when multiple users share the same world.

In the current implementation, avatars are rigged 3D models that can be selected within the Portal Hopper. Custom avatars are packaged as Unity asset bundles and can be installed, for example after acquisition via the Marketplace, so that they can be used consistently across different locations and sessions.

Templates:

Templates provide predefined starting points for authoring new worlds. They:

- offer ready-made environments such as classrooms, laboratories or other educational scenes, which can be reused across different projects
- reduce the time and effort required for world creation by allowing authors to adapt and extend an existing structure instead of beginning from an empty scene.

Templates can include complete projects with assets and logic files and can be stored locally or distributed through the Marketplace. Once available, they appear as options when creating new projects in the World Builder, allowing authors to quickly instantiate a suitable base environment and focus on the specific pedagogical content.

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3. XR4ED Demos and Features

3.4 XR4ED World Builder and Portal Hopper

World Builder

The World Builder (WB), also often referred to as the Authoring Tool, is meant to provide users with an easy-to-use solution to create interactive 3D content.

It runs on Windows 10 or 11. The generated content however, can be explored on multiple platforms (see Portal Hopper).

Nomenclature

The WB distinguishes between locations and worlds. Locations are settings which share the same set of assets and are grouped into a project folder. Locations are always uploaded onto the same server/domain. Worlds are independent projects which may be running on different servers across the internet.

An asset is a thing which can be imported and used within the WB. Assets can be audio recordings, 3D models, videos and many more.

General Settings - Menu Selection

The WB can be set depending on the sophistication of the user. He can display or hide the following menus,

- Test
- World Menu
- Location Manager
- Asset Manager
- Location View
- Signals Manager
- Logic Editor

The intent is to hide functionality which might confuse the current user or is beyond the scope of his

role.

General Settings - Shortcuts

Most apps running on Windows have been standardized to have shortcuts such as Ctrl-C for “copy” or Ctrl-S for “save”. The WB has a set of other shortcuts which can be freely assigned by the user.

Asset Management

The WB can import a wide range of asset types,

- 3D Models: GLB, FBX, OBJ, GLTF
- Audio files: MP3,
- Video files: ASF, AVI, DV, M4V, MP4, MOV, MPG, OGV, VP8, WEBM, WMV
- Image files: JPG, PNG, PSD, TIF, BMP, RAW, SVG, WEBP
- Skyboxes: JPG, PNG, HDR
- Image Sequences: JPG, PNG, PSD, TIF, BMP, RAW, SVG, WEBP, GIF, PDF, PPT
- Scripts: C#
- Unity Asset Bundles

Most asset types will be converted during import.

One other asset type is a material. Materials can be attached to an object (statically or dynamically) to change the texture or colour of the object. To create a material, the Material Creator is invoked.

Location Editor

In the location editor, assets can be dragged into a location, where they then will be placed, rotated and scaled according to current needs.

Besides assets, **predefined objects** with an attached functionality can be placed into the location,

- **Button**

  Buttons can be single clicks or toggle (on/off) switches. They can Have custom images or 3D objects attached to them as well as text

- **Trigger Zone**

  These zones are used as areas which start a predefined action such as switching on the hall light when a person enters the zone

- **Snap field**

  Similar to trigger zones, these areas can start an activity. Additionally, they “snap” an object into a predefined position. Such zones are usually visible and can have the shape of the object which is supposed to be placed into that place.

- **Slider**

  Sliders are used to control an analogue value such as brightness or audio volume.

- **Knob**

  Knobs work the same as Sliders, but the value is changed by rotating the object instead of a linear shift.

- **Text Display**

  A Text display is used to present information to the user. It is highly customizable. Besides showing a static message, its content can be updated via scripts or the logic editor as well as display image sequences with automatic page turning.

- **Light**

  Lights are used to illuminate areas of the location. It can be a coloured spot light or a general directional light (such as the sun).

- **Reflection Probes**

  These are rarely used but crucial if shiny reflective materials are used. To achieve a proper reflection, this probe is needed to define the area from which a reflection may be sourced.

- **Empty Object**

  Any location is seen as a hierarchy of objects. Especially in complex scenes, it makes sense to group objects which belong together under one (named) empty object. Thus, a multiple of objects can be affected (moved, rotated) at the same time by selecting their parent object.

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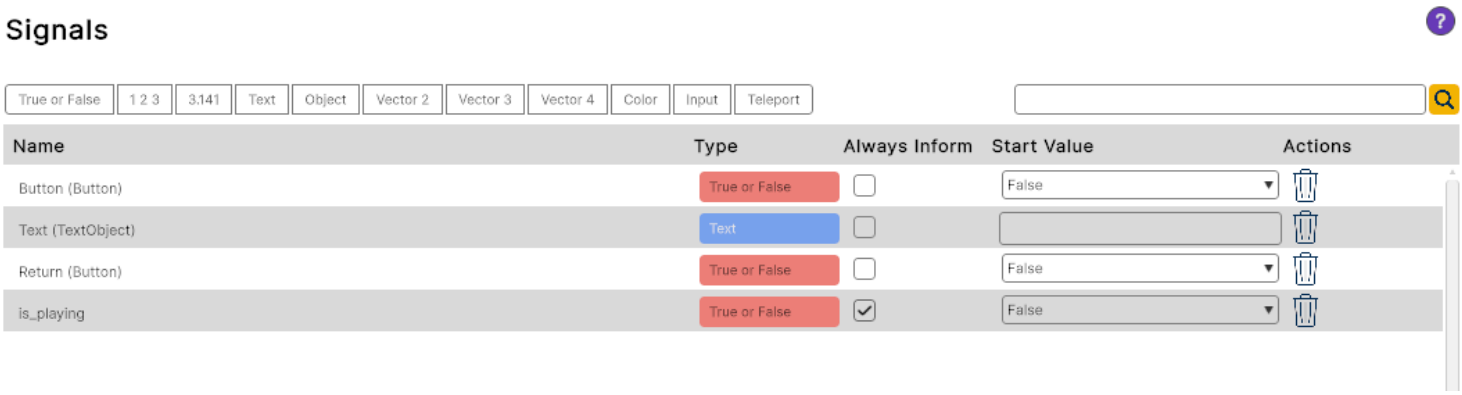
- **Script**

  Scripts (in C#) can be placed upon objects to further control their functionality. Each script contains a class which is structured like Unity scripts. The script is compiled by a JIT (just in time) compiler at runtime to ensure it can run on any target platform.

Signals

Signals are used to either start an action or to provide a value. A lot of the abovementioned asset types have trigger inputs and outputs. For instance, a button has a trigger output which can be connected to a light to toggle it on and off without needing any code. A Snap Field can invoke an action when the correct object snaps into place. Audi and video players have analog inputs for volume and position which can be controlled by signals directly.



Signals are vital to the logic editor where they can be used to start more complex activities or store values which may be used at a later time for a calculation.

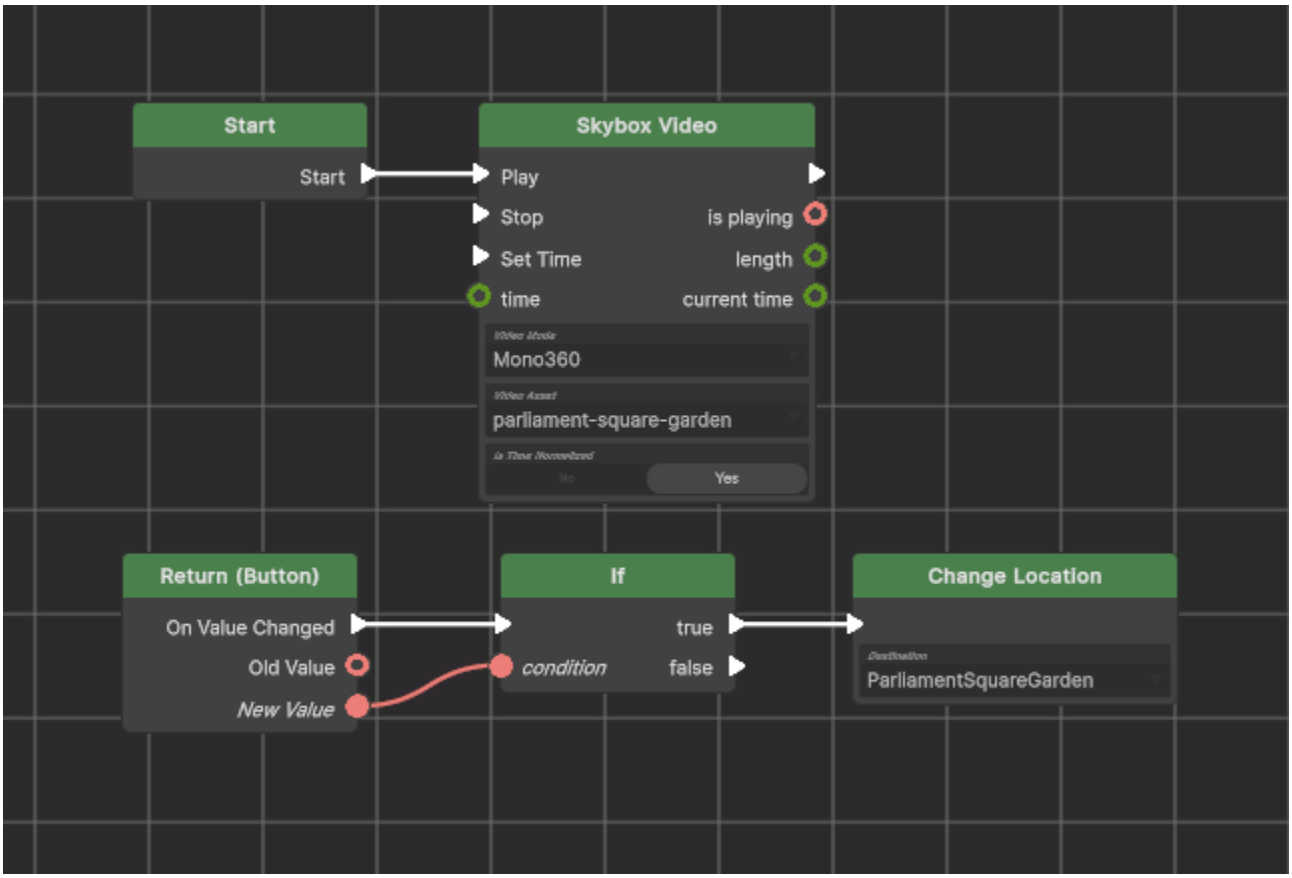
The Logic Editor

For more sophisticated interactions, a graphical user interface is available which provides a whole range of functions called Nodes. The functionality ranges from simple constant values such as float or Boolean to complex structures to control communicating with web-based APIs.

Nodes are connected by arrows to signify in which order they are executed and where they read or send their data. Each location has its own logic file attached to it.

Professional developers can program additional Nodes using the JIT compiler which can be

specifically designed for this one user/customer. To enable external developers to build custom nodes, they have been provided with a set of example Nodes to learn from and use as a template.



World Settings - Publishing

To publish a finished project, three steps are required,

1. Enter Creator Details which will be presented in the XR4ED Shop
2. Define a publishing Target. This is either a Shop Item or a package to be deployed on a remote server
3. Declare the item(s) to be published

Publishing Templates

One special case of publishing is the Template item. Templates can be sold through the shop. They

can contain complete projects including assets of any kind and logic files.

Of course, templates may also be stored and imported manually.

Once purchased, such templates will appear as a selection when new projects are created. Thus, the user has a starting point for his next project. This can be very useful if the user is building a series of similar projects/worlds which have coding or assets in common, be it a company logo or for instance lab equipment which is used in several tutorials/experiments.

Plugins

The term plugins in the context of the World Builder describes either dynamic link libraries (DLLs in Windows lingo) or runtime scripts which internally are compiled into DLLs and connected to the WB.

The WB supports these types of plugins,

- Publishing Wizards support the automatic handling of publishing a product in a shop or on a server. The XR4ED Publishing Wizard is an example of such a plugin
- The WB can be extended in his functionality through plugins. The camera controller at the top of the Location Editor's screen is an example of such a plugin.
- Sets of scripts which are associated with location objects. These runtime scripts can reprogram the behaviour of an asset in a location, f.i. rotate the 3D object to always face the user's camera. The same can be achieved through a Node script where the node needs to be informed about the user's position.

Portal Hopper Features

The Portal Hopper is meant to be used by the audience for whom the World Builder creates his content to interact with the resulting worlds. It is distributable free of charge. The WB itself integrates the Hopper into his workflow by using the Hopper to test-display its content on a local server before the content is distributed.

The app is currently available for Windows, MacOS and Linux, but it can also be adapted to Android systems. However, this would require a registration at the Google or Samsung stores which wasn't needed for the XR4ED project.

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The Portal Hopper ("Hopper") provides the user with a range of interactions.

Interaction - View Mode

Three different view modes can be selected,

- VR Mode
  This requires a VR headset to be attached to the PC
- 1st Person Mode
  On screen this mode almost looks like VR Mode. Looking around is controlled by mouse movements. Zooming in and out is controlled by the mouse wheel.
- 3rd Person Mode
  An avatar is displayed on the screen. The view camera is placed behind the avatar and can be rotated around the avatar using the mouse.

Interaction Movement

In general, movement can be accomplished in one of two ways.

In screen modes, users can move around by pressing the WASD or arrow keys on the keyboard. The look direction of the camera defines the movement's direction. In VR Mode, this movement is achieved by the user by physically walking around.

The second means of movement is teleportation. This means the user points to a place where he wishes to go and instantly teleports to that place. In screen modes, this is done by a mouse click, in VR the user can point the controller at a place and use the controller's thumb stick to teleport.

Moving Between Locations or Worlds

The Hopper keeps track of visited locations through a history much like a browser history. At the top of the screen, this history can be displayed to allow the user to "hop" to previously visited and possibly favourite locations. The user may also type in a link to hop to like in a browser.

The user may even select the current location as a destination which effectively restarts the current task.

At the bottom of the screen, he can also select a home destination (configurable) to go to.

It is also common to hop between worlds through a Node in the Logic File for this location.

Other Interactions

The Hopper needs to be able to interact with the objects in the location. In screen Modes, the hopper changes the mouse cursor shape to signal that some interaction with the object is possible. These interactions are teleport, grab and click. The grabbing and subsequent movement of the grabbed object can be switched between on a plane to up and down.

Selecting the Avatar

The default avatar can be changed either in the Settings Section of the Hopper by calling it with command line parameters which instruct it to register a new avatar. This can be used to install an avatar after buying it in the shop.

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Avatars are fully rigged (as humanoid) 3D objects. This means they can move their legs, arms and head. However, currently only one walking style and speed is allowed to prevent crazy avatars dashing across the location.

The file format of a custom avatar is a Unity asset bundle. It must contain the fully rigged model, an animator and the bundle must be stored in a publicly accessible server location. This is necessary so multiuser environments can display the avatar for other participants.

VRML Files

The Portal Hopper requires a VRML file to describe a location. The file can be downloaded from the shop or created manually by a developer. These files contain instructions how to load and display a location but not the bulk (assets such as videos, 3D models, etc.) of the location data. The VRML file is constructed in XML format which allows for easy verification and editing.

In the VRML file, sections are defined as **protocols**. Such protocols tell the Hopper what type of content he is looking at. There must be at least three protocols in any valid VRML file,

- **creatorInfo**

  This protocol describes copyright information. This follows the laws regarding website ownership and responsibility

- **META_INFO**

This protocol contains a name and description of the location and may have a reference to a image depicting the location

- The actual loading protocol. Currently the following loading protocols are supported,
    - **WORLD_BUILDER_PROTOCOL**

      This references a scene description archive and all the assets which are used in the location. The World Builder creates and publishes these archive files as well as the matching VRML file.
    - **DOWNLOAD_AND_RUN**

      This references a remote installer file which will be downloaded and run. After its termination, optionally the installed program can be run automatically. This protocol is used as a last resort when a project is too complex to be created inside the WB.
    - **PORTAL_HOPPER_PROTOCOL**

      This references a scene asset bundle and optionally additional asset bundles and DLLs which the scene (read 'location') requires to run.

Note that one WB project can theoretically hop between locations which are run by different protocols, which is the case in some XR4ED projects.

Documentation

The complete documentation of the project is available at https://www.portalsunited.com/docs/ and is regularly updated when new features are implemented.

Demos

The demo for both the tools is available at https://www.portalhopper.com/XR4ED/ with installation and update instructions.

3.4.1 Integration of the XR Module in Open-Call Pilots

Multiple winning pilot projects from XR4ED's Calls for Pilots adopted the XR Module as their authoring and delivery environment. The call itself required pilots to deploy and customise XR4ED solutions in real educational settings – meaning teams had to use the XR4ED platform's World Builder (for content

creation) and Portal Hopper (for multi-platform XR access). For example:

- **XR2LEARN** – Education and Learning Enhancement through eXtended Reality. This pilot integrated XR4ED's platform to let educators design and deploy immersive training content with AI enhancements. Over its 12-month span, XR2LEARN evolved from concept to a fully validated prototype within the XR4ED ecosystem, enabling non-programmers to create XR lessons. It incorporated an AI-based 3D content generator and voice chatbot into XR4ED's World Builder, allowing real-time interactions. The XR2LEARN tools were successfully pilot-tested with 107 students, yielding higher engagement, motivation and knowledge retention. This demonstrated the XR Module's usability and impact in formal learning environments.
- **XRAqua** – An Immersive Aquaponics Learning Experience with XR. XRAqua combined a real aquaponics system and IoT sensors with a VR application built through XR4ED to create a "living lab" for science classes. Using the World Builder, the team developed an interactive VR simulation (deployed via Portal Hopper on Meta Quest headsets) where students experiment with managing a virtual ecosystem. A custom "digital platform" integrated live sensor data, quizzes and simulations. The pilot was rolled out in four Portuguese schools, training 20+ teachers and engaging 150+ students in hands-on STEM learning. Notably, participating classes saw science test scores improve by ~94% after using XRAqua – a dramatic learning gain attributed to the immersive XR approach. This evidences robust user uptake and pedagogical validation for XR4ED's tools.
- **SURE–VFT** – Virtual Field Trips for Surveying Education. This pilot designed and deployed a suite of virtual field trips on the XR4ED platform, targeting university surveying engineering courses. Using the XR Module, the team created interactive field exercises (e.g. photogrammetry and remote sensing labs) in VR, which students could "attend" via Portal Hopper instead of costly physical excursions. The XR4ED World Builder enabled integration of 3D terrain models, instruments and step-by-step guides into immersive lessons. By leveraging the platform's multi-user and navigation features, SURE–VFT successfully bridged academic theory and field practice in an XR setting. The project produced replication guides and technical manuals for educators, ensuring the VFT modules can be reused and adapted. The fact that SURE–VFT's virtual trips ran entirely within XR4ED's ecosystem underlines the XR Module's extensibility for specialised

training scenarios.

- **AgriTwix** – Immersive Digital Twins for Sustainable Agronomy Education. Focused on smart farming, this pilot created 3D digital twin crop simulations using XR4ED's authoring tool. As part of the XR4ED ecosystem, AgriTwix provides an interactive 3D environment with lectures, quizzes and realistic crop management tasks. Students in a precision agriculture master's course used Portal Hopper to enter a virtual field where their irrigation decisions affect plant growth and yield in real time. Built on a scientific biophysical model, the simulation turns complex agronomic data into intuitive visuals. AgriTwix thereby showcases how the World Builder can be extended via custom plugins and data integration. Its deployment in an academic course (University of Bologna) allowed learners to experiment safely and develop practical skills in an immersive manner, validating the XR Module in higher education.
- **TEXIVOS** – XR for Construction Vocational Training. This project explicitly harnessed XR4ED's World Builder and Portal Hopper to create VR training for construction students. The team designed two VR-based modules using XR4ED tools (the World Builder and platform), focusing on construction safety and skills. These modules were piloted with young apprentices and adult trainees at a building trade institute in Bologna, Italy, with instructors observing how VR improved engagement. The XR content was tailored to complement the existing curriculum – e.g. a virtual scaffolding assembly exercise – and was delivered via the Portal Hopper in a classroom setting. TEXIVOS also ran a "train-the-trainer" session to familiarize teachers with XR4ED's interface, ensuring sustainable uptake. The successful field assessment of TEXIVOS confirms that even non-technical vocational trainers can deploy World Builder-authored simulations in real classes, demonstrating the platform's accessibility.

Many other pilot teams likewise utilised the XR Module: for instance, **GLEAM** built a mixed-reality game promoting inclusivity by linking visually impaired and sighted players in a mythology challenge and **Harmony4ED** developed VR music therapy tools for ASD learners – both creating immersive content via XR4ED. **VR4BEES** produced interactive 360° VR field trips about beehives as teaching tools, which were accessible to students through the XR4ED platform. **XR2CLASS** leveraged XR4ED's avatar and gamification features to craft virtual ICT labs with personalised learning paths. Each of these pilots used some combination of the World Builder and Portal Hopper to author and deliver their innovative learning

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experiences.

The final technical review of the pilot projects in October 2025 confirmed that all selected pilots successfully integrated and deployed XR4ED's World Builder and Portal Hopper. Several pilots conducted hands-on sessions with teachers and students, reporting measurable improvements in learning outcomes, engagement and motivation. Notably, **XR2LEARN** and **TEXIVOS** both delivered **comprehensive validation reports**, including detailed feedback on interface usability, avatar systems and multi-user features. Projects like **AgriTwix**, **VR4BEES** and **XRAqua** demonstrated how custom assets and environmental data were integrated into XR lessons using XR4ED's plug-in architecture and logic editor, validating its extensibility and pedagogical applicability across disciplines.

3.5 XR4ED Marketplace

The XR4ED Marketplace is a central hub within the XR4ED platform that provides one-stop access to XR educational content and tools. It effectively combines an XR solutions catalogue with an open Marketspace, meaning the platform not only curates existing XR resources but also allows the EdTech and XR community to submit and promote new ready-to-market content. In practice, this marketplace serves as a centralized location for accessing, purchasing and downloading a wide range of digital XR assets. Educators, students and developers can browse through available XR applications (e.g. immersive lessons, 3D models, avatars, virtual environments) and obtain them directly via the platform[. The Marketplace is implemented as a standalone web application integrated into the XR4ED ecosystem. It prioritizes usability and inclusiveness – for example, it adheres to open standards like WebXR/OpenXR to ensure content is interoperable across common devices and browsers without special plugins. This design focus aligns with XR4ED's goal of making advanced XR content easily accessible to all learners and teachers, lowering technical barriers to adoption. In summary, the XR4ED Marketplace provides a unified catalogue of XR learning solutions and an interactive Marketspace for community contributions, underpinned by EU principles of openness, privacy, ethics and inclusivity.

Features

1. **XR Solutions Catalogue and Marketspace**
    a. The Marketplace organises XR content into a structured catalogue of solutions, tools and assets for learning, training and education. Each entry includes descriptive metadata such

as educational domain, target group and XR technology.

b. Alongside the catalogue, a Marketspace concept supports the publication of offers and requests for XR-related services (for example integration, customisation or support), reflecting the offer–demand space described in D4.2 and consolidated in D4.5.

2. **Search, filtering and discovery**

a. Users can search the catalogue using keyword queries and refine results through filters such as subject category, target audience or device compatibility.

b. Content is grouped into categories and tagged with relevant attributes so that teachers and learners can browse by topic, type of resource or technology and quickly discover suitable XR applications and assets.

c. Version 2 introduces personalised recommendations based on user profiles and solution metadata, providing suggested XR resources that align with user interests and previous activity.

3. **Solution and asset onboarding**

a. Registered providers can submit XR solutions, tools and components through a guided onboarding workflow. They upload binaries and assets, provide metadata (for example title, description, supported platform, licence) and specify pricing or access conditions.

b. Submissions go through an administrative review and approval process before publication, ensuring that entries in the catalogue meet quality and policy requirements.

4. **Download, installation and access flows**

a. The Marketplace supports device-specific access flows for XR content. Depending on the type of solution, users can download applications directly, follow installation instructions or use QR-based flows for mobile and AR devices, as described in the Version 2 implementation.

b. For assets such as 3D models or avatars, users can download files for integration into tools like the World Builder or into their own XR environments.

5. **User roles and administration**

a. The Marketplace distinguishes between different user roles, including end-users (such as educators and learners), content providers and administrators. Each role has access to specific views and functions within the same web application.

b. Administrators can manage catalogue entries, categories, user accounts and permissions and can monitor submissions and platform activity through a dedicated administration interface.

6. **Integration with XR4ED tools and services**

   a. The Marketplace exposes XR4ED consortium tools and components as catalogue entries, including authoring tools (such as the XR Authoring Tool and game authoring tools), the XR4ED DevOps platform and reusable XR/AR UI components and avatars.

   b. It also integrates an assets library that aggregates XR resources from EU and national projects, along with links to external repositories, catalogues and libraries, in line with the XR4ED proposal and the D4.2 baseline.

7. **Licensing, rights management and compliance**

   a. Licensing information is recorded at product level and enforced through Marketplace workflows. Automated mechanisms for licence key generation and tracking, together with the associated microservices, ensure that access to XR content is consistent with the specified terms.

   b. The Marketplace operates within the broader XR4ED ecosystem of trust and compliance framework, which covers data protection, content licensing and terms of use, as described in D4.2 and D4.5.

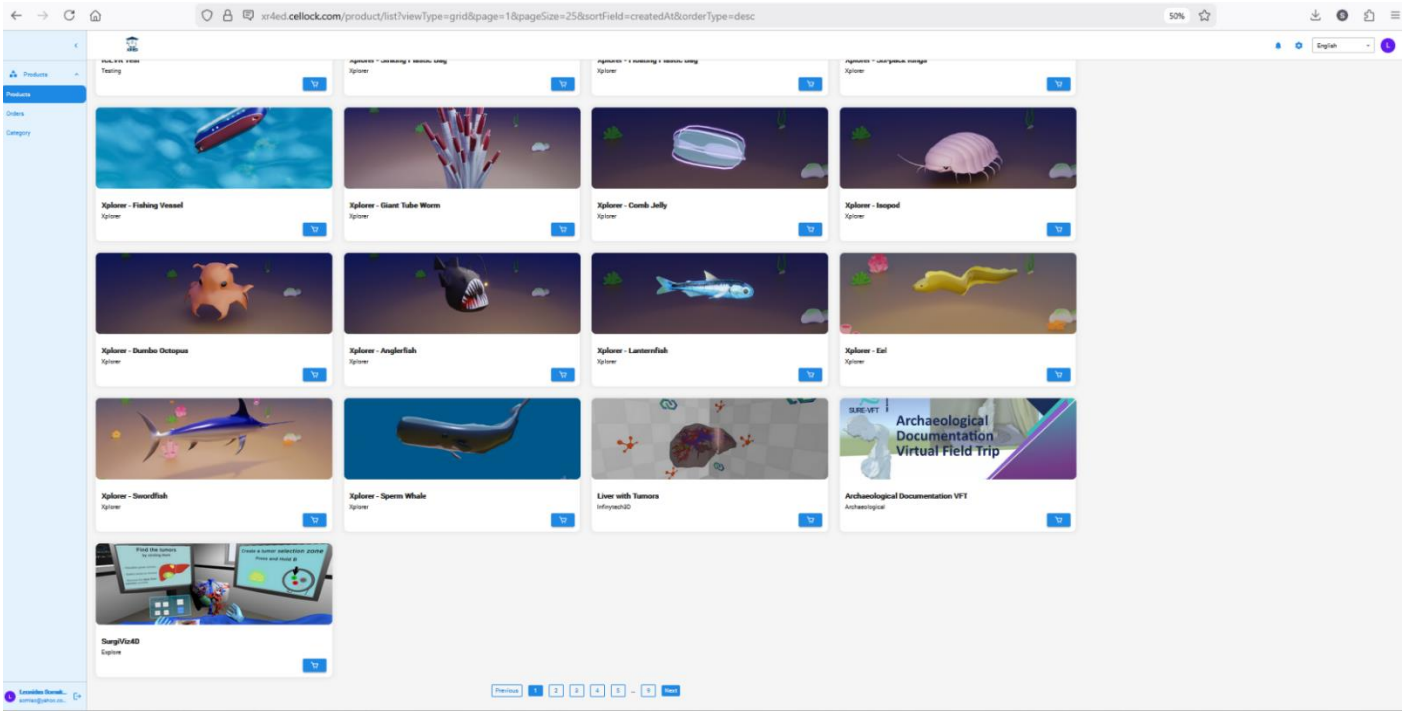
8. **User experience and accessibility**

   a. The Marketplace provides a modern, responsive web interface that supports access from desktop and mobile browsers and is aligned with common web accessibility practices, as described in the Version 2 UX implementation.

Overall, these features reflect the transition from the initial prototype described in D4.3 and the blueprint in D4.2 to a populated and operational Marketplace that is integrated into the XR4ED platform backbone and

used to expose both XR4ED assets and third-party XR solutions.

Integration of Open-Call Solutions: The final XR4ED Marketplace not only hosts the project's native components but also serves as the dissemination hub for third-party outputs. Notably, the **winners of XR4ED's open calls** have utilized the Marketplace to **deploy and share their XR learning solutions**. By design, all funded pilot and developer teams were required to **publish their outcomes in the XR4ED Solutions Catalogue** (the Marketplace's repository). This means that **educators and learners can discover the new XR applications,**



lessons and assets produced by these external projects directly via the Marketplace. For example, several **pilot-developed experiences** – virtual field trips, science simulations, training scenarios, etc. – were packaged as reusable modules on the platform. A case in point is SURE–VFT's surveying field trips, which are listed in the catalogue for any interested university to adopt. On the developer side, the Marketplace now also **offers novel components** like AI-driven virtual teacher avatars and a mobile 3D-scanning tool contributed by open-call winners, alongside XR4ED's own tools. By **exposing these third-party solutions within a unified catalogue**, the Marketplace accelerates community uptake and growth of the ecosystem. It validates the one-stop-shop concept: educators can not only find XR4ED's World Builder and Portal Hopper here, but also **access a growing library of XR content and plug-ins from external innovators**. This open, federated approach to populating the Marketplace has been key to demonstrating scalability and relevance across diverse educational domains.

Documentation

The marketplace has a built-in helpdesk and FAQs for common issues as well as tutorials for effective usage.

Demos

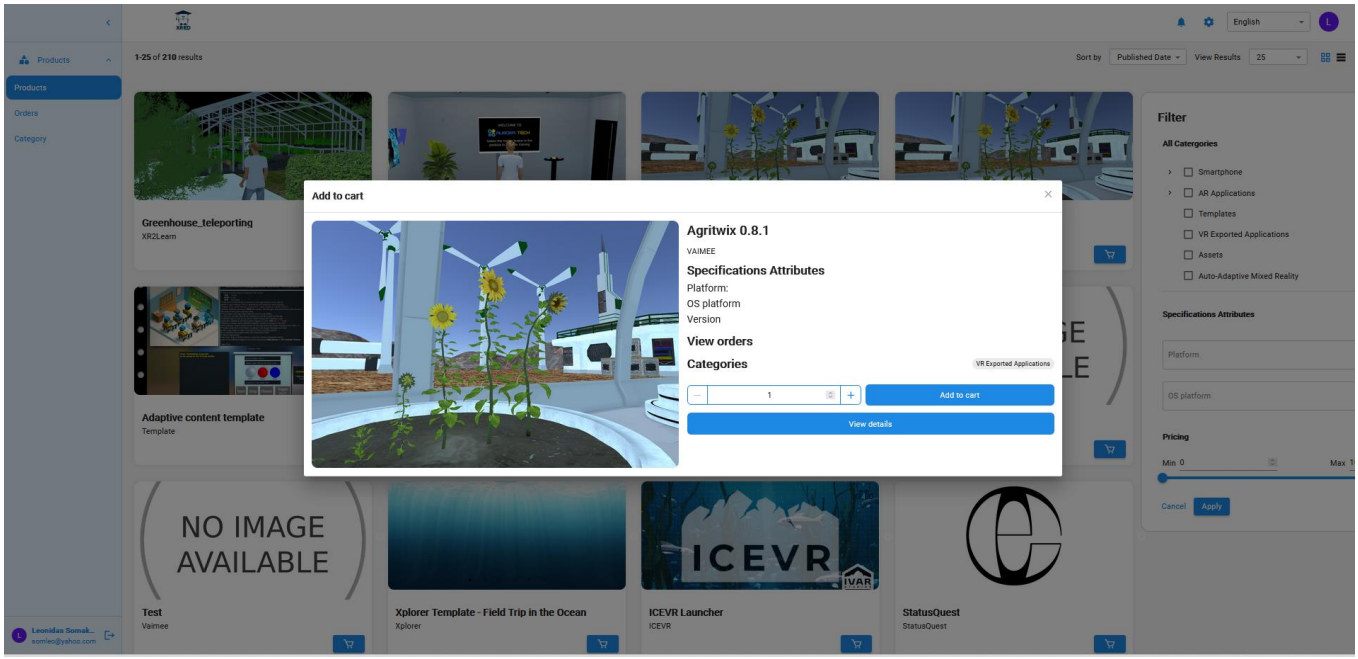
The Marketplace is available here: https://XR4ED.cellock.com/

3.5.1 Use of the XR4ED Marketplace by Third-Party Projects

Beyond content creation, several open-call projects relied on the XR4ED Marketplace as a deployment and distribution channel. The XR4ED Marketplace evolved into a one-stop "app store" for education and open-call winners have contributed to populating it with new XR learning content, assets and services. In fact, under XR4ED's funding programme, all projects are required to publish their outcomes in the European XR4ED Solutions Catalogue, the Marketplace's curated library XR4ED.eu. This has ensured that the immersive solutions developed by third parties become accessible to the wider community through the XR4ED platform. For example, the **SURE–VFT** team prepared its virtual field trip modules for listing on the Marketplace so that other universities can download and adopt them. Likewise, many pilot experiences (e.g. XRAqua's aquaponics VR lesson and **VR4BEES's** 360° videos) are expected to be packaged as XR learning objects in the catalogue, allowing educators beyond the pilot schools to access these via the Marketplace interface. This approach turns successful pilots into shareable resources, multiplying impact.

Several developer projects also extended Marketplace functionality or supplied new content to it. The XR4ED Marketplace is not only a content repository but also an access point to tools and assets – and some winning projects took advantage of this. For instance, **TUTORIST** (an open-call developer project creating AI-driven virtual teacher avatars) aligned with XR4ED's avatar system. Custom avatars in XR4ED are packaged as Unity asset bundles that can be acquired through the Marketplace and then used in Portal Hopper across different virtual worlds. TUTORIST's generative teacher avatars are expected to be distributed in this manner, enriching the Marketplace's asset library for personalisation. Another developer team, **myVirtualTrip**, worked on integrating real-time personalisation components into XR4ED's field trip content – their solution can be deployed via the Marketplace so that educators can easily find and activate adaptive virtual trip modules. Moreover, tools like **VERTEX** (a mobile 3D scanning

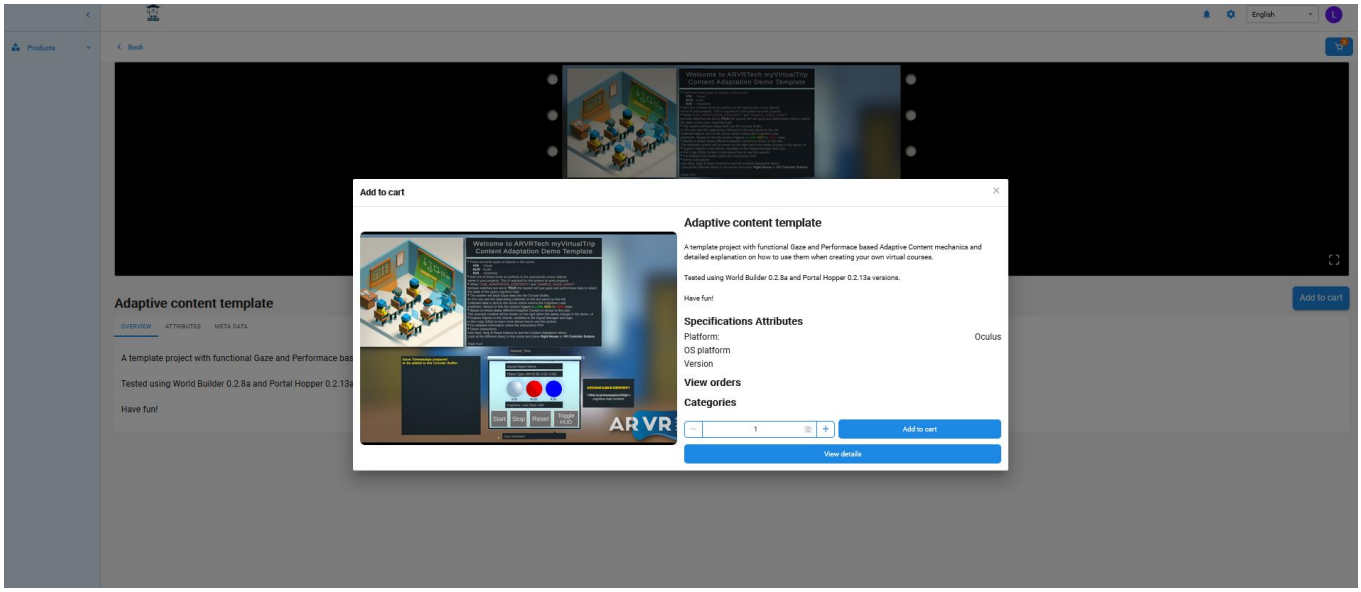
app) complement the Marketplace by supplying user-generated 3D models that educators can import into the World Builder, expanding the repository of shareable assets. In short, the XR4ED Marketplace has been utilized by third-party projects both as an output channel – to publish and license new XR educational materials – and as an entry point for accessing XR4ED tools and extensions. This cross-pollination via the Marketplace underscores its role in hosting an expanding ecosystem of solutions from the XR4ED community.



In addition, Users encounter a web-based catalogue interface that is intuitive and familiar. All available XR content is presented as a browsable catalog of content tiles or listings, each showing key information like the title, provider and a preview/description of the XR asset. The interface supports multi-language navigation (e.g. English by default) and straightforward navigation controls. Content items can be organized by category or tags (reflecting subject area, content type, etc.), thanks to a built-in categorization system. This allows users to filter or sort the catalogue to find relevant XR applications – for instance, one can narrow the view to 3D models, virtual field trips, AR lessons and so on, as categorized in the platform. A search function is available as well, enabling keyword queries to quickly locate specific assets (e.g. searching for “IoT lesson” or “photogrammetry VFT”).

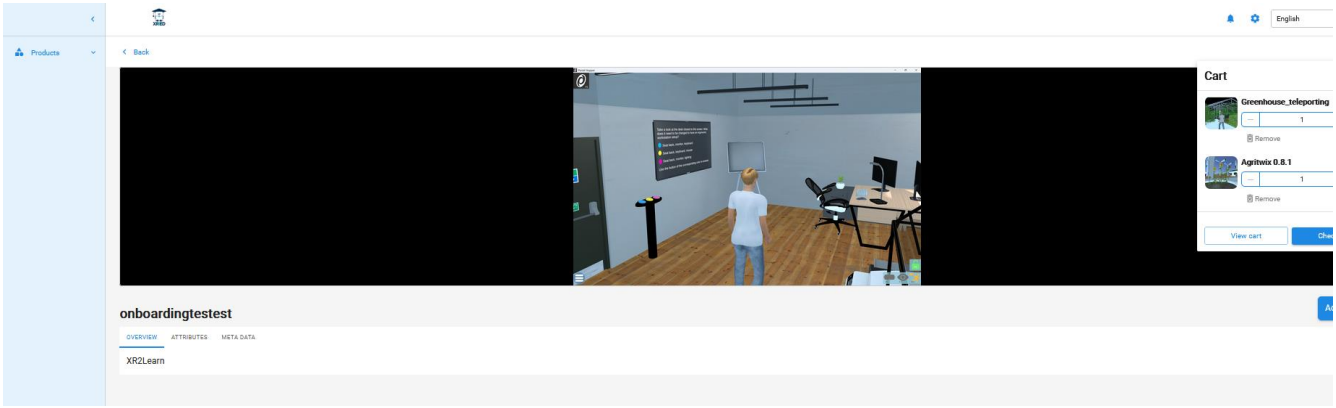
Each content listing is linked to a detailed product page with multiple tabs for information. On a product page, users can see an Overview (description of the experience or asset, often including an educational

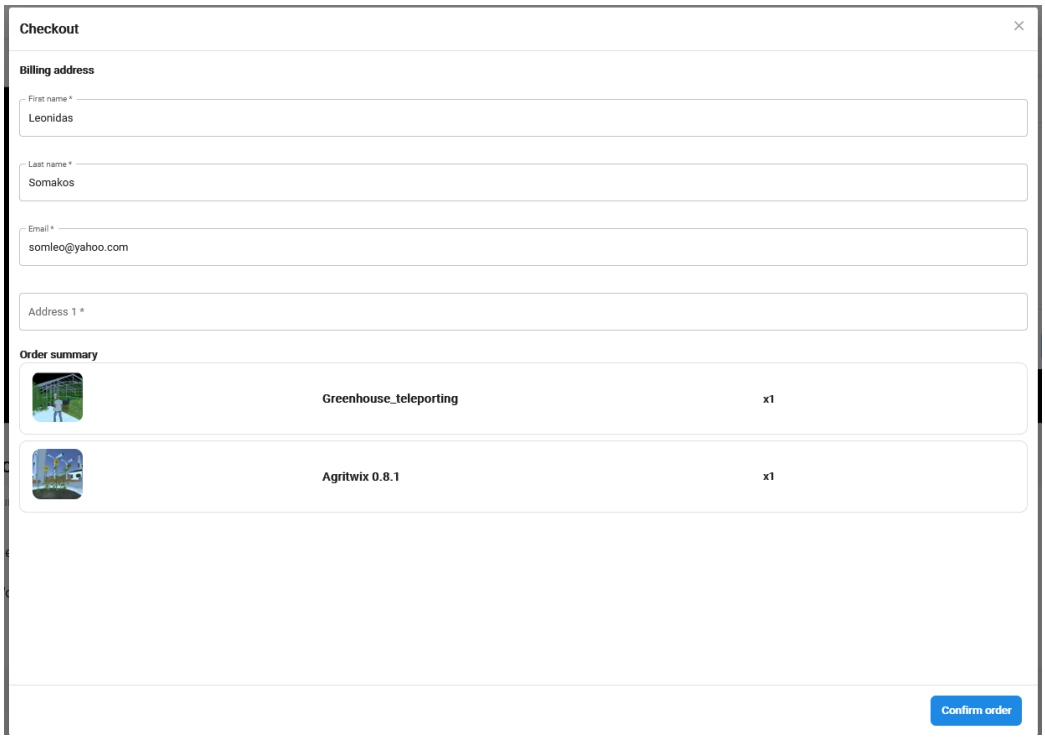
storyline or usage instructions), technical Attributes (e.g. platform/OS compatibility, file size, version, educational level, etc.) and Meta Data (such as the author/provider name, release date and any metadata like keywords). An example is the “Greenhouse: IoT Lesson” asset, whose page shows an Add to Cart button and tabs for Overview, Attributes and Meta data, along with the provider name (e.g. “CellockERP”). This structure is based on standard e-commerce design, making it easy for users to understand how to proceed.

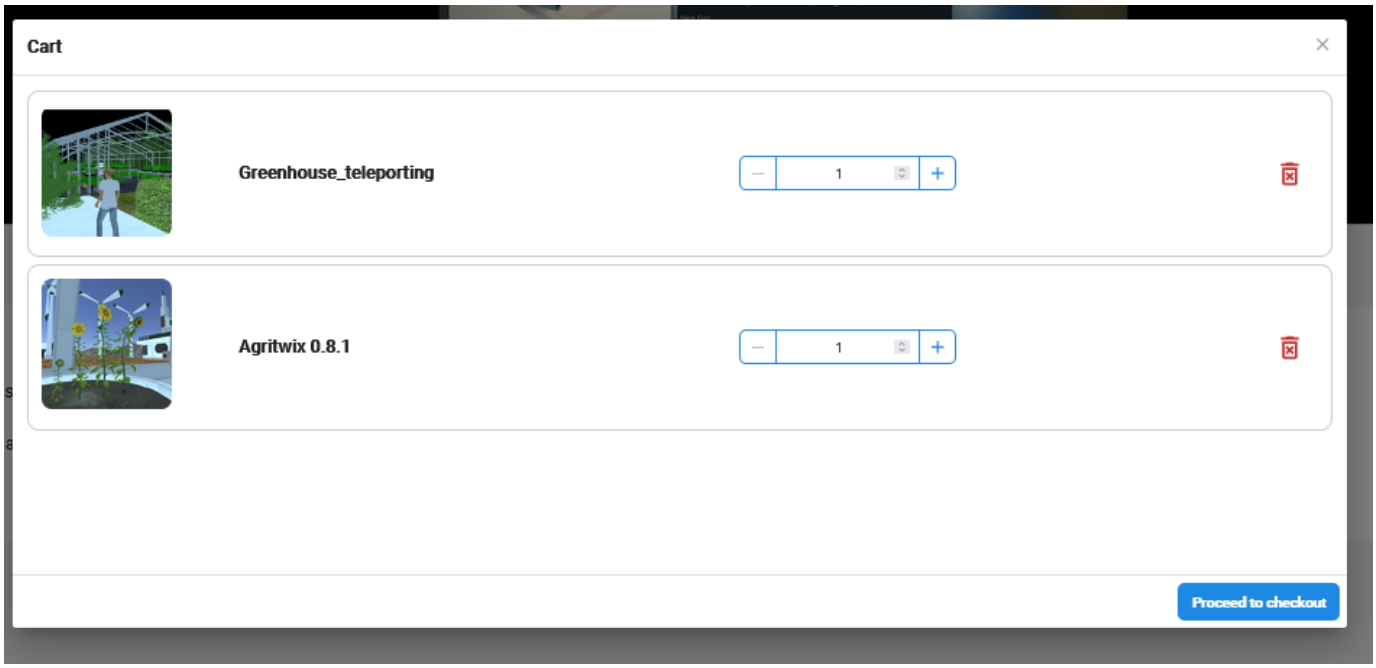


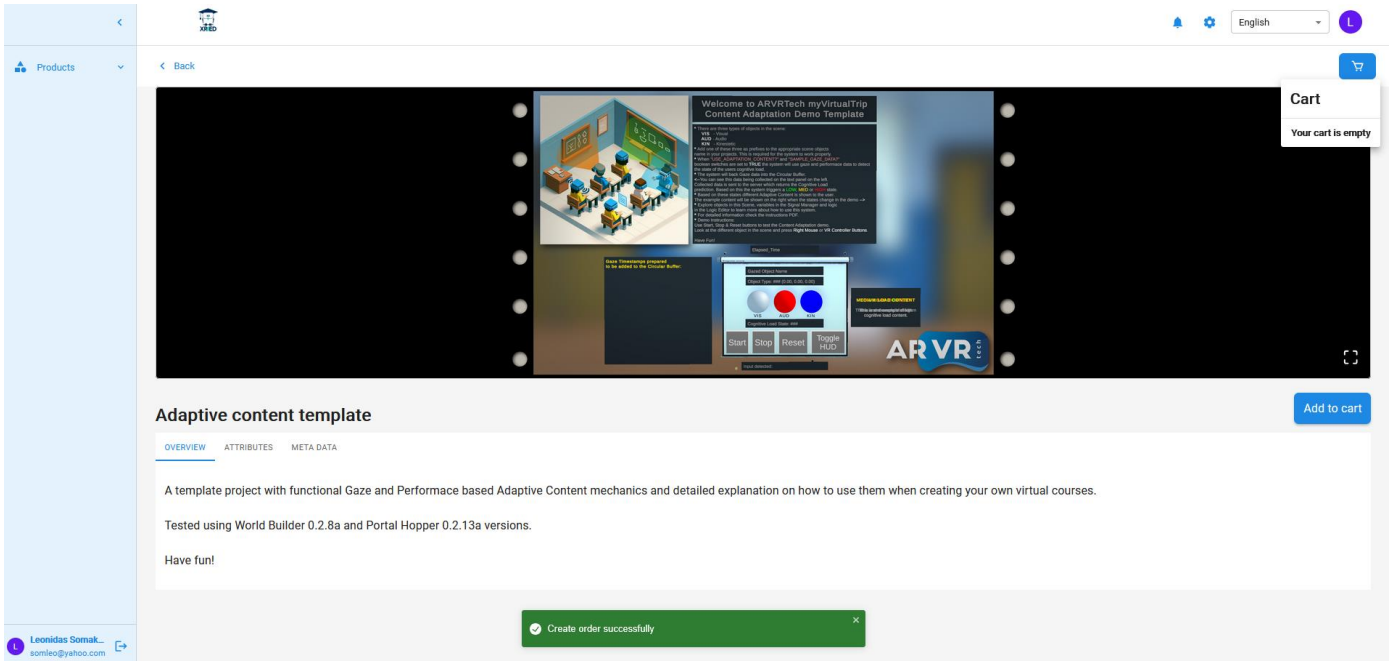
Critically, the Marketplace interface includes a shopping cart and checkout system for acquiring content. Users may add one or multiple items to their cart and then proceed to checkout when ready. For free assets (as is the case for most current XR4ED Open Call pilot content), the checkout simply zero-prices the items but still goes through the “purchase” step so that the content is registered to the user’s account. For paid assets (future or commercial content), the Marketplace supports secure payment integration as well. In all cases, the platform manages the transaction process in a user-friendly way – the interface clearly guides the user from selecting an item to confirming the “purchase” and then to downloading it. Once a transaction is complete, the item typically becomes available for immediate download or launch. Users are provided with a download link for the XR content (often a VR scene file or package) and, where supported, a one-click “Launch in Portal Hopper” option. This launch link uses a custom URI scheme (e.g. hopper://...) to automatically open the XR experience in the Portal Hopper desktop application,

seamlessly transitioning the user from the web catalogue to the 3D immersive environment. This tight coupling of the web UI with the XR player ensures a smooth user experience: for example, a student can register on the marketplace, add a virtual field trip lesson to their cart, check out (for free or with provided credentials), then immediately launch and experience that lesson in Portal Hopper with minimal friction. Overall, the interface's emphasis on user accessibility means educators and learners with minimal technical expertise can navigate the catalogue, find appropriate XR resources and start using them without hassle. The design has been informed by user co-design feedback, stressing ease of use and broad accessibility (e.g. support for standard PCs without requiring specialized VR hardware).









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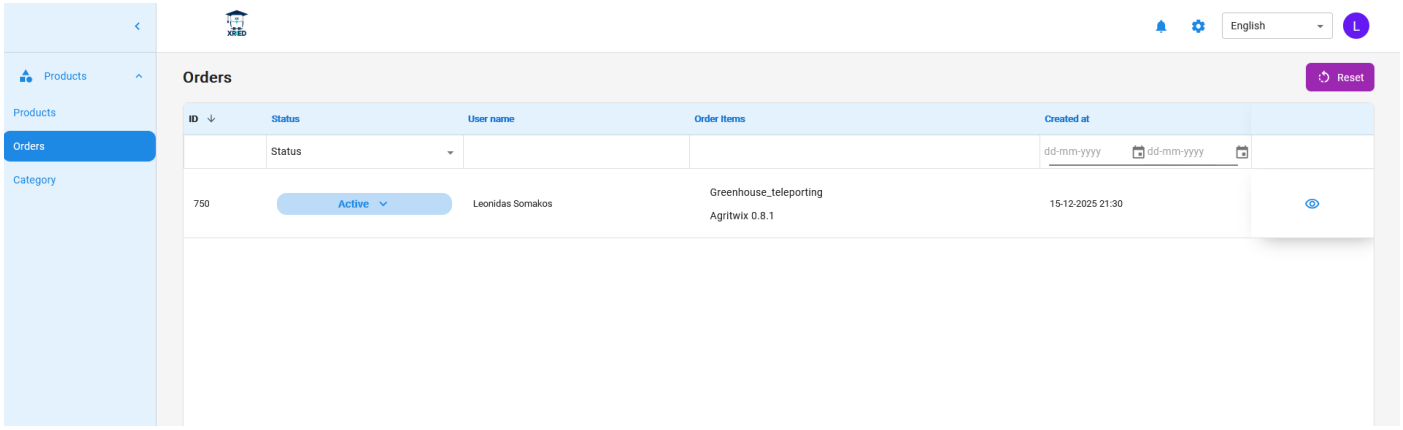
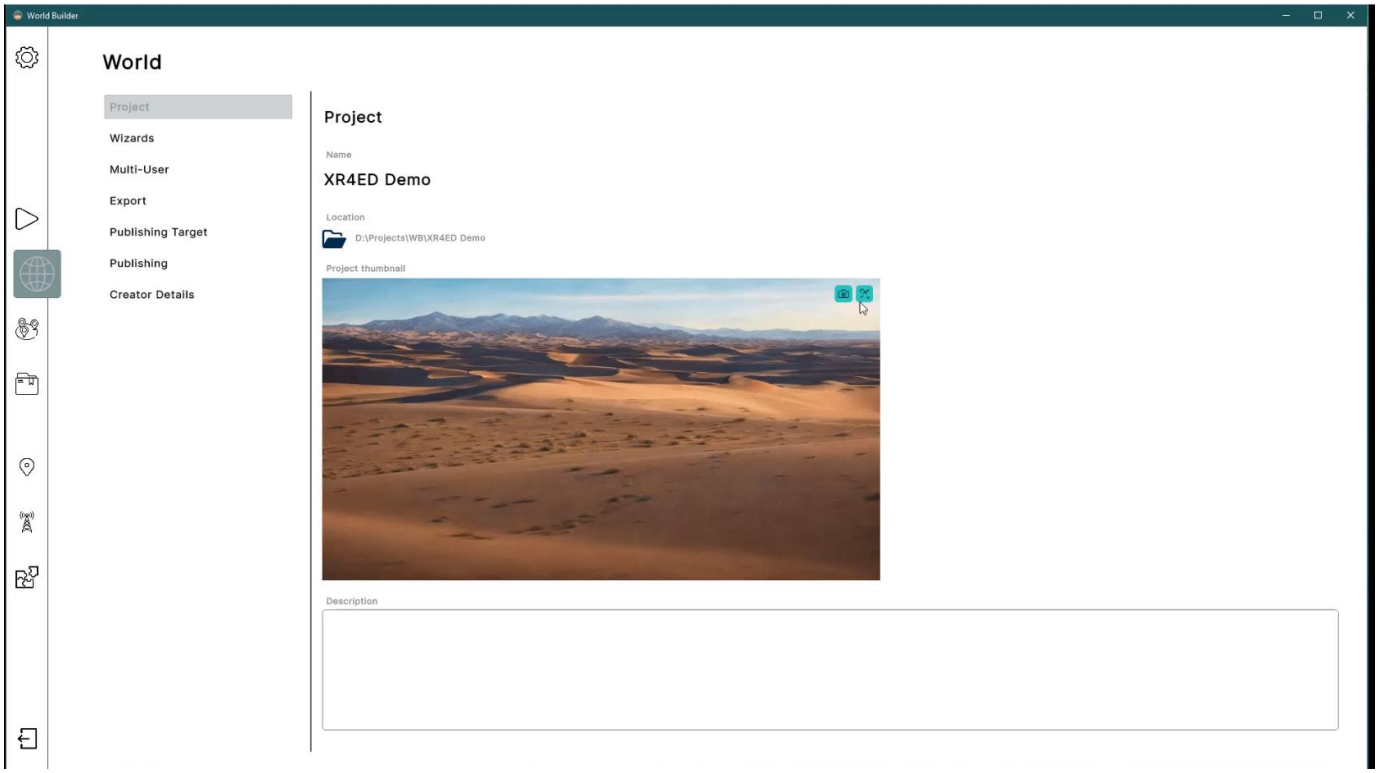


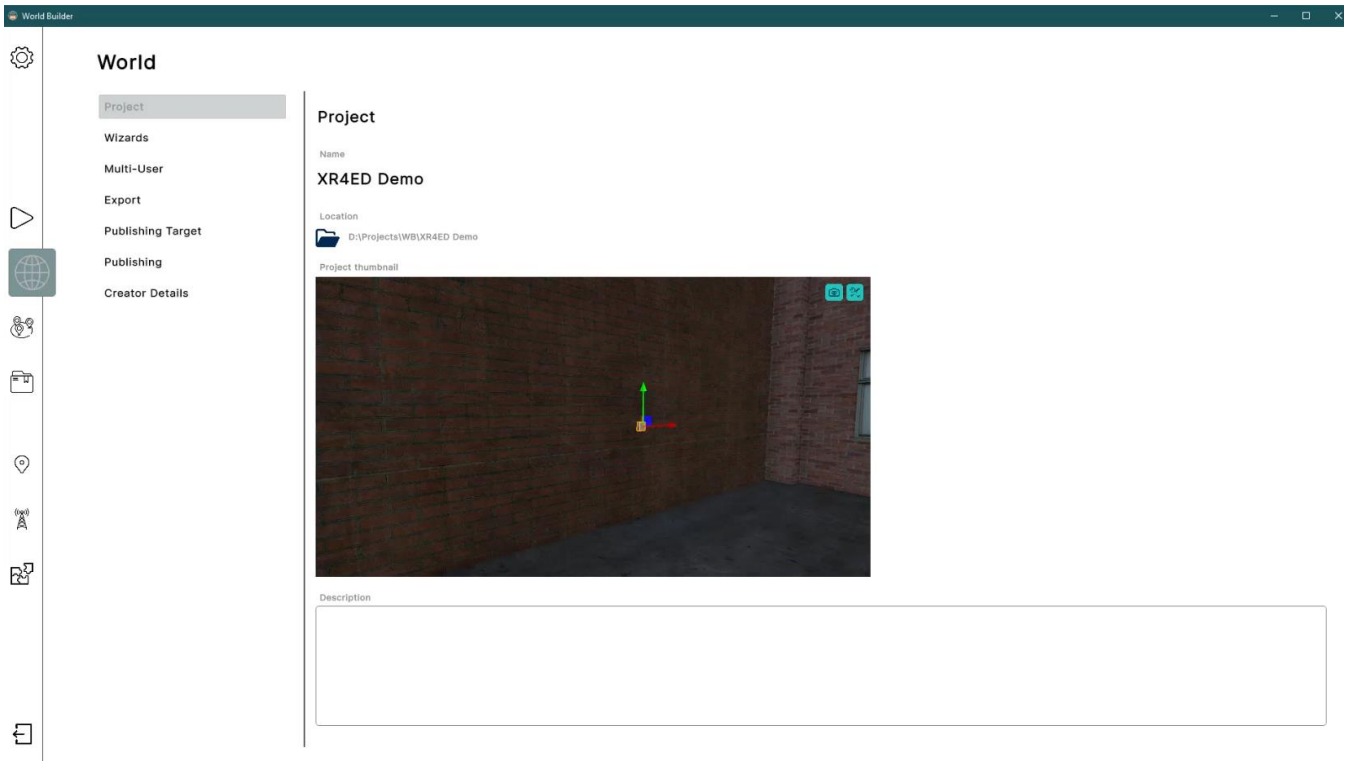
3.5.2 From the Worldbuilder to the Marketplace

After creating a “World” from the builder and want to publish it to the Marketplace, we must track the following steps:

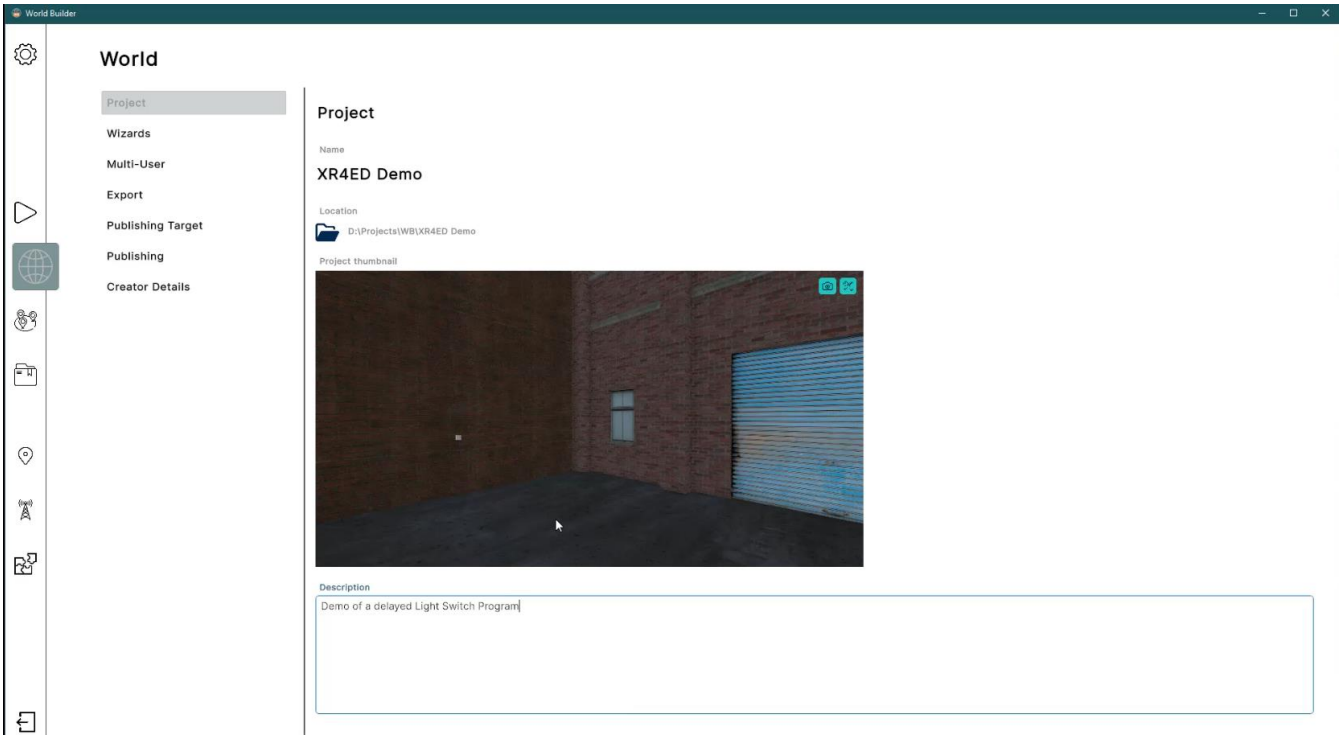
First, we need to publish whatever we have created by the builder to the Marketplace



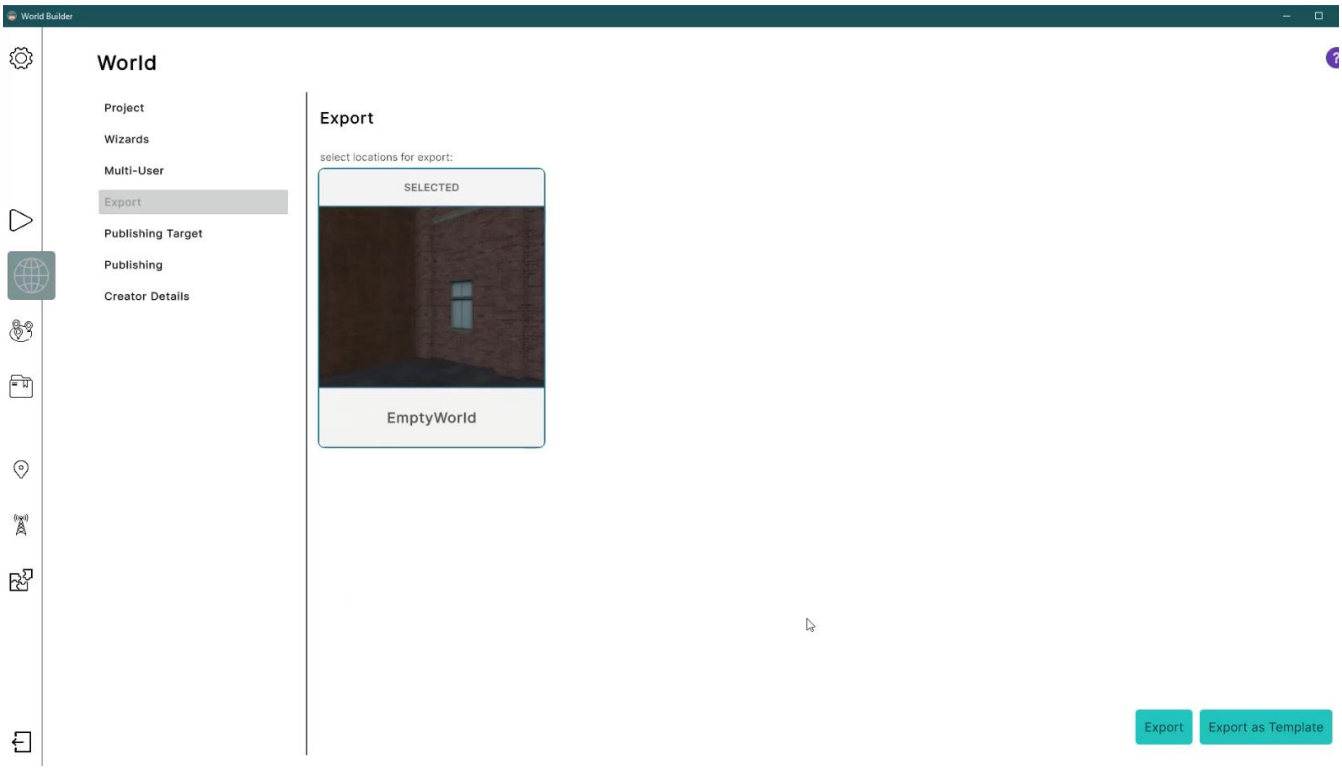
We first save it as a project photo



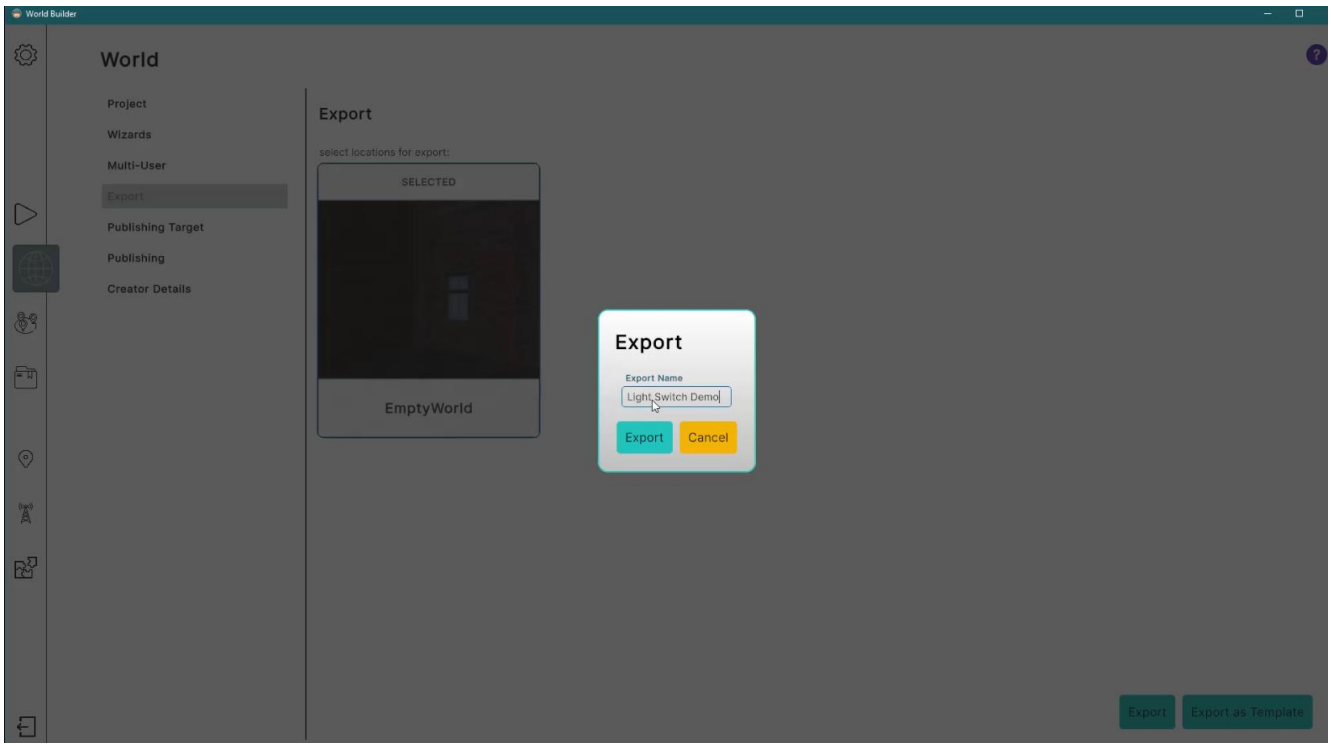
We then save it with a description



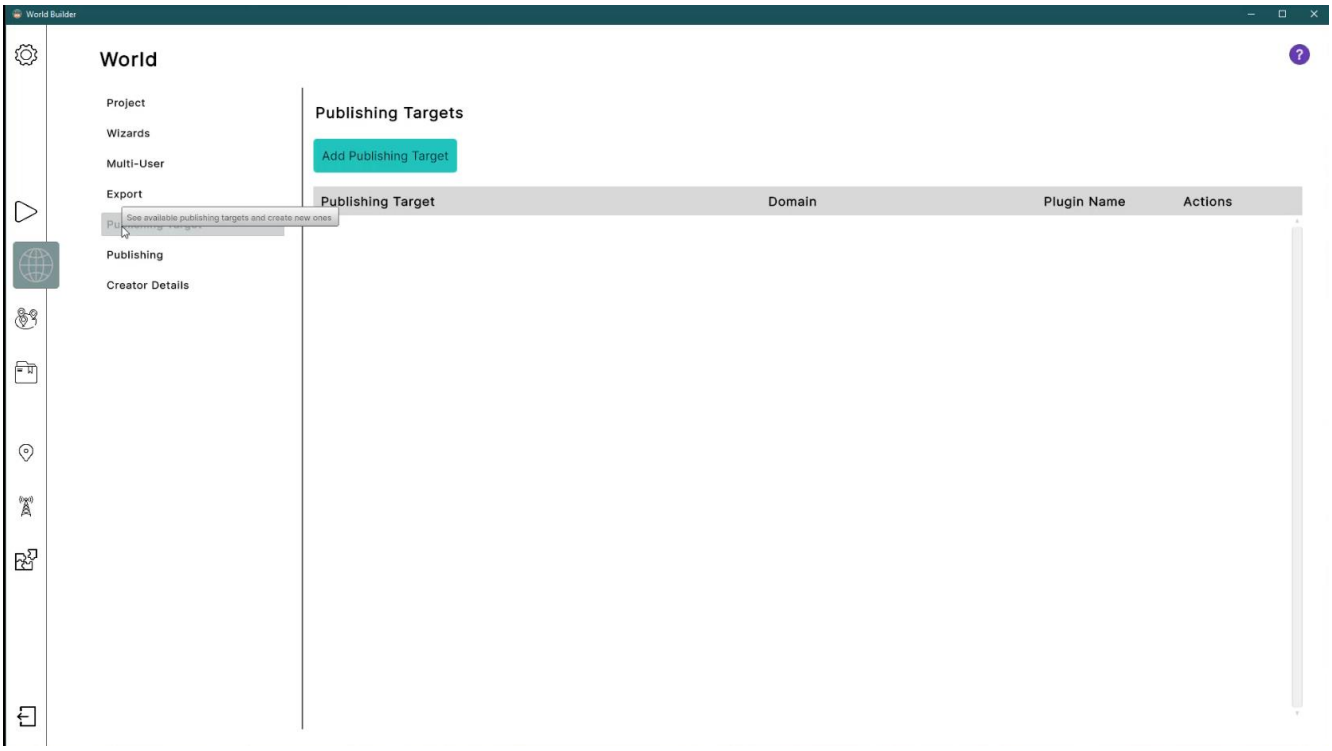
Then export it to the Marketplace



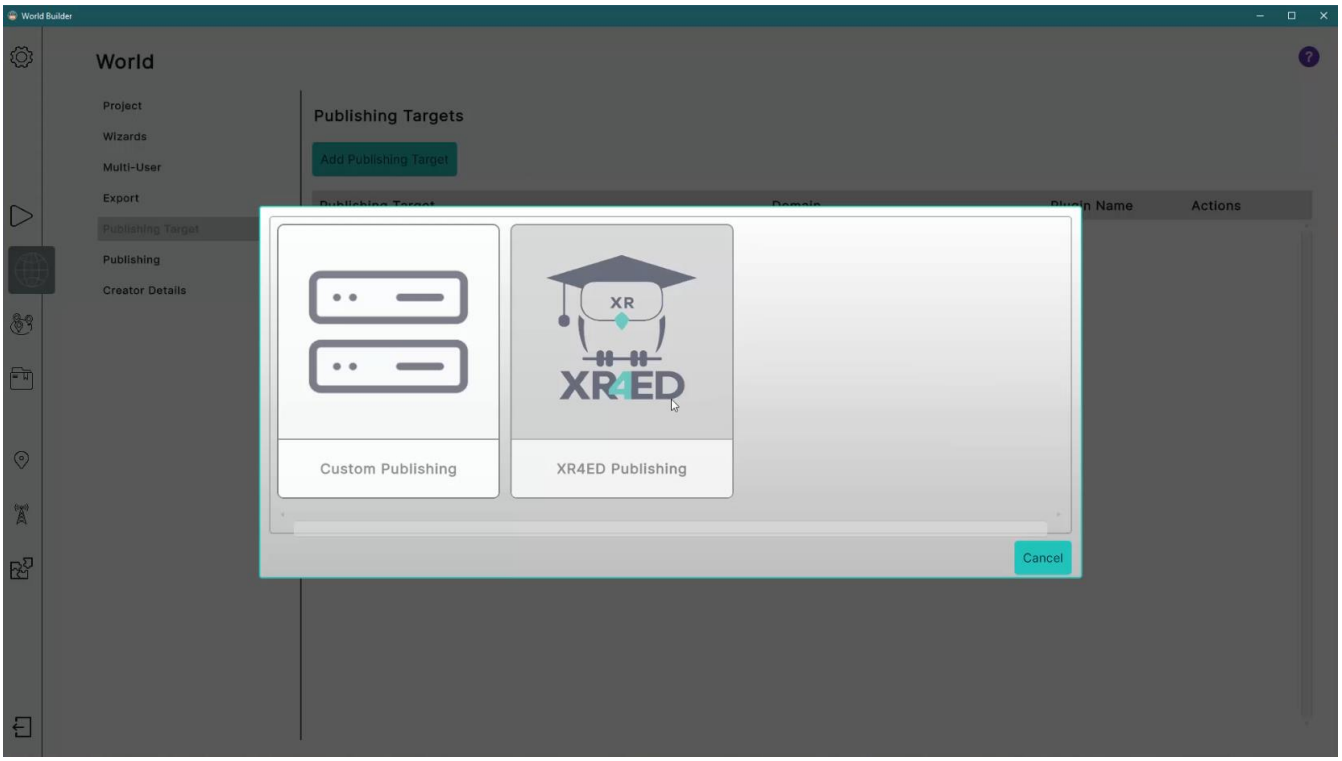
Provide a name for our work



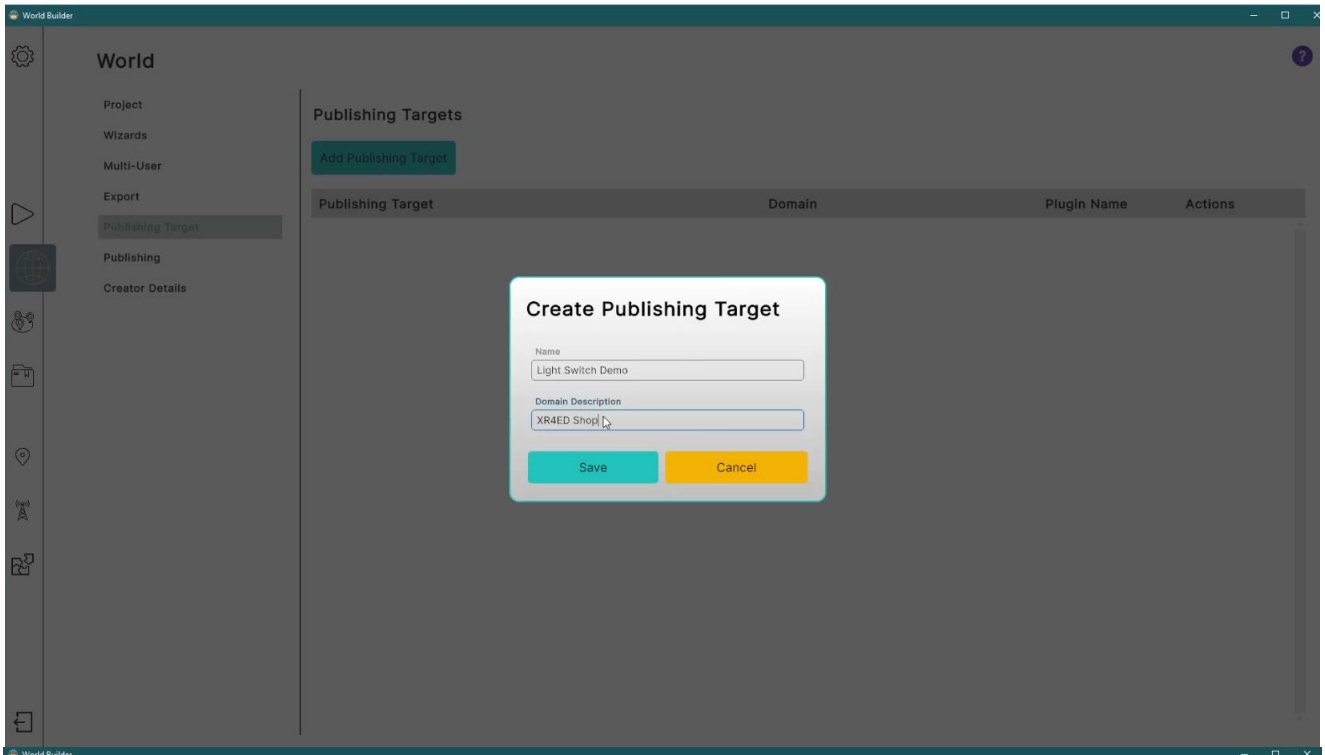
We then tell the system that we have a publishing target

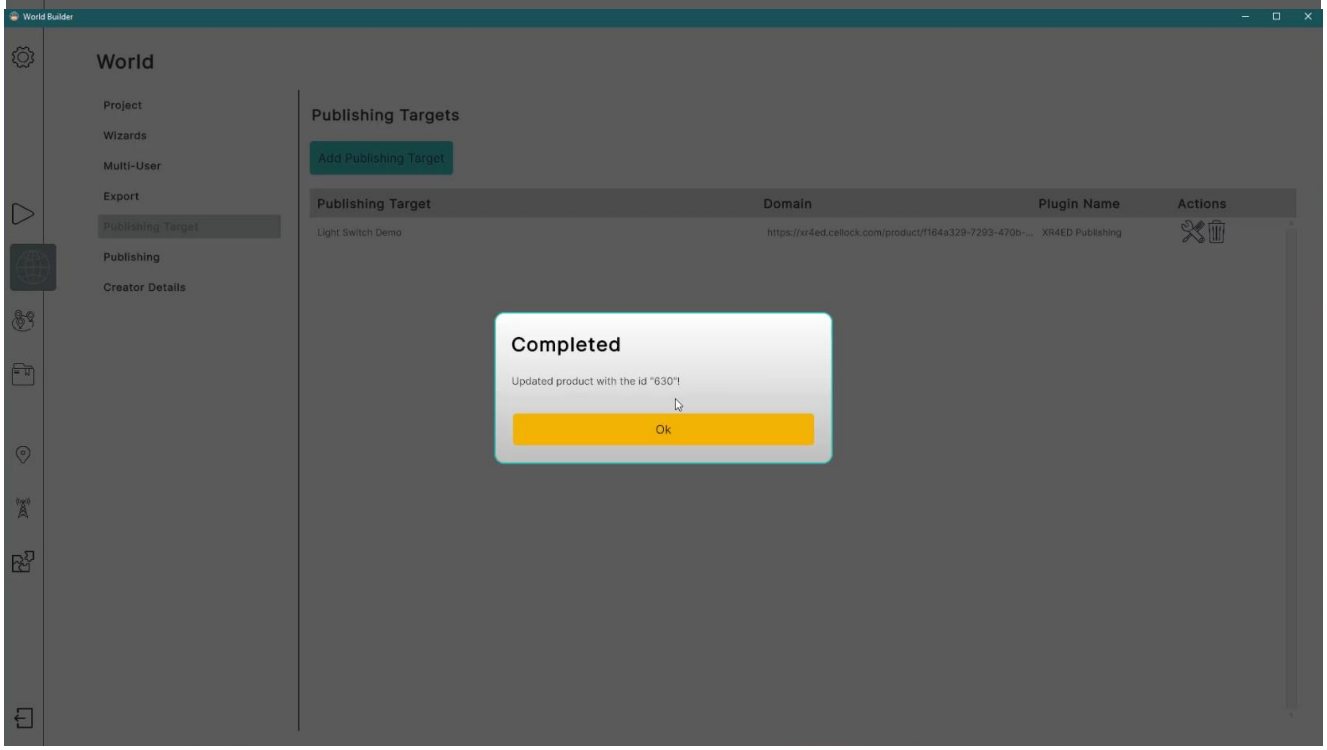


And we tell it to which target project we want to include our work

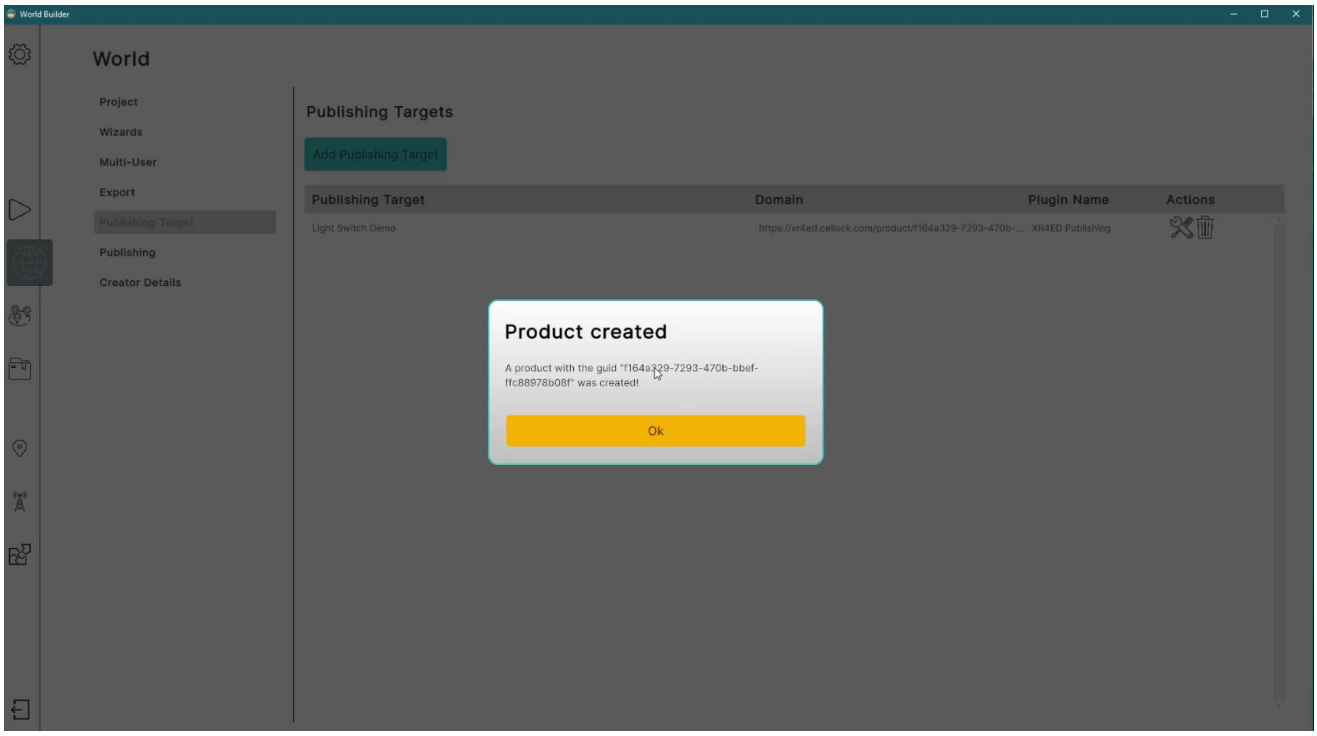


And we sent it then to our publishing shop

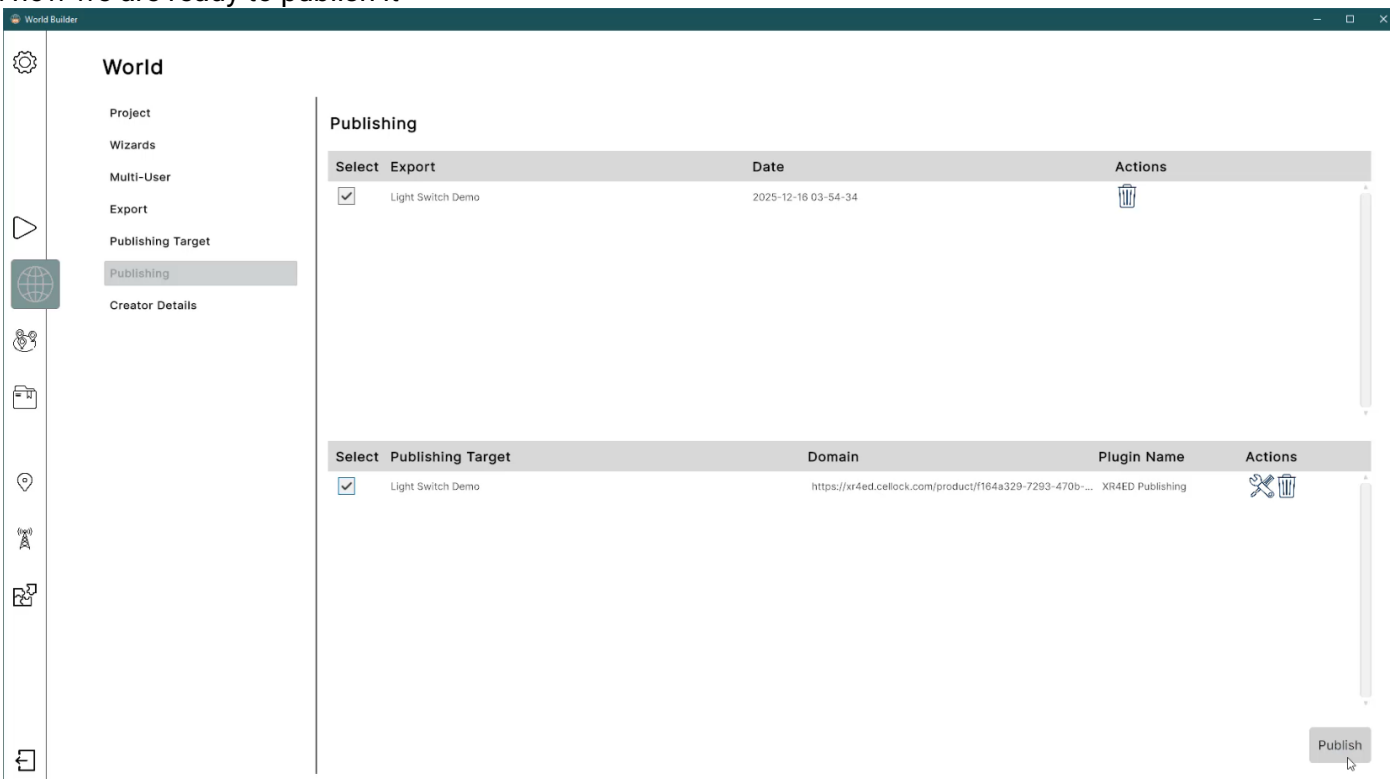




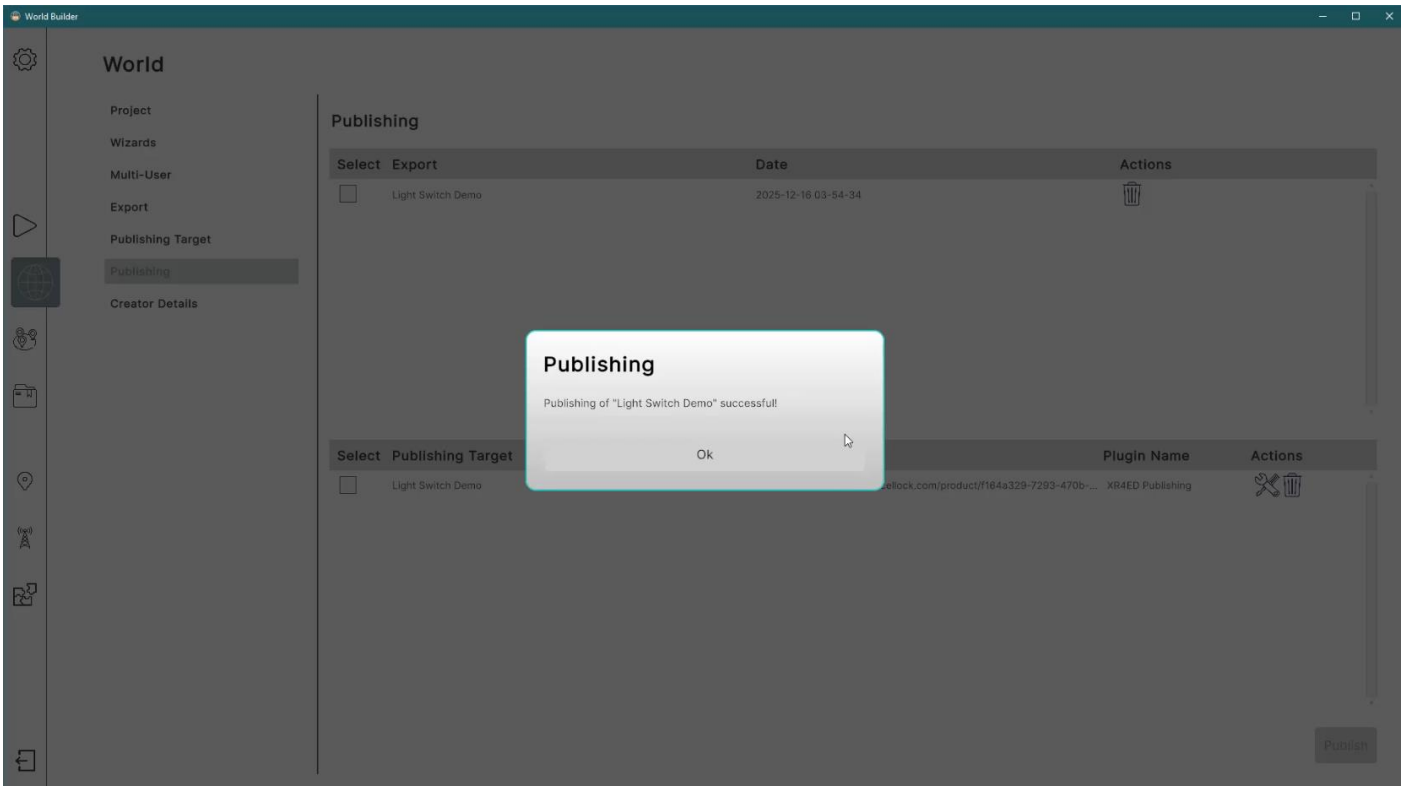
And the product we created gets automatically an ID in the shop



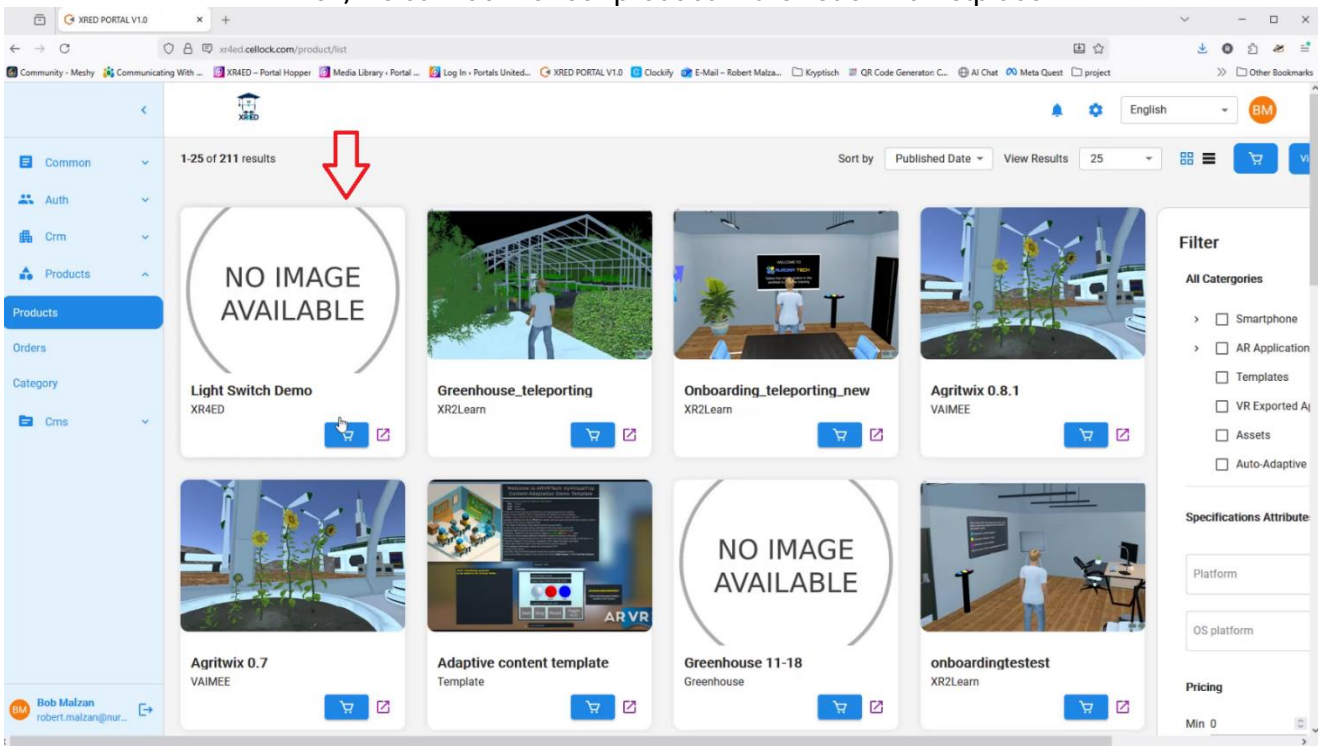
And now we are ready to publish it



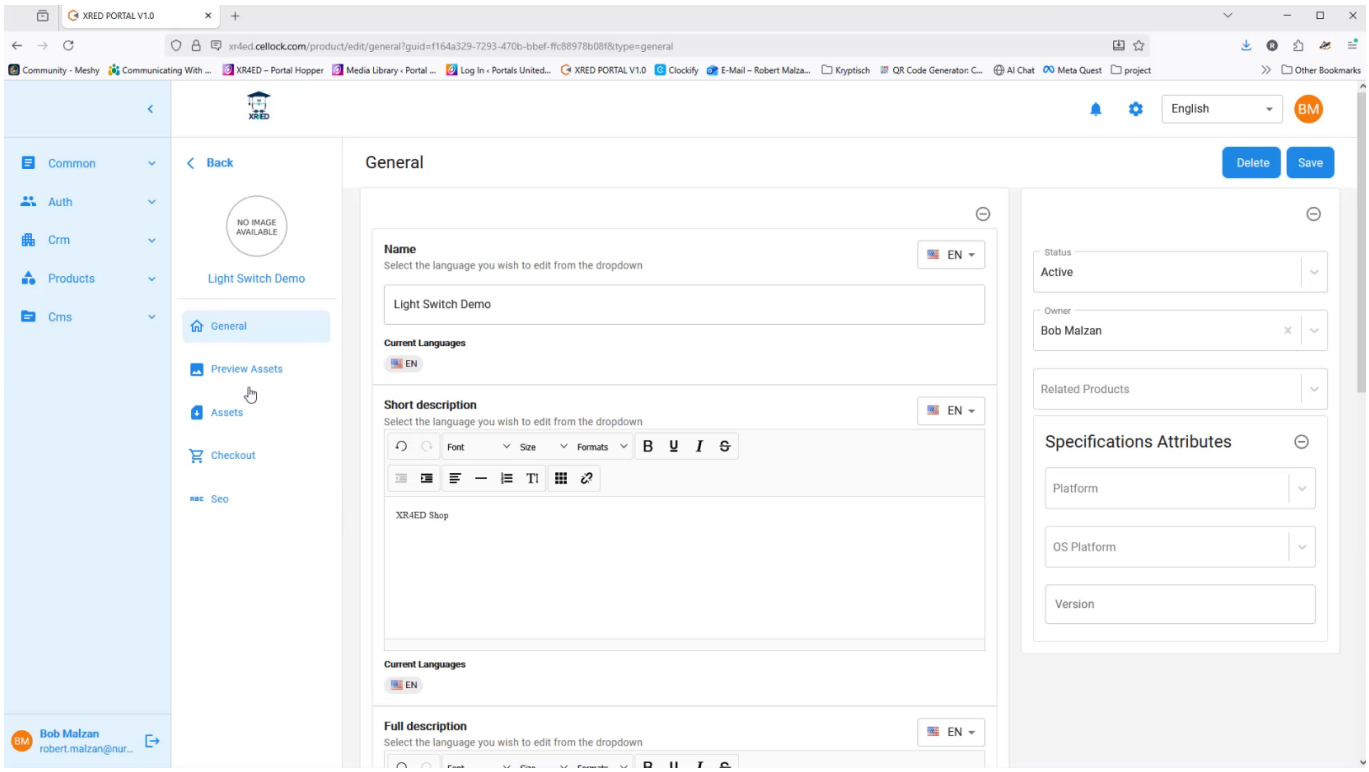
After some reasonable computational time, the publication to the Marketplace is complete



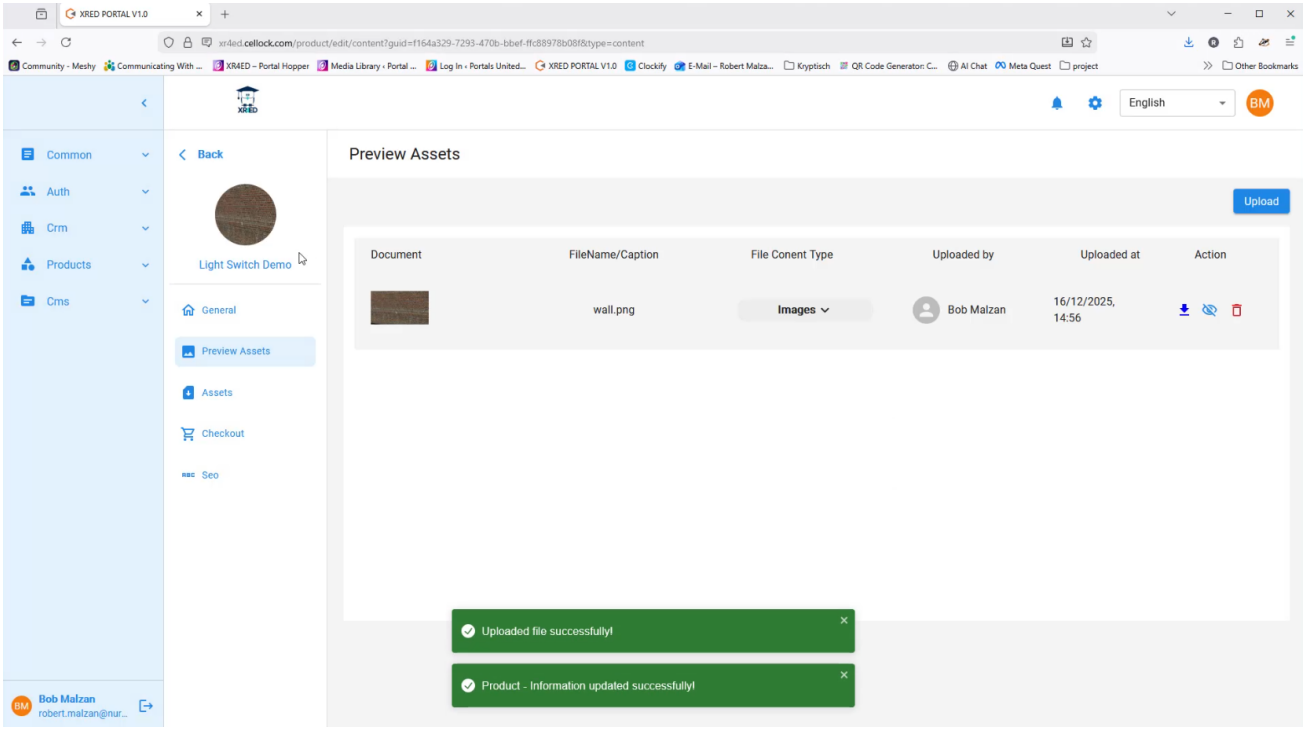
Then, we can look for our product in the list of Marketplace



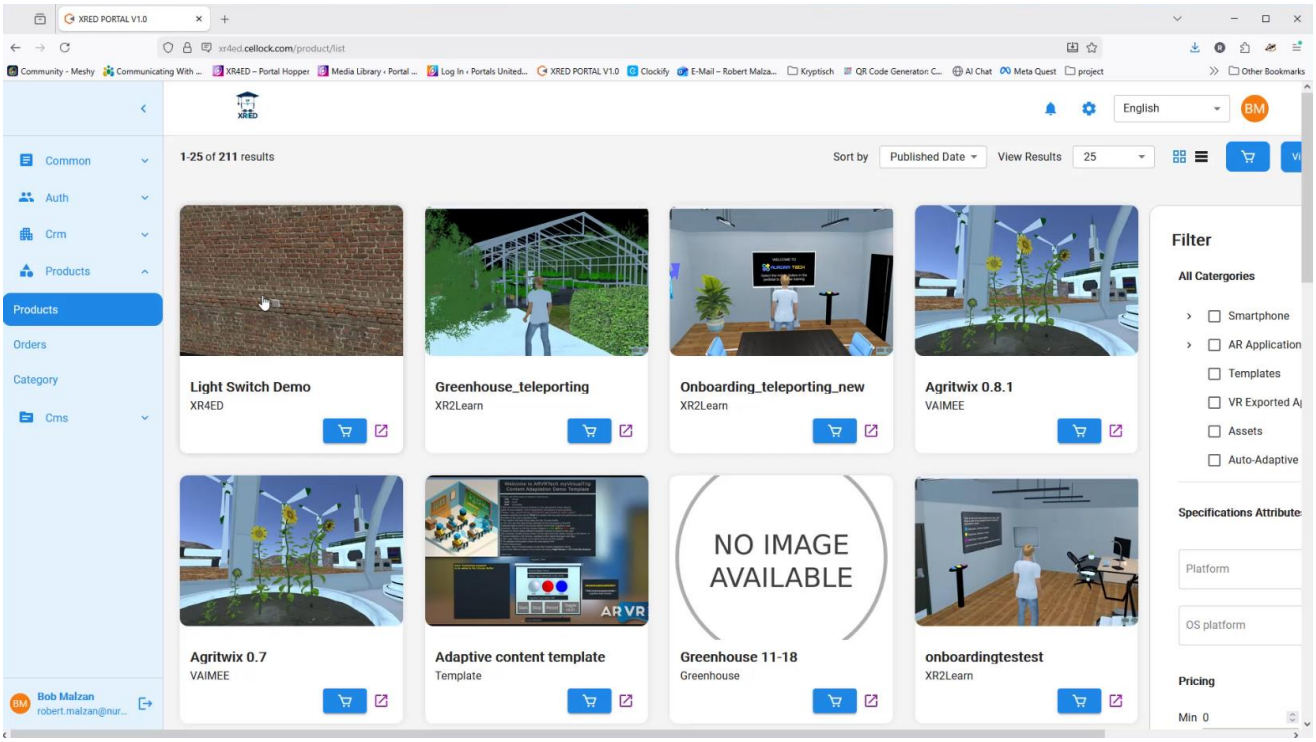
We can then preview our asset



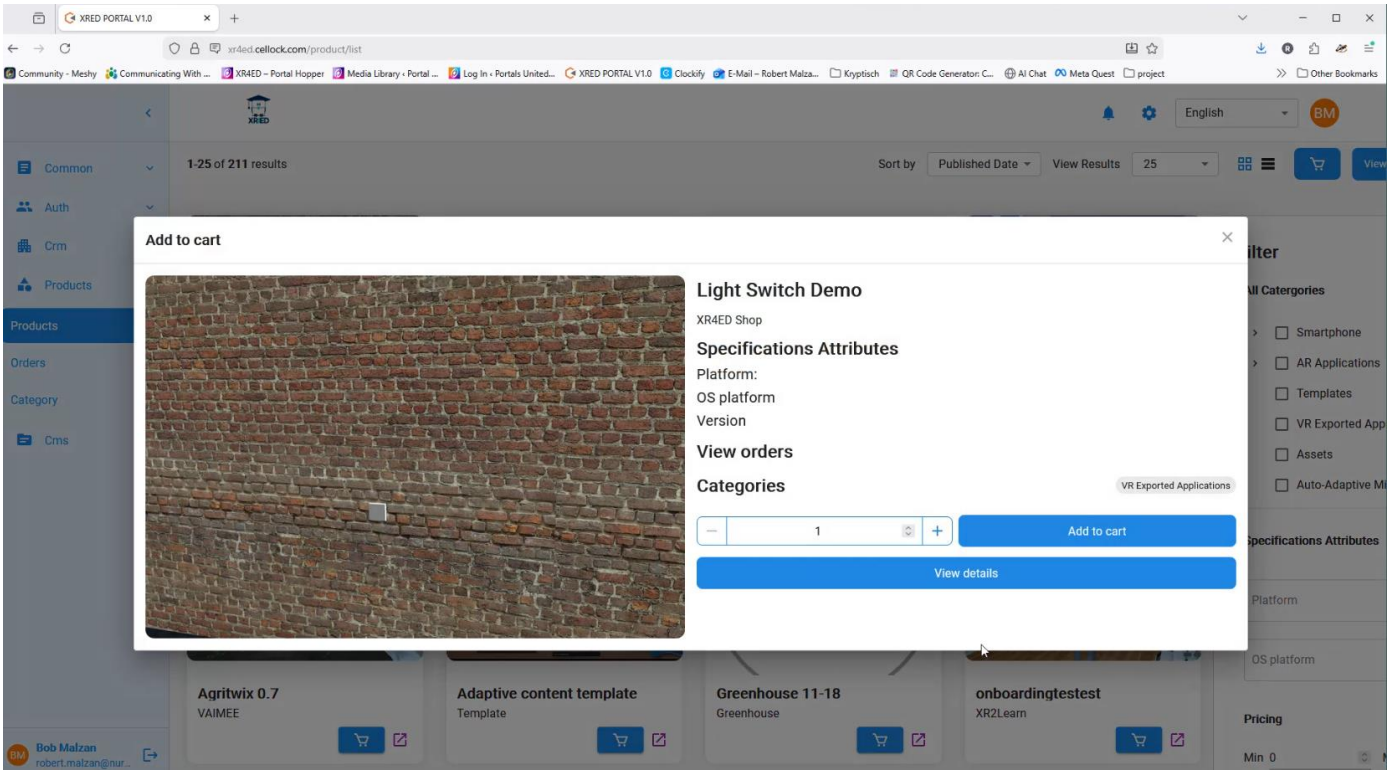
We can make changes such as add a preview screen



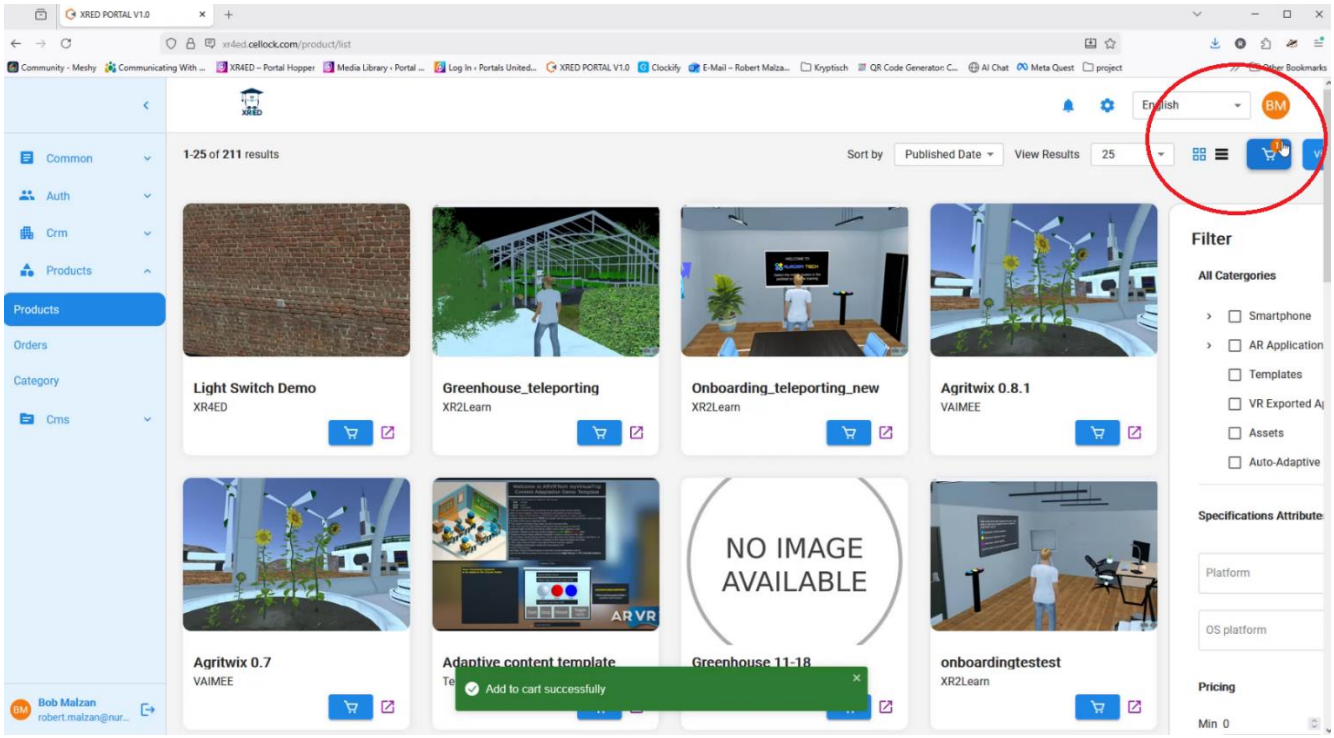
And then the preview screen has been added to our asset.



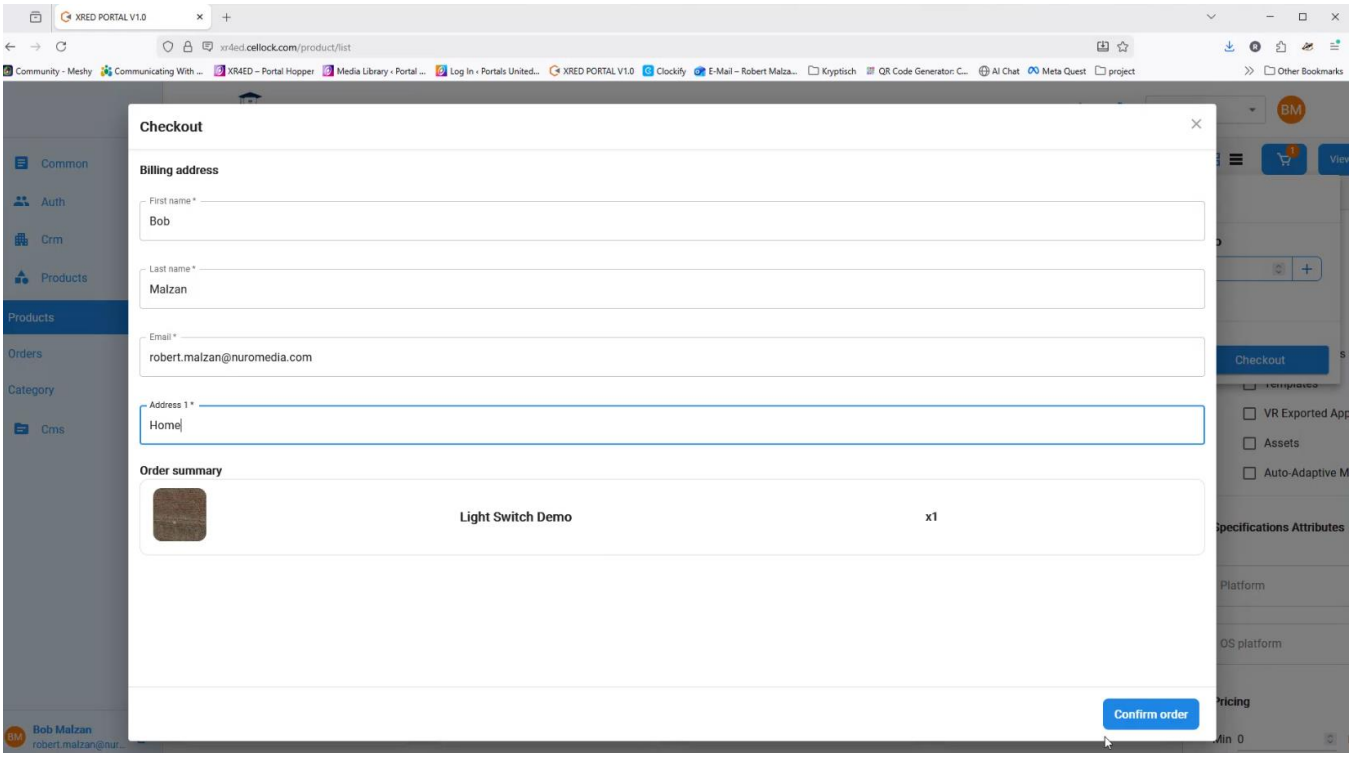
Then a customer may choose to buy it



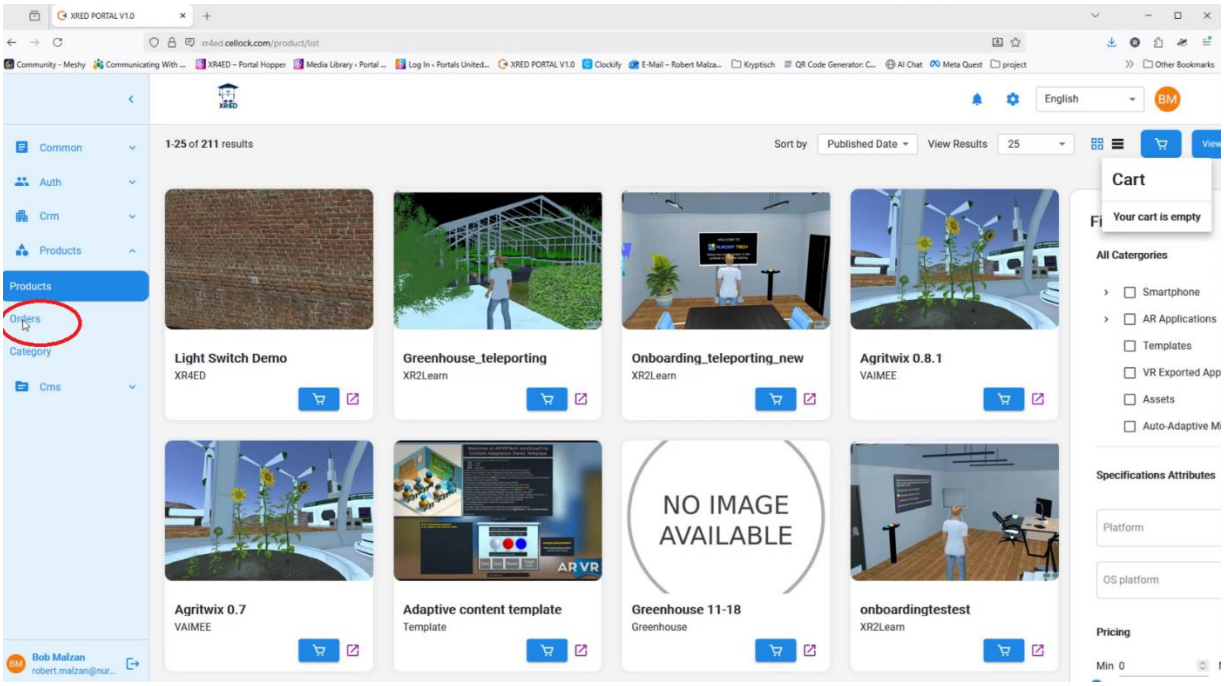
Add it to the cart



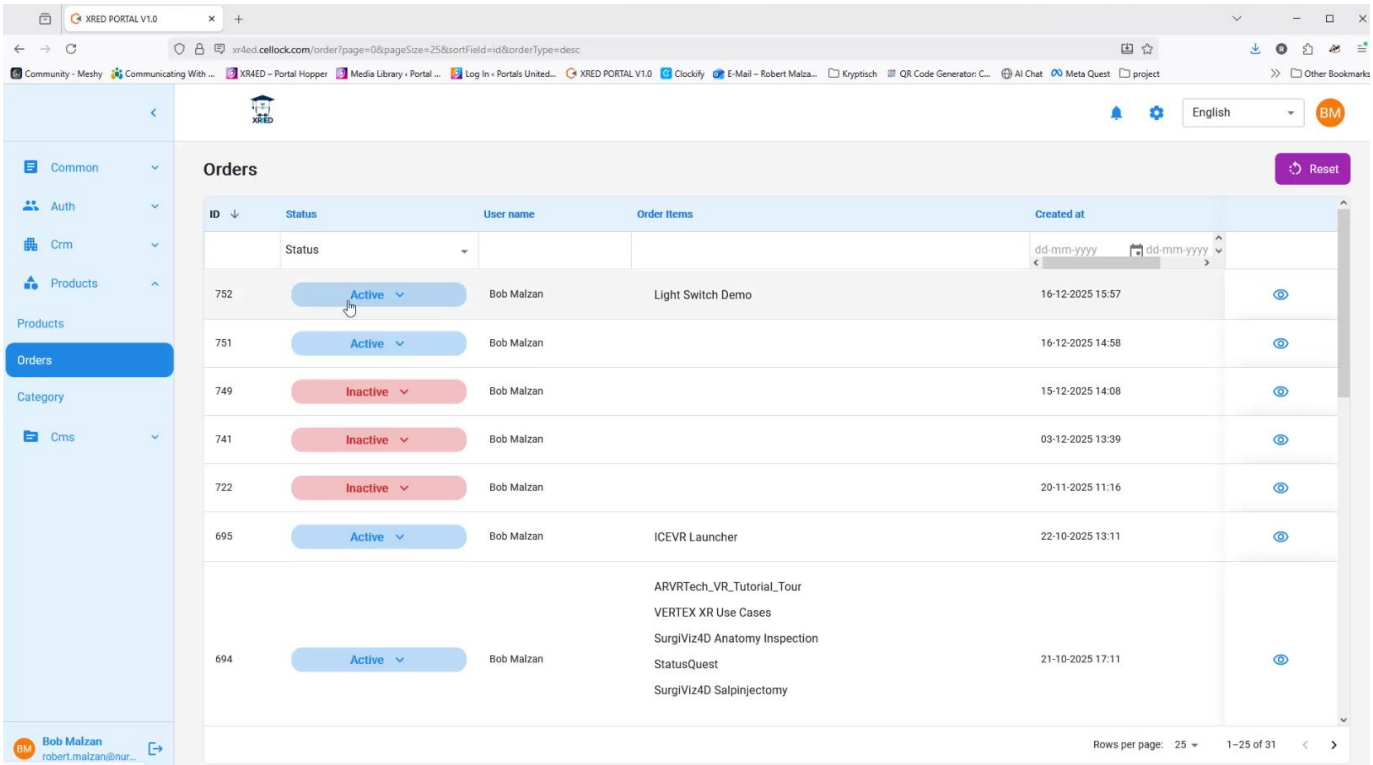
Then we checkout and confirm the order



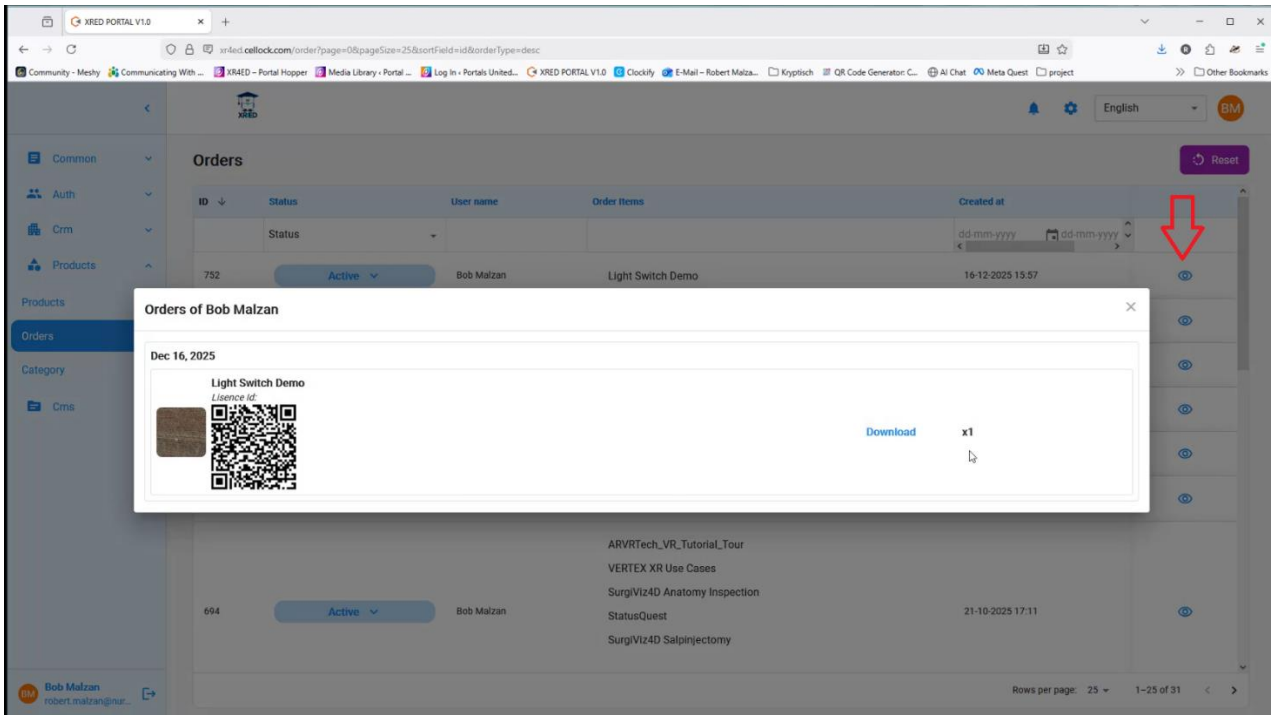
Then check the order



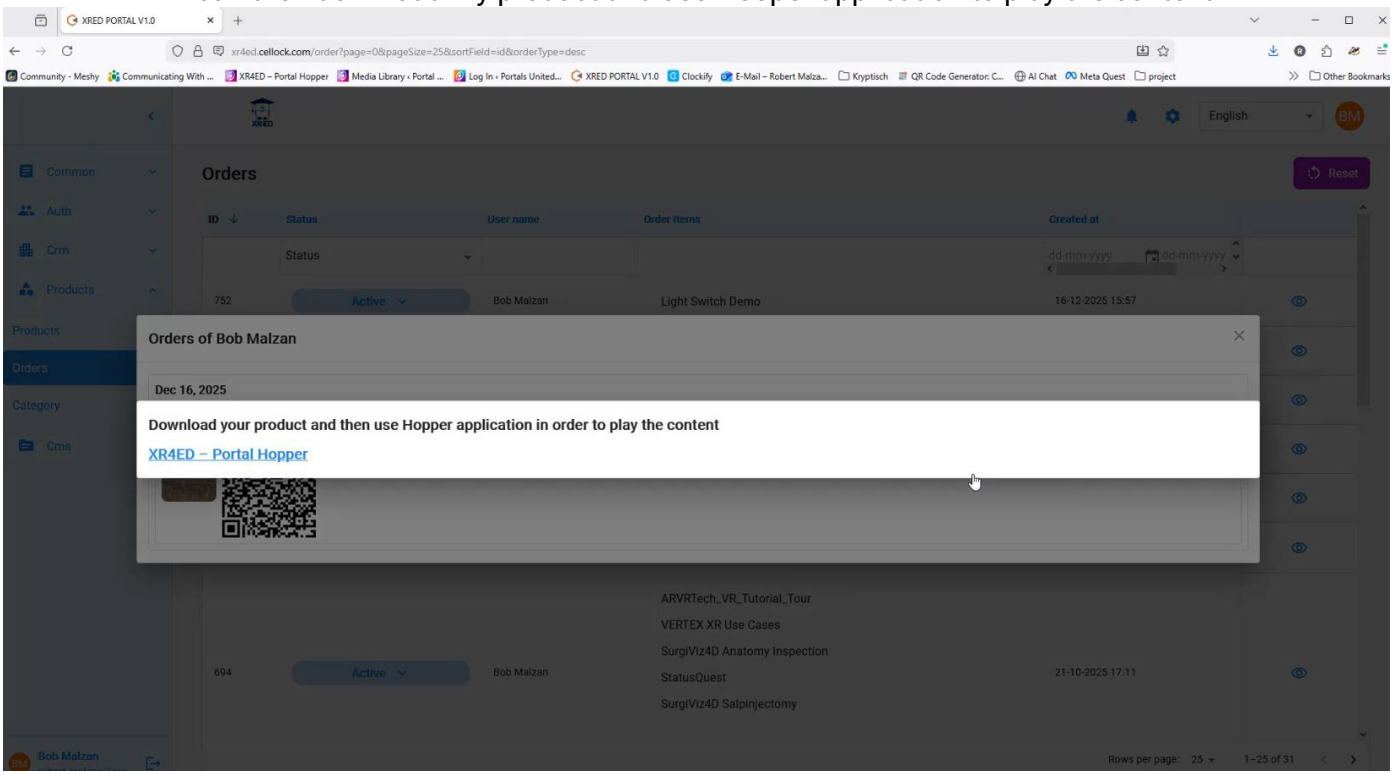
And find it as my most recent



I can also click on my “view order”



I can then download my product and use Hooper application to play the content



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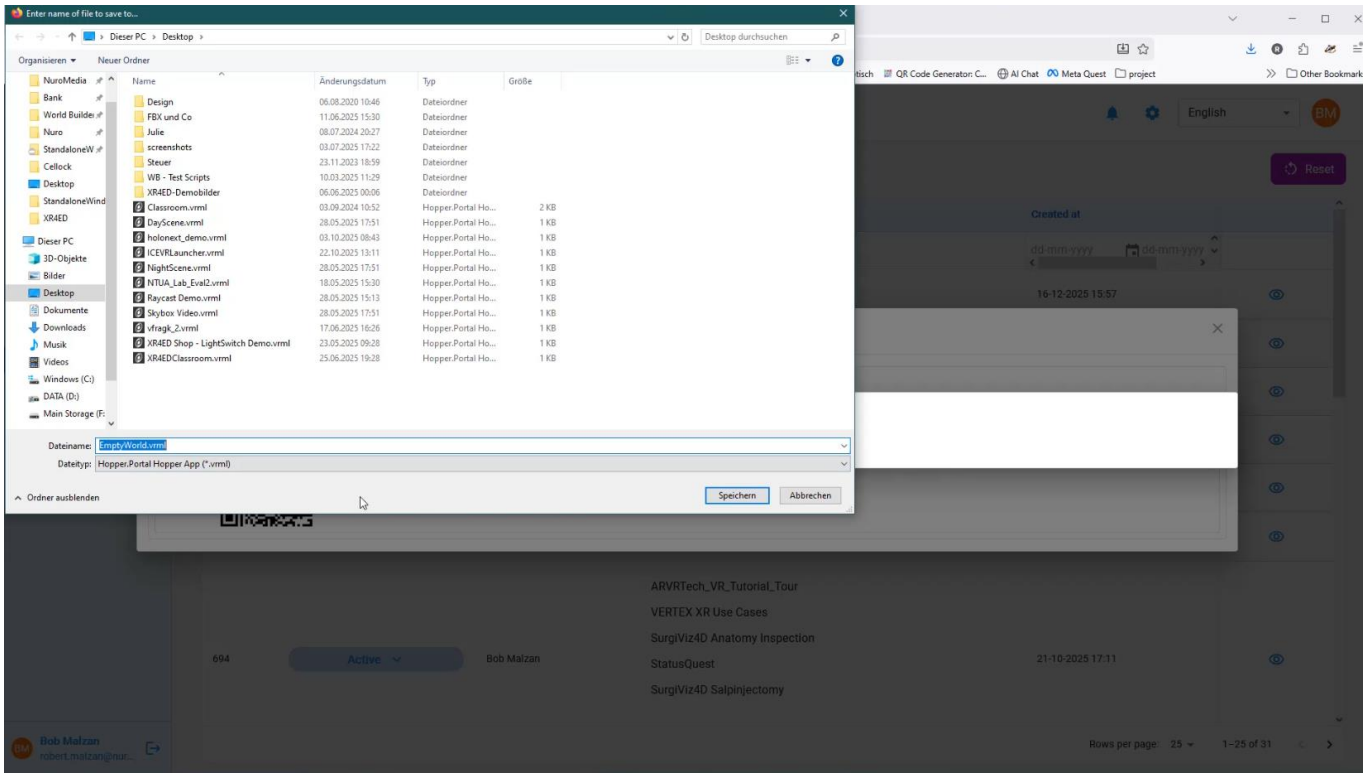
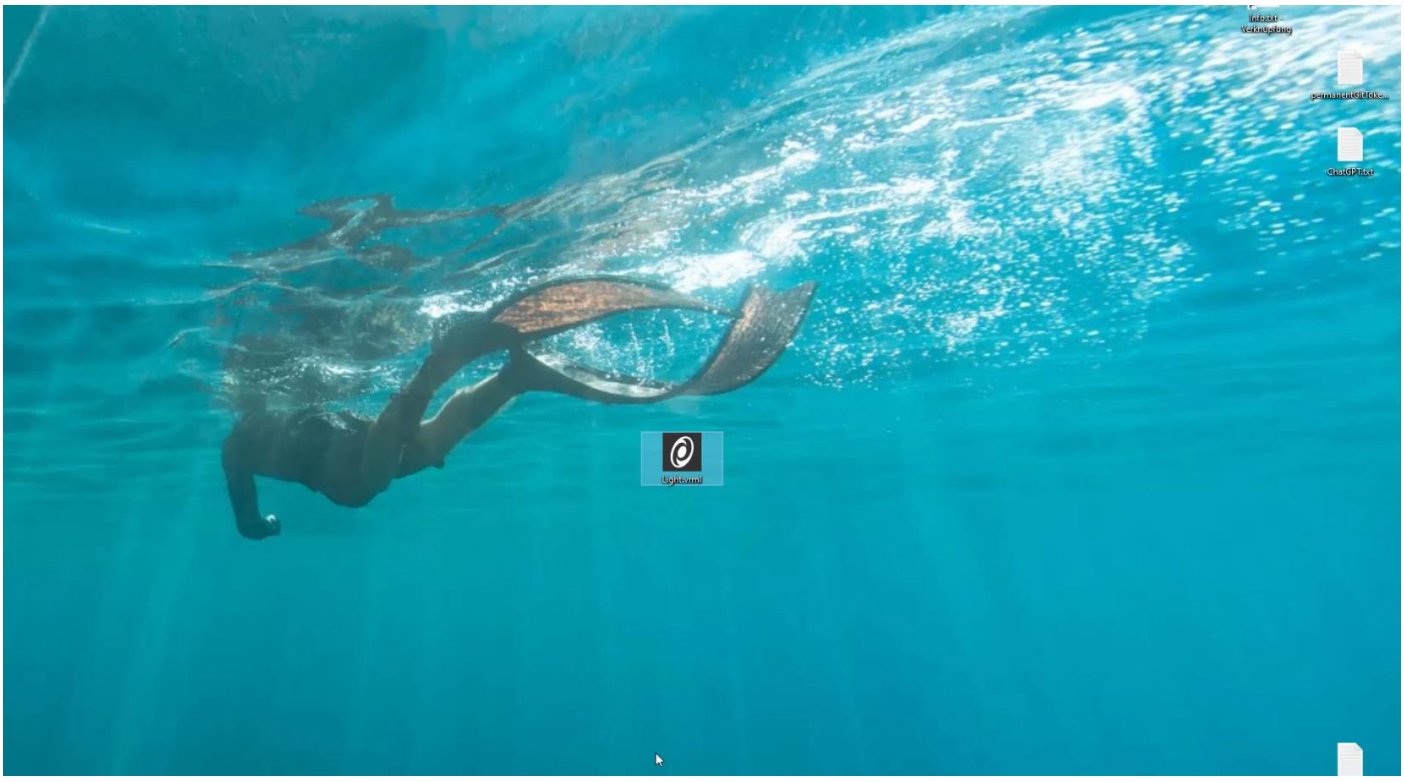


After saving to the location of my choice, here the Desktop



If I double click on the icon, the Hopper App will play the content after loading all its assets

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3.5.3 Content Submission and Moderation

The XR4ED Marketplace not only distributes content to end-users, but also provides tools for content creators/providers to submit their XR learning assets into the platform (the "Marketspace" functionality). The system includes capabilities to "Manage Products", allowing authorized contributors (e.g. XR developers, Open Call winners, project partners) to upload and manage their own XR offerings. Through a web-based submission dashboard (accessible after creator login), a provider can create a new product entry by entering a description, uploading the content files, specifying relevant metadata and categorizing the asset appropriately. For example, a developer publishing a VR lesson would fill in fields for title, overview, educational domain tags, supported platform (e.g. VR/PC), etc. and attach the content package (such as a VRML scene or asset bundle).

The Marketplace supports various XR content formats – including 3D models, complete applications or "worlds," Unity asset bundles, etc. – as long as they align with the platform's open standards and can be launched via Portal Hopper. (Notably, purely mobile XR apps (e.g. standalone .apk files) are not directly listed at this time, as the platform focuses on content that runs through the XR4ED environment; developers of such apps are instead guided to provide PC-based equivalents or integrate with the Portal Hopper protocols)

All newly submitted content undergoes administrative moderation to ensure quality, interoperability and compliance with ethics and privacy guidelines. The XR4ED platform includes a dedicated Web Administration panel for authorized administrators, which serves as the administrative front-end to the marketplace. Through this interface, moderators can review submitted listings before they go live, checking that the descriptions are clear, the content runs properly in the XR4ED environment and that no harmful or inappropriate material is present. Administrators can approve, request changes, or reject submissions as needed.

They also manage higher-level catalogue organization (e.g. defining categories, featuring certain content) and can remove or update content in case of issues or new versions. This moderation process ensures that the open Marketspace remains trustworthy and pedagogically valuable – while anyone in the community can propose content, the listed XR assets will meet baseline standards and respect intellectual property rights and data privacy (aided by the platform's built-in digital rights management). In sum, the Marketplace balances openness with oversight: content providers are empowered to publish

their educational XR creations and the platform team exercises lightweight curation and moderation via the admin tools to maintain content quality and user safety.

3.5.4 Licensing and Access Flows

A core function of the XR4ED Marketplace is handling licensing and access control for the XR content distributed through the platform. The system incorporates a robust licence management micro-service, which is invoked whenever a user "purchases" or downloads an item. Upon checkout of an asset, the platform generates a unique license record (or license key) tied to the user and that product. This ensures that each piece of content has an associated usage right granted to the specific user or institution that acquired it.

In practice, for free educational content, this license issuance is largely transparent to the user – the item is simply added to their account's library with unlimited personal use. For any paid or otherwise access-restricted content, the license might enforce conditions (e.g. an expiration date or a limit on number of concurrent uses) and the system would issue and later validate license keys accordingly. The XR4ED license microservice is capable of issuing, renewing and validating licenses across the platform's applications.

This means, for instance, if a school purchases a premium XR training module, the Marketplace would issue a license key based on the purchase and the Portal Hopper (or other XR4ED tools) would verify this license before running the content, ensuring only authorized users access the material. The platform also makes the usage rights clear to users on the product page (via the "Meta data" or license info section) – creators' rights are protected and users are informed of what they can do with the downloaded content (for example, personal educational use, number of installations, etc.).

The checkout and download process is streamlined for user convenience. After a successful checkout (free or paid), the user is typically presented with a Download button or link. In many cases this will download a VRML file or a package file for the XR experience.

At the same time – as noted in Section 3.5.1 – the interface may offer a "Launch" link using the custom hopper: protocol. This link encapsulates the necessary information (including the secure content URL and license token) to open the content directly in the Portal Hopper viewer. The Portal Hopper application, when triggered by such a link, will automatically download any required assets (if they aren't already

present) and then load the XR experience for the user. This provides a one-click playback experience post-purchase. For example, in the case of the SURE-VFT virtual field trips, once a student "purchases" the free VFT module from the marketplace, they can immediately launch it in Portal Hopper; the system will validate their user license and then immerse them in the virtual field trip environment. Early adopters have successfully used this flow – a collaborator who published a "Greenhouse IoT Lesson" noted that after the item was added to the XR4ED shop and purchased by a user, the VR lesson file could be downloaded and then opening it via Portal Hopper would run the interactive lesson. Minor iterations are ongoing to make this process foolproof (for instance, ensuring that the "Launch in Hopper" button always appears once a purchase is complete and that naming conventions of files do not hinder automatic launching).

From an administrative standpoint, the license service works hand-in-hand with the marketplace transaction system: when a user completes a purchase, the Products microservice handles the transaction details and triggers the Licenses microservice to create the appropriate license entry. This decoupled design means license generation and validation are consistent across all content and user sessions. The end result is a Marketplace that not only delivers content files but also manages access rights in a scalable, automated way. Users have a clear path to acquire content legally and use it as intended, while content creators have their rights (and potential revenue models) respected through the licensing mechanism. The platform's approach to licensing and access thus balances openness (many resources are openly available for free) with the infrastructure needed for future commercial sustainability (e.g. enabling paid content or subscription-based offerings with license keys, should the ecosystem grow in that direction). Overall, the XR4ED Marketplace's licensing and access flows ensure that obtaining XR educational experiences is as simple as a few clicks for the user, while behind the scenes the system securely handles the entitlements and provides integration with the XR4ED runtime (Portal Hopper) for a seamless experience from purchase to immersion.

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4. Conclusions

Deliverable D4.6 provides the updated, final version of the XR4ED platform prototypes that were initially introduced in D4.3. It consolidates and extends the description of the XR Module (World Builder and Portal Hopper) and the XR4ED Marketplace, reflecting their current implementation at the end of the project and positioning them within the overall platform backbone and user experience defined in D4.1, the Marketplace evolution documented in D4.2 and D4.5 and the testing and validation activities that will be reported in D4.4.

The World Builder, Portal Hopper and Marketplace collectively represent a coherent suite of tools that implement XR4ED's vision of enabling intuitive creation, management and interaction with immersive 3D educational environments. The XR Module supports the authoring, publishing and exploration of interactive worlds across multiple platforms, while the Marketplace offers a central hub for discovering, managing and distributing XR assets and solutions with appropriate product management, access and licensing mechanisms. The availability of online documentation and demonstration instances for both the XR Module and the Marketplace ensures that educators, learners and developers can access, configure and experiment with these components beyond the scope of this document.

Taken together, the platform prototypes documented in D4.6 complement the platform backbone and integration work of D4.1, the Marketplace implementation reported in D4.2 and D4.5 and the testing and verification activities in D4.4. They operationalise key elements of the XR4ED concept described in the Description of Action, including the provision of a pan-European XR platform, an XR solutions catalogue and a marketspace for XR tools and content in education. As such, D4.6 completes the documentation of the XR4ED platform prototypes within WP4 and provides a stable technical basis on which the project's open calls, pilots and exploitation activities can build during the final phase of XR4ED and beyond.

Platform Validation Through Pilot Implementations: The XR4ED platform and its components have been rigorously **validated in real-world educational pilots** during the project. Through the open-call programme, **ten pilot projects** in schools, universities and training centres across Europe **deployed XR4ED's World Builder and Portal Hopper in everyday learning scenarios**. These implementations provided invaluable feedback and proof-points. In total, the pilot experiences engaged **several hundred end-users,** including students, teachers and vocational trainees, demonstrating the platform's usability

and impact at scale. Critically, **outcomes from the pilots indicate enhanced learning effectiveness and engagement**. For example, one science pilot reported a ~94% improvement in student test scores after using an XR lesson, while another pilot saw XR training modules receive **8.7/10 average satisfaction ratings from learners**. Across the board, educators noted increased motivation and hands-on skills acquisition when using XR4ED in the classroom. These successful trials confirm that the XR4ED ecosystem is **technically robust and pedagogically beneficial**. By **meeting user requirements in diverse contexts,** from inclusive music therapy for ASD students to construction safety training, the platform has proven its versatility. The pilots also helped refine features (e.g. interface adjustments from teacher feedback, added templates for common lesson types), ensuring the final prototype addresses real user needs. In conclusion, XR4ED exits its prototyping phase with a strong evidence base: the **platform has been battle-tested in authentic educational environments**, validating its concept and readying it for wider adoption and sustainable impact beyond the project.

These results were further confirmed during the formal technical review of the open-call projects, held in October 2025, where all pilot and developer teams demonstrated working XR4ED-integrated prototypes and shared validation data, confirming the platform's effectiveness across real educational deployments.

In line with the project's sustainability plan, partner CELLOCK will ensure the continued availability of the XR4ED Marketplace and XR Module tools by hosting them on its own dedicated cloud infrastructure for a minimum of two years beyond the project's end. This commitment guarantees that educators, learners and developers can continue to access, test and build upon the platform outputs and that third-party XR4ED projects selected through the Calls for Pilots and Developers can retain their integration pathways and exposure beyond the funded period.

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