AIMCH

TRANSFORMING
HOW WE BUILD HOMES

Work package 10:

Project: Advanced Industrialised Methods for the Construction of Homes (AIMCH)

October 2021

MTC Manufacturing Technology Centre · L&Q · Construction Scotland Innovation Centre · Forster Group · Stewart Milne Group · Barratt Developments PLC · Industrial Strategy · UK Research and Innovation

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1. INTRODUCTION

New house building is facing a huge skills shortage, with the sector currently unable to meet customer and Government demand for 300,000 new houses year on year. The construction industry is changing in order to meet these targets, with offsite manufacture seen as a way to increase productivity, and improve standards of Health, Safety & Quality Assurance.

The AIMCH project presented the opportunity for Forster Roofing to partner with The Manufacturing Technology Centre (MTC), an independent Research & Technology Organisation (RTO) that develops and proves innovative manufacturing processes and technologies in an agile, low risk environment, in partnership with industry, academia and other institutions.

In 2019 Forster Roofing and MTC started developing an advanced roof tiling solution to address these challenges. The potential benefits of a successful project could significantly reduce site installation times, in turn increasing productivity, as well as a range of health and safety benefits.

Successful trials have been performed at MTC's workshop and on Forster's live construction sites in Scotland. These trials are still ongoing as the solution is further developed. The next stage includes productivity studies to validate the expected benefits.

Work package 10 is focused on a feasibility study and development of a Proof of Concept demonstrating the usage of Augmented Reality (AR) or Mixed Reality (MR) technologies to guide and facilitate the installation of Forster's advanced roof tiling system.

The core aim of this report is to explain the hardware evaluation process, the solution design, the lessons learnt and conclusions after the development and testing of the Proof of Concept (PoC) solution.

2. REQUIREMENTS

As part of the process of Forster's advanced roof tiling system, the need was recognised to streamline the process of identification of materials.

The following PoC was proposed:

- The evaluation and test of different AR or MR devices to identify which ones meet the required Health and Safety criteria to be used at heights and are suitable to be used in an outdoors environment.
- The usage of AR or MR technology to assist a worker during the process of roof installation providing information to assist in the correct selection, orientation and installation of roofing products in new build housing.
- The development of an application to run on an AR or MR device with functionality to read tile barcodes/labels, and execute augmented instructions for installation in the correct orientation and location.
- A solution capable of:
  - o Identify a point of reference to overlay the augmented instructions either by using a fiducial marker or other appropriate means.
  - o Display augmented reality information in two different common house types (Fig 1 & 2).
  - o Display three common types of roof tile (Fig 3).
  - o Display the position of different features, including integrated Solar PV panel configurations.
  - o Facilitate the generation of different variants of roof configurations.

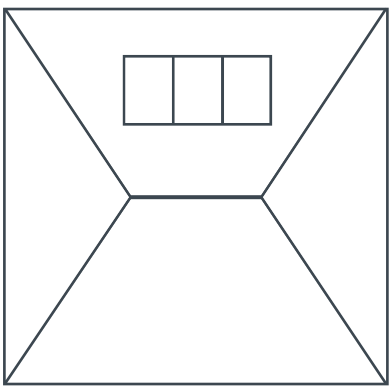


Figure 1 – House Type A

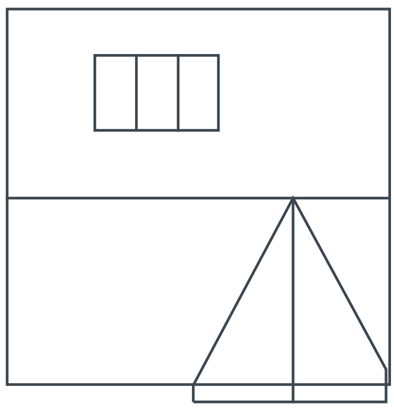


Figure 2 – House Type B

Flat Tile	Profile Tile	Flat Mock
		
Redland Mini Stonewold or equivalent supplier	Redland Grovebury or equivalent supplier	Redland Mini Stonewold Mockbond or equivalent supplier

Figure 3 – Common Tile options

3. METHODOLOGY

Despite of the PoC nature of this project and the aim to showcase the state-of-the-art technology for advanced visualisation in construction, some early concerns have been raised regarding the feasibility of the usage of Mixed Reality devices at height. This impact on the user could provoke distractions or field of view occlusion, with the increased risk of accidents.

In order to design the solution the Human Factors of the operation were considered, usability analysis performed and a full device evaluation to identify what is the best technology to be used in the required scenarios.

Due to data dependency from other work packages of the project, some assumptions and requirements (detailed below) were defined to allow the delivery of accurate and meaningful AR or MR information.

1. The solution will be provided with accurate geometry and measurement of the roof, to allow the application to generate a 3D replica of the basic features of the real environment.
2. The solution will be provided with a "Material List" document defining the relative position, shape and rotation of each of the roofing product in relation to a defined point in the Real World.
3. Roof tile packaging containment trays will have in any form a Barcode or QR Code, which will define the ID of the materials or an encoded list of Tiles ID allowing the individual identification of each of materials stored.
4. Due to Covid travel restrictions imposed during the project, a test rig will be available at the MTC workshop for testing.

Based on these assumptions the basic functionality flow of an ideal solution with independence of the hardware selected should consists of the next functionality processes:

- Roof and material list data loading, locally or from a remote server.
- Interpretation to convert this data into 3D information to be displayed in the real world.
- A generation of an AR Anchor to align real world with AR content
- Scanning of a Barcode to identify the list of materials in AR
- AR step by step guidance for material placement

4. AR DEVICE EVALUATION

Two categories of XR devices have been considered and evaluated during this project. Microsoft HoloLens 2 Mixed Reality Head Mounted Device (HMD) performance and the industrial focused version - Trimble XR10, integrated in a construction hardhat - have been compared in a Pugh Matrix against hand-held AR reality devices; the latest generations of iPhone and iPad that incorporate specialised LIDAR hardware.

Augmented Reality Enabled hand-held devices

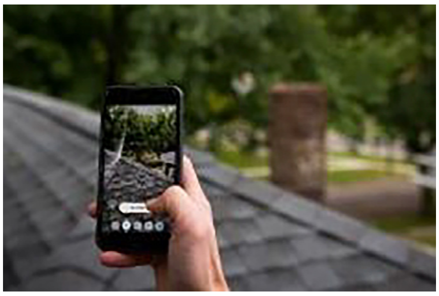


Figure 4 – iPhone and iPad

Mixed Reality Headsets

Figure 5 – Trimble XR10 and HoloLens 2

Special emphasis has been put into identifying and evaluating any potential safety risk for the worker due to the use or wear of each one of the specific devices at the working location, the suitability of the technology for being used safely outdoors during sunny days and possible mitigations.

Risk Evaluation

- Identify potential environmental and task risks
- Identify early mitigations

Device Evaluation

- Display capability – weather
- Assess devices using a Pugh Matrix
- Summary

4.1 Device Evaluation

During our evaluation, despite HMD devices providing a stable, hands free, and more natural XR interaction with the virtual information, the low brightness and high reflective screens make the device unsuitable for outdoors scenarios. Our final decision was therefore to use smartphones. However, smartphones created new technical risks due to their low accuracy, which leads to poor stability in the placement of the augmented imagery overlaid onto the real world AR technology based on Computer Vision Simultaneous Localization and Mapping (SLAM) from a single camera leads to positional errors of more than 20cms in each of the 3D axis, resulting in a solution unusable. This risk was mitigated by using the last generation (at the time of purchase January 2021) of smartphones (iPhone 12 Pro with ARKit) that includes LIDAR sensors and reduces AR drifting to the acceptable levels.

Head-Mounted Devices:

Pros

- Hands-free interaction with AR content
- No risk of dropping compared to hand held devices
- Added functionality such as remote assist for future proofing e.g. Remote Assist
- Technology will evolve, opportunity to de-risk and pioneer head mounted AR

Cons

- MR headsets have a limited near focal range at 40cm (recommendations are 1-2m for ideal comfort)
- Can become uncomfortable on head/neck/shoulders due to weight (0.5-1.25kg)
- MR use can cause eye strain over longer periods of use
- Varying light may impact tracking accuracy and cause drift
- Battery life is <3hrs – continuous use
- Expensive price point (£3.5-£5k)

Handheld Devices:

Pros

- Better display than HoloLens 2 /Trimble overall particularly in bright/sunny conditions
- Waterproof
- May be better received by operators - can be used to step towards introducing head-mounted devices once technology has matured further for outdoor use

Cons

- Risk of dropping –mitigated by attachment accessory
- Risk of distraction still prevalent
- Not hands-free
- Direct sun on screen will result in glare
- Tracking system not as sophisticated as headset resulting in drift

To compare the hardware in a systematic manner a Pugh Matrix was used. The iPhone 11 score confirmed that the usage of hand-held AR capable devices was more suitable for this project than Mixed Reality HMD despite of being the State of The Art technology for visualisation.

5. SMARTPHONE AR FOR TILE PLACEMENT POC

After the device evaluation phase, the Proof of Concept (PoC) application was developed in three stages:

1) Concept Design,

2) Solution Design and

3) User Experience (UX) design.

Each discussed below. The iOS AR application was developed using Unity 3D and Apple ARKit.

5.1. Concept Design

The proposed solution would allow the user to:

- Select one of the 3 pre-made roof configurations files that contain the information to be overlaid onto the real environment.
- Identify an AR marker as a point of reference to place AR generated content on top of the real environment.
- Identify a barcode or QR code to recognise a packaging containment tray and the materials stored on it.
- Visualise real world position and rotation of materials.
- Visualise real world position and rotation of preconfigured PV panels, vent tiles, fire barriers and tiles that require fixing.

This sequence is illustrated in figure 8 below.

5.2. Solution Design

To validate the benefits of the solution for different use cases an iOS application have been designed this design was divided in two stages, User Experience and Architecture design to fulfil the proposed functional design requirements:

UX Design

A application design was created making use of simple and intuitive interactions with the device.

The application flow was composed of 5 stages:

- App Lander: The user can select one of the different configuration files to visualise in AR.
- Data Deserialization: The selected configuration file is processed, and user can previsualize a 3D representation of the roof configuration.
- World Origin Setup: The worker uses the smartphone camera to create an AR Anchor that will help to overlay the 3D AR layer content on top of the Real-world Roof.
- Tile Tray Barcode Scanning: The user makes use of the smartphone camera to scan a barcode tag placed on one of the material trays to install.
- AR Navigation: The user visualises the real-world location of the roof materials can or filter any other individual roofing materials to be displayed as an AR layer of content.

Solution Architecture

This AR solution is based on the combination of different functional blocks working together as a Unity3D application for iOS:

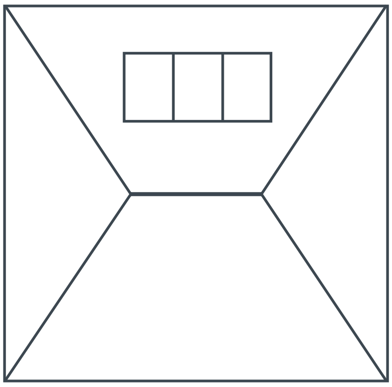
- AR Marker (ARKit): Reads sensors data and camera feed to translate the world space position and rotation of the device in relationship with the world origin, defined as an AR Maker, and based on that renders the 3D content overlaying the real environment.
- Input Data: Processes roof configuration files, including roof and tile models de-serialise tile layout files. Also provides the right information to the other functional blocks when required.
- Material Cutter: Generates in runtime 3D models of materials, based on the input layout JSON files for each roof area.
- Roof Mesh Generator: Generates in runtime 3D models of all extra content added to the application as Input data, this data can be the 3D geometry of the roof, or a custom PV panel configuration.
- Barcode Manager: Uses computer vision techniques to translate the device video feed into a serialised list of materials stored into a tile tray, this information is used to identify which materials need to be presented in front of the user to be installed correctly.
- Tile Manager: Controls which 3D information is shared with ARKit to be rendered in the real world.

Input Data

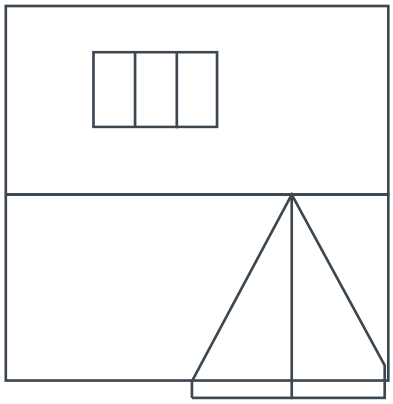
In order to generate and display all the 3D content, the application design combined the usage of pre-authored data with runtime generated 3D content. Each of the different preconfigured roof configurations available to the user are authored in Unity as a "ScriptableObject" and compiled into the application. Roof Configuration are composed of roof and material geometry files stored on device memory and parameters used to generate Tile Layouts and PV Panels elements in runtime.

Roof Configuration File are composed by these core elements:

- **Roof Geometry:** FBX 3D model with the roof 3D geometry definition and local position of each one of the roof valleys. This file can also define the existence and 3D shape of any number of Fire Barriers to be displayed.



House Type A



House Type B

- **Tile Geometry:** FBX 3D model with the 3D geometry definition of each one of the different tile configurations.

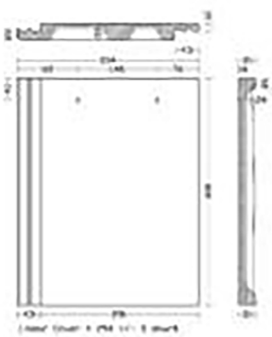
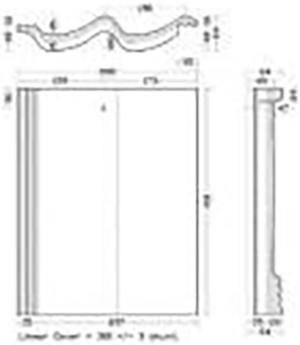
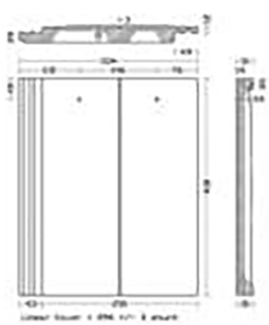
Flat Tile	Profile Tile	Flat Mock
		
Redland Mini Stonewold or equivalent supplier	Redland Grovebury or equivalent supplier	Redland Mini Stonewold Mockbond or equivalent supplier
		

Figure 11 – Tile Configurations

- **JSON Tile Layout:** JSON file generated by the “Roof tiles calculator”. This file defines the position and shape of each one of the tiles of each valley of the roof.
- **PV Panel Configuration:** Serialised file that defines the local position, size and specifications of each one of the PV Arrays to be visualised, these arrays extend to any number of columns and rows and any of the PV Panel models are represented using colour code.

Roof Configuration files also include IDs to recognise tiles that need extra fixings during the installation or correspond to a Vent Tile.

Once files are structured and compiled into one single configuration file, when loaded in the application, a new roof is dynamically generated with all the defined characteristics.

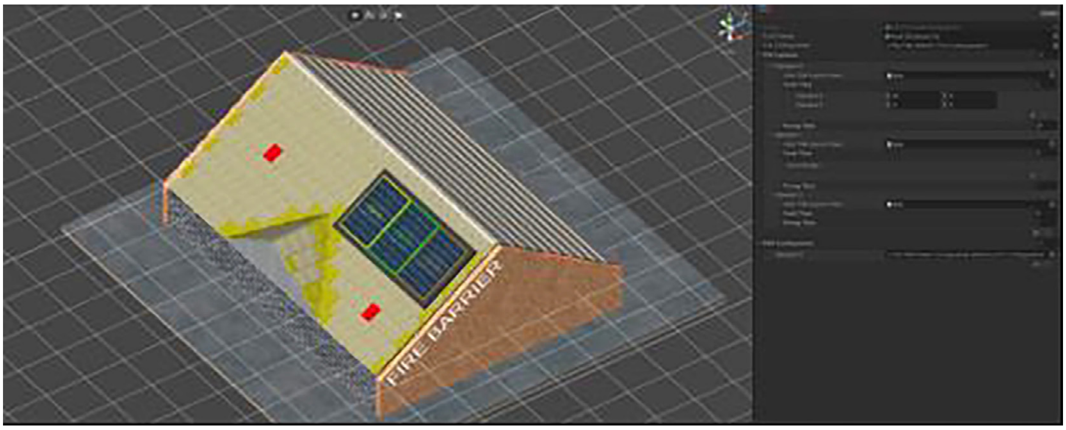


Figure 11 – Configuration File and Output roof generated in runtime

6. AR ANCHORS

To display Augmented Reality information on top of the real world, it is required to align the real-world space with the “Augmented Reality World Space”. There are different techniques to achieve this but one of the most common and also used in this PoC is the overlay using an AR Anchor.

This technique consists of recognise one or a set of points, position and orientation, in the real world that corresponds with the same Augmented World points and anchor them together, this is process is defined as “AR Anchor Creation”.

To simplify this process of point identification we can place in the environment an AR Marker.

Figure 12 – Image used as AR Marker and position and rotation recognition in the camera stream

On occasions and depending on illumination or camera quality, errors can be produced when identifying an AR Marker or in the alignment with the AR Anchor due to AR Drifting. Therefore it’s necessary to allow the users to reset the anchor position rescanning the AR Marker or manually manipulating the AR Anchor to align it with the real world.

6.1. AR Anchor Drifting

AR Drifting is a technical limitation of actual AR technologies due to the inability of the device to know with accuracy its own position and rotation in relationship of the AR Anchor. When sensors are obstructed, lose track or the device is too far from the original reference, AR content can be rendered in the wrong position and orientation. This means the functionality of the solution is compromised as information is not placed correctly.

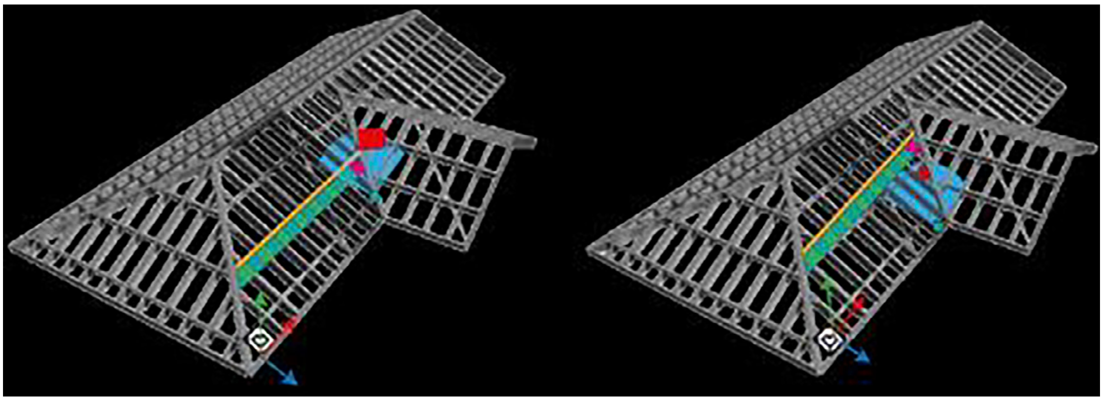


Figure 13 – Expected correct AR alignment (left) and orientation errors due to drifting at 5m from world origin

On the opposite side, smartphones utilise standard RGB cameras and accelerometers to keep track of their own position and rotation on the environment adding position error the longer the application is used and further away the device is from the AR Anchor.

6.2. LIDAR Sensor

Some trials have been performed to evaluate the tracking and AR content stability capabilities of iOS devices (iPhone 12) that include LIDAR sensors and they are specifically designed to render AR content using ARKit.

In comparison with the previous generation devices iPhone 12 accuracy increased significantly with less positional errors when the device is far away from the AR Anchor or losing track of the tracked environment and recovering the accuracy once the original AR Anchor is detected.

In general experience with LIDAR sensor are much more accurate, allowing the device as a reliable tool to display information anchored to the environment in a natural way. The user can shake the device, occlude the cameras and depth sensors and the device normally is aware of its own position being able to guide the user. But still accuracy is not reliable enough to give instructions of guidance to place objects with positional errors below 1 cm.

Figure 14 – iPhone 12 Lidar Point Cloud

7. DEMO SCENARIOS

To demonstrate the flexibility of the solution to generate different Roof Configurations in runtime based on the input data loaded, three different roof configurations have been authored and made available to the user to visualise using AR. Each one of them, demonstrating the combination of different roof shapes, tile models, and different configurations of PV Panel Arrays.

Roof Configuration A

- 3 JSON Tile Layout Files, one for each of the roof valleys
- 2 Vent Tiles
- 27 Indications of Tile Fixing Requirements
- 3x1 PV Panel Array
- 2 Fire Barriers

Roof Configuration B

This Roof Configuration file included:

- 6 JSON Tile Layout Files
- 2 Vent Tiles
- 27 Indications of Tile Fixing Requiremens
- 2 2x1 PV Panel Arrays

Roof Configuration C

This Roof Configuration file included:

- 4 JSON Tile Layout Files
- 1 Vent Tiles
- 27 Indications of Tile Fixing Requiremens
- 2x2 PV Panel Array

8. CONCLUSIONS

8.1. Conclusions

This PoC demonstrates the added value of the AR technology for training, and delivery of 3D information to workers.

It concludes that Mixed Reality HMD are not the most appropriate technology to display AR information on roofs due to the low brightness of the waveguide displays that make hard to distinguish the AR data. There were Health and Safety risks identified due to the highly reflective displays that can obstruct workers view increasing the risk of accidents at heights.

However, AR stability of handheld AR devices with LIDAR overpassed initial expectations offering a reliable and accessible alternative to consume AR information in comparison with HMDs.

This PoC solution could be expanded adding the capability of pulling Roof Configuration data from a remote server instead of being pre-authored in the application.

Evolution of the AR technology and in particular mobile LIDAR is likely to offer a complete solution for 3D roof scanning and measurement, roof configuration, material list generation and display of AR materials using one single pocket device in a single application.

GLOSSARY OF TERMS

Term	Meaning
The Project	The AIMCH project as described in the Project Application
AIMCH	Advanced Industrialised Methods of Construction for Homes
Partners	Members of the consortium who have signed the Consortium Agreement
AR	Augmented Reality
MR	Mixed Reality
PoC	Proof of Concept
HMD	Head-mounted Display
HS&E	Health, Safety and Environmental
Tiled area	The area of the roof that requires tile coverage.
Solar PV	Roof Integrated Solar Photovoltaic panels
JSON	JavaScript Object Notation
SLAM	Simultaneous localization and mapping

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