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MAAP Annotate: When Archaeology meets Augmented Reality for Annotation of Megalithic Art

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Abstract—Megalithic art is a spectacular form of symbolic representation found on prehistoric monuments. Carved by Europe’s first farmers, this art allows an insight into the creativity and vision of prehistoric communities. As examples of this art continue to fade, it is increasingly important to document and study these symbols. This paper presents MAAP Annotate, a Mixed Reality annotation tool from the Megalithic Art Analysis Project (MAAP). It provides an innovative method of interacting with megalithic art, combining cross-disciplinary research in digital heritage, 3D scanning and imaging, and augmented reality. The development of the tool is described, alongside the results of an evaluation carried out on a group of archaeologists from University College Dublin, Ireland. It is hoped that such tools will enable archaeologists to collaborate worldwide, and non-specialists to experience and learn about megalithic art.

Index Terms—Mixed Reality, Annotation, Digital Heritage, Megalithic Art.

I. INTRODUCTION

Mixed and Augmented reality (MR and AR) tools present possibilities for enhanced understanding in many fields of research, and one of the most exciting areas of such exploration is in archaeology. Unlike Virtual Reality (VR) that immerses users within pure virtual environments, AR consists in displaying digital information on top of real images. According to Azuma [1] three main constraints need to be fulfilled in AR: (1) integrating virtual objects in a real scene, (2) in real-time and (3) registered in 3D. The last criterion means that virtual objects should be positioned and orientated correctly in 3D according to the real environment (i.e., in a plausible way).

Since both AR and VR deal with virtual objects (within a virtual environment for VR and within the real environment for AR), they are generally admitted to be part of a continuum. Indeed, Milgram and Kishino [2] proposed the “Reality-Virtuality” continuum where VR lies at an end while the physical reality is at the other extremity. It is usually admitted that the limit between VR and AR can be fuzzy and as a consequence, the term Mixed Reality (MR) can be used when both real and virtual objects coexist within a scene.

Mixed reality tools merge physical and digital content in real time, allowing users to interact with their surroundings in new and exciting ways. The potential of such technologies to enhance archaeological outreach and research has long been

recognised [3], and developing augmented reality tools for use in archaeology is a captivating field of research.

One of the latest mixed reality head mounted displays (HMDs), the Microsoft HoloLens¹, is an optical see-through HMD that blends virtual images within the user’s view of their real surroundings. We believe that such devices could become important in archaeology where research typically involves visiting remote terrain, excavating and surveying, and interpreting the data gathered. Nevertheless it can sometimes be difficult to access the sites and artefacts necessary for one’s research. VR or AR HMDs can address this problem, by allowing archaeologists to closely examine 3D models of sites, objects, or excavations from the comfort of an office or a classroom. While it is always best to study an artefact or site in reality, it is unfortunately not always possible to do so. HMDs can provide an excellent substitute for this experience.

Archaeologists studying megalithic art, a form of prehistoric stone engraving, are one of many groups who could benefit from such devices. Megalithic art is found in a geographically limited area, and the monuments on which the art is located can be difficult to access, particularly during the winter or in peak tourist seasons. For this reason, having access to a 3D model of the art, which can be manipulated and annotated by archaeologists worldwide, would be useful.

The tool described here, MAAP Annotate, forms part of the Megalithic Art Analysis Project (MAAP)². MAAP aims to explore how low cost 3D scanning devices (e.g., the Xbox Kinect sensor) could be used by archaeologists to generate 3D models directly in the field. One of the goals of the project is to create a queryable database of annotated 3D models. In order to create this database, it is necessary to first have a tool which can be used to annotate the art. This was one of the primary motivations for the development of MAAP Annotate. While the current focus of the tool is megalithic art, it is intended that this tool could be used to annotate any other archaeological artefacts (i.e., any other type of rock art, pottery).

This paper is divided into five sections. Section II introduces the reader to the archaeological context, and briefly review prior research in this area. Section III outlines the system

¹<https://www.microsoft.com/en-us/hololens>

²<http://maap.ucd.ie/>

design and the software used to create MAAP Annotate, before giving a detailed description of the tool. Section IV describes the evaluation of the tool by archaeologists, and summarises the results. Section V discusses how this tool could be improved in the future, and what features remain to be implemented. Section VI concludes the paper with a brief exploration of the potential of MR tools in archaeology.

II. MIXED REALITY AND ARCHAEOLOGY RELATED WORK

Megalithic art bears testament to the creativity and vision of Europe's first farming communities. It is found carved or painted onto Neolithic monuments, usually, although not exclusively, passage tombs [4]. These tombs date between 4200-3000 BC, and were used for the deposition of human remains, as well as other ceremonial activities [4]. Unfortunately, due to the deterioration of these monuments over time, the art is often exposed to the elements where it is in danger of being vandalised, weathered, or covered by plant overgrowth.

Archaeological research has focused on documenting, preserving and analysing this art [5], [6], [7]. In certain cases, previous research and sketches of the art are all that remain. Traditional methods of recording megalithic art involved sketching or tracing the art; however, recent work has moved towards non-contact digital techniques, such as photogrammetry or laser scanning [8]. These digital methodologies often produce 3D models, which can be shared between archaeologists and act as a virtual record of the art. MAAP Annotate was built with these 3D models in mind, and aims to provide a user-friendly method of annotating and studying megalithic art.

To date, few annotation tools have been created for examining megalithic art, and other forms of engraved art. One exception is the tool developed by Seidl et al. [9]. This team developed an annotation tool to annotate the engraved panels found in the World Heritage Site at Valcamonica, Italy. They developed this tool in order to facilitate machine learning and auto-classification of early medieval petroglyphs. This tool used images rather than 3D models, and was used on a desktop computer. Indeed, there are few examples of how mixed and augmented reality tools have been applied in an archaeological context. In many cases, these devices have been used to enhance the user experience within a museum [10].

Other researchers have experimented with reconstructing and examining excavations using augmented reality. In 2004, a device called VITA (Visual Interaction Tool for Archaeology) was developed to facilitate off-site visualisation of an excavation [11]. VITA utilised a head-mounted device (Sony LDI-D100B) and a hand-tracker (Essential Reality P5 glove) to allow users to control the visualisation of 3D terrain models, Harris Matrices (widely used archaeological diagram representations of temporal relationships), and virtual artefact trays [11]. Lercari et al. [10] is another example of researchers attempting to recreate and study excavations. However, in general, augmented reality has not been utilised to a large extent in archaeology, and there are no AR annotation tools developed for use in archaeological research.

Although AR annotation tools have not yet been explored in archaeology, they have been investigated in other fields. An application, TagIt!, was created for use with the Google Glass and Google Tango [12]. This application allowed users to annotate objects and places in their surroundings. Like our tool, it utilised voice to text commands in order to write the annotations, which were then linked to a specific location or object. However, apart from the method of annotation this tool has relatively little in common with our application, as it focused on annotating real objects, as opposed to 3D models.

There are a variety of methods developed to annotate real life objects in the Microsoft HoloLens. One of these methods allows multiple users to annotate a scene, using a combination of the HoloLens and Skype [13]. This requires one person to wear the HoloLens, and call the other users over Skype. The other users will be able to see what the HoloLens wearer sees, and annotate objects in the scene using Skype drawing features on Skype-enabled devices such as tablets or PC's. These annotations are then displayed in real time to the person wearing the HoloLens.

It is also possible to annotate objects in your surroundings using the HoloLens alone. Unlike the Google Glass, the HoloLens does not require the use of an additional device such as the Google Tango in order to accurately annotate objects in the user's environment. The HoloLens annotation works by casting a ray from the user's gaze through their fingers. There are two methods of annotation: Surface Drawing and Air Drawing. In Air Drawing, the drawing is placed at the user's fingertip and is projected onto the world model on release. In Surface Drawing, the drawing is made directly onto the world surface, which is modelled by the HoloLens. Cheng et al. [14] found that Surface Drawing was both more accurate and preferred by users. As a consequence we chose this method when developing MAAP Annotate.

III. DETAILED METHODOLOGY - MAAP ANNOTATE

This section covers most details of MAAP Annotate, from the design to the implementation. More information about MAAP Annotate, as well as the source code of the application and some examples can be found on the project's online repository³. There is also a video on the same web page demonstrating the different options we present in this paper⁴.

A. System Design

MAAP Annotate was designed with input from archaeologists who had no prior experience with the HoloLens or other Mixed Reality devices. One of the primary goals of this project was to be user friendly and to present a unique method of examining megalithic art off-site. The following is a walk-through of the current user experience. It should be noted that the application is as yet incomplete, and further features will be developed, as described in Section V.

Upon opening MAAP Annotate, a 3D model of a stone with megalithic art is displayed alongside a menu with three

³<https://github.com/aventresque/MAAPAnnotate>

⁴<https://www.youtube.com/watch?v=XUPRaAGhMAw>

choices. This menu allows the user to manipulate the stone, annotate the stone, and view previous annotations. There is also a spotlight option, which can be switched on or off. It is possible to move this light around the stone, casting shadows to highlight different aspects of the art. Two boxes are also displayed on either side of the stone, both of which are used during annotation. Currently, the user can select and use the spotlight, or the first two options on the menu, manipulation and annotation. You can see the HoloLens global view in Figure 1.



Fig. 1. HoloLens global view of the 3D model, the main menu, the flashlight on the left and the option menu on the right.

a) *Manipulation*: When this option is selected, a new menu is displayed. The user can move, rotate and scale the stone, permitting them to view the stone from a variety of angles, and interact with it in a way that is not possible in other media. The reset button can be selected to orientate the stone and the menus towards the user's current position. Originally, two methods of scaling the stone were implemented, and tested by archaeologists. The user could use a sliding bar displaying the scale percentage, or they could select the stone and then move their hand forwards or backwards to change the scale. The latter was chosen after the evaluation, and is the option currently implemented in MAAP Annotate.

b) *Annotation*: Once again, upon selecting this option, the user is displayed with a new menu. In this menu, the user is presented with an option to start dictation and three others to select a portion of the stone in three different ways: drawing selection, rectangle selection and rectangle projection, see more details in Section III-E. Annotations are added using a voice-to-text input when the user hits Start Dictation. The annotations are displayed in a window next to the stone, which can be moved around the room and placed in a convenient location. Currently it is not possible to save either the annotations, or the selected portions of the stone. However, when the application is completed, it will be possible to save the results, and edit poorly transcribed words. These annotations will then be sent to a MAAP Annotate database, which will store models and annotations. However, this database is not yet functional. This is discussed in more details in Section V.

c) *Previous Annotations*: although this is a fundamental part of MAAP Annotate, which will be developed before the final version of the application, it has not yet been implemented. Currently, the option is displayed, but cannot

be selected on the menu. The annotation box to the left of the stone will be used in this feature.

B. Software Library

Microsoft HoloLens offers a developer centre⁵ with a Windows SDK (Software Development Kit) and resources such as documentation, tutorials, and source code. The recommended tools for HoloLens include: Visual Studio 2017⁶, HoloLens Emulator⁷ and Unity⁸. Note that Unity also offers a holographic emulator which is really helpful as it decreases the amount of time spent deploying the application onto the HoloLens. The open source 3D creation software Blender⁹ was used primarily to process the 3D models offline in order to display them in the HoloLens. Indeed, in order to display 3D models in real-time in the HoloLens, it was often required to pre-process them to lower the mesh quality (i.e., reduce the number of vertices and faces) and to add a high resolution texture as well as a normal map. This allowed use to accommodate the HoloLens requirements while presenting the best possible visual representation of the stone, allowing archaeologists to examine the megalithic art in sufficient detail. HoloToolkit¹⁰ is an open source toolkit for HoloLens development in Unity. It provides scripts and components that were extremely useful while developing this application. For instance, we can use events managers to know when a source (voice, hand, gesture) is detected or lost by the device. Moreover when that source is a hand we can access its position, which we use during the selection process.

C. Implementation

In this project, we developed methods for manipulating and selecting areas of interest of 3D models. The user can activate any of the methods by quickly pinching the related button in the menu. If they wish to interact with the model, they must hold the pinch and move their hand appropriately. For example, in order to move, users should first pinch the "Move" button, while to move the rock, they should pinch it and move their hand left or right. When they release the pinch, the rock will stop moving (see Figure 2). To ease users' interactions, we added an interactive cursor from the HoloToolkit library that shows where the user is currently gazing at.

D. Manipulation Methods

It was necessary to allow users to see the 3D models from different angles as well as to allow them to interact with them in a more natural way. Translating (Moving), Rotating and Scaling are the basics manipulation methods implemented. The three of them are based on displacement of the users' hand. This is computed as the difference between the hand position

⁵https://developer.microsoft.com/en-us/windows/mixed-reality/install_the_tools

⁶<https://developer.microsoft.com/en-us/windows/downloads>

⁷https://developer.microsoft.com/en-us/windows/mixed-reality/using_the_hololens_emulator

⁸<https://unity3d.com/>

⁹<https://www.blender.org/>

¹⁰<https://github.com/Microsoft/MixedRealityToolkit-Unity/>

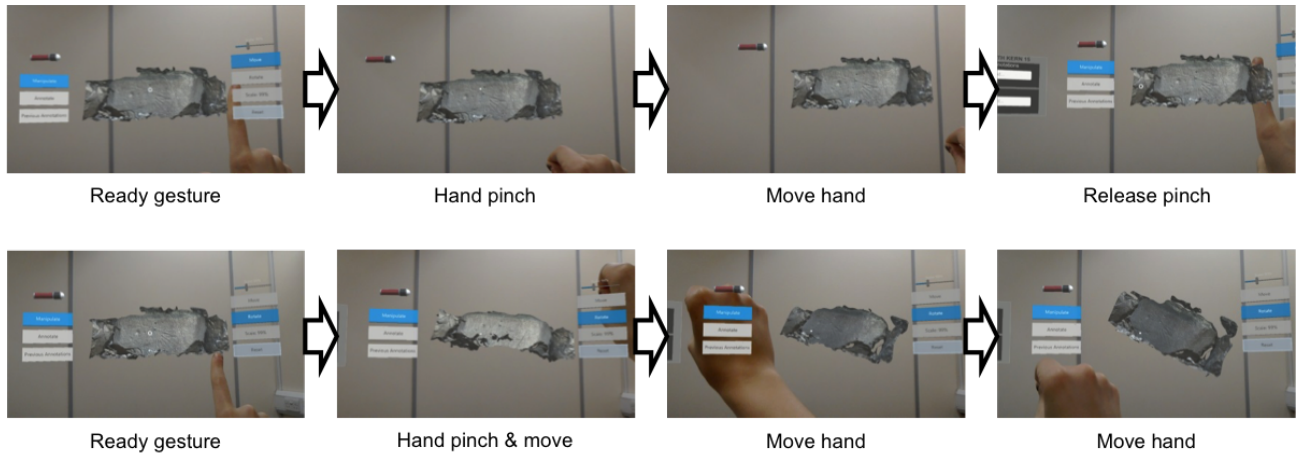


Fig. 2. Move (top row) and Rotate (bottom row) features implemented through hand gestures.

when the user pinched his thumb and index together while gazing at the stone and the current position of the user's hand.

For the translation, the movement of the hand is projected on all of the user's axes (X, Y and Z) and the model follows it exactly. While translating, the menus are hidden providing an unobstructed view to the user (see Figure 2). For the rotation, the hand movement is projected on the user's right axis (X) to rotate the stone to the right and left, and it is projected on the user's up axis (Y) to rotate the stone up and down. During rotation, forward and backward movements of the hand (Z axis) are not taken into account and the 3D model will not rotate. Similarly, the scale option is projected only on the user's forward axis (Z).

E. Selection Methods

Three different methods of selection were designed in order to select areas that the user wishes to annotate. The first type, Drawing Selection (DS), makes it possible to draw lines on the 3D model and can be used either to draw directly on the symbols or to encircle specific symbols. Both the second and third types are based on a rectangle created and extended close to the stone following the user's hand movement (see Figure 3). When released, the rectangle is projected on the stone as a rectangle - Rectangle Selection (RS) - or is projected as a new mesh following perfectly the stone's own mesh - Rectangle Projection (RP).



Fig. 3. Creation of a rectangle for selection methods.

1) *Drawing Selection (DS)*: In order to activate this method, the user must make the ready gesture (back of the hand facing you with index finger up), and then clasp their

forefinger and thumb together (hold gesture). Holding this pose, they can then trace the outline of the symbol they wish to draw using their hand. When the tracing is completed they should release the hold gesture, returning to the ready position. To draw the results of the DS method onto the model, it is necessary to cast a ray through the user's head and hand position and save the hit positions between this ray and the 3D model. This ray must start at the point where the user is gazing and go through the user's head position in order to avoid occlusion. If the ray has two moving points (head and hand), the drawings are very shaky and unpleasant for the user. Moreover, our target application, namely archaeology, requires accuracy. Thus, we had to find a way to provide users with a steady selection mechanism. In order to do this a fixed point behind the user's head following their gazing direction is computed. This point is set with the first pinch and stays constant until the pinch is released. The ray is cast through this point and a fake hand position calculated at the position where the user is gazing. A line is drawn and extended with every hit position between the ray and the megalithic rock as displayed in Figure 5. During the drawing a rainbow cursor follows the current ray hit position so that users can have a visual feedback of where they are drawing (see Figure 4).

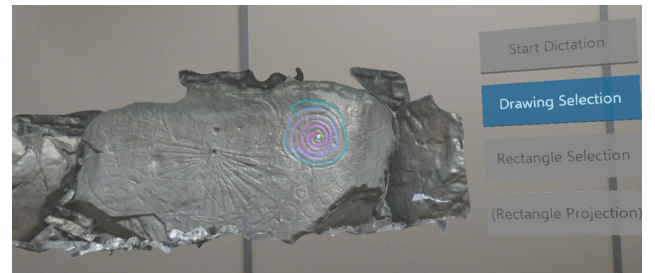


Fig. 4. Spiral outlined with the drawing feature.

2) *Rectangle Selection (RS)*: Rectangle selection, allows the user to select a portion of the stone using the drag and select rectangle familiar to users in photo editing software. The

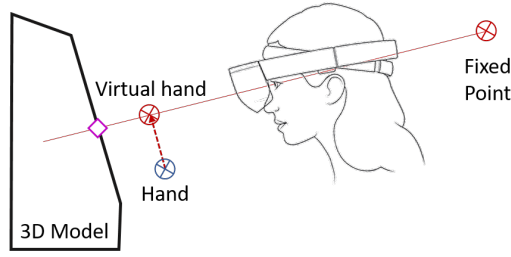


Fig. 5. Illustration of the implementation of the drawing mechanism.

user can do so by making the ready gesture, and then clasping their thumb and forefinger together and dragging to create a rectangle. Everything within this rectangle is then selected, and can be annotated. For both rectangle methods, the rectangle is created and extended in the same way as during manipulation i.e., by measuring the distance between the first and current hand positions projected in the X and Y user's space (see Figure 3). One corner of the rectangle corresponds to the first hit point on the 3D model, the user can then extend by moving their pinched hand around their environment. When released, the rectangle is projected on the stone by casting a ray in the user's forward head direction for each corner. If the stone is hit, this value is kept as the new corner value, if not, a ray is cast closer and closer to the first hit point until a portion of the stone is hit (see Figure 6).

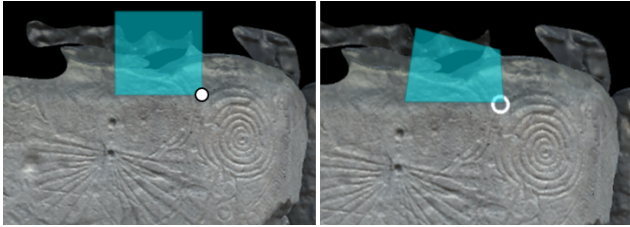


Fig. 6. Rectangle Selection (RS) before and after releasing the rectangle.

3) *Rectangle Projection (RP)*: The Rectangle Projection mechanism is created similarly as the RS. When released, the whole rectangle surface is raycasted in the direction the user is facing. The larger the dimensions of the rectangle, the more rays are cast on the rock. When rays hit the mesh, the three vertices of each triangle that is hit are saved. Afterwards, these vertices are used to create a new mesh on the rock (see Figure 7). This method perfectly matches the stone surface but is much slower and memory intensive. Unfortunately large projections can cause the application to crash. The Microsoft HoloLens has 2GB of memory but the available amount is only 900MB – as the Operating System and some necessary libraries already take some memory. When creating these new meshes, a lot of memory is consumed, and the 2GB limit is reached. At that point the application crashes, and must be relaunched. This is an issue that must be resolved before the application is made publicly accessible. A possible solution is to optimise the mesh, by saving as few vertices as possible.

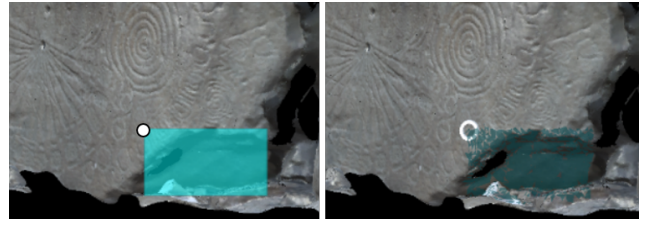


Fig. 7. Rectangle Projection (RP) before and after releasing the rectangle.

F. Additional Features

The type of stone art we consider in our study (megalithic art) is sometimes of mixed to poor quality - e.g., weathered, vandalised. Identifying the art is then not an easy task which often requires using lighting equipment. MAAP Annotate provides archaeologists with a virtual lamp so that they can (re-)examine the art present on the 3D models of the stones. The lamp is set to face the centre of the stone when switched on. While switched on it can be rotated around the model by pinching the handle of the lamp, and holding the pinch while moving your hand. When it is turned off, it does not face the stone and can be moved freely around the room. In order to switch the lamp on and off, the user simply has to make the pinch gesture on the ball in front of the lamp. This ball is white when turned off, and yellow when turned on.

The menus are locked in the Y axis, so that they remain vertical. The other axes are set to face the user at all times, allowing an easy interaction with the model. When the model is moving, or being scaled, these menus disappear, to facilitate movement and prevent the user's view from being obstructed.

IV. EVALUATION OF MAAP ANNOTATE

In order to evaluate whether MAAP Annotate is considered useful by the wider archaeological community, the tool was tested by 10 archaeologists from University College Dublin (5 females and 5 males; 4 under 30, 4 under 50 and 2 over 50). These archaeologists had a variety of experiences, in both commercial and academic archaeology.

The evaluation had three stages, and took approximately 30 minutes per person. First, each participant was taught how to use MAAP Annotate, and introduced to each of the features that were being tested. The HoloLens was connected to a laptop, which displayed the user's field of view. This allowed participants to observe an experienced user using MAAP Annotate, and learn how to use each of the features. They then wore the HoloLens for approximately 5-10 minutes, assessing all functional features. For the first few minutes, they were observed and guided using the laptop. When they understood how the different gestures worked, they used the HoloLens without guidance. Afterwards, they were asked to fill out a brief questionnaire, consisting of 15 questions.

The first ten questions were based upon the System Usability Scale (SUS) developed by Brooke [15]. It consisted of an equal number of positive and negative phrases, each of which the users rated based upon how much they agreed with

each phrase. Each phrase was scored from 1 - 5 with one being strongly disagree, and five being strongly agree. Note that the usability tested was that of the features developed by the MAAP team, rather than the usability of the HoloLens.

These questions were aimed at the 3D model translation and rotation, the two different scaling methods, the two different selection methods and about the use of the virtual light.

The remaining five questions gathered information about the users themselves, and their opinions of MAAP Annotate. This section invited opinions, suggestions for the application, and comments about all of the features.

This combination of quantitative and qualitative data collection allowed a well-rounded assessment of how useful the tool is, and how it could potentially be improved. The results of this evaluation are outlined below.

A. Results

Results of the SUS were overall positive (see Table I), with an average score of 80.75 out of 100. According to [16] anything above 68% is to be considered good, and a value over 80.3 corresponds to grade A (the best). The lowest score attained was 57.5, and the highest was 95. When analysing scores for the individual answers, interesting results arise.

90% of respondents felt that using MAAP Annotate felt natural and logical, scoring it between 4 and 5. All participants felt that the movement tool was well designed and that the rotation tool was easy to use, giving both features scores of 4 or 5. While all participants agreed that both the scale bar and the hand scale were well designed and easy to use, 60% of them scored the hand scale option 5 out of 5, while only 40% gave the scale bar a score of 5 out of 5. This suggests that the hand scale may be more usable, and comfort our choice in providing it as the default scale mechanism.

60% of the participants rated the drawing selection as a 3, suggesting that this is a little difficult to use, and requires some improvement. This is supported by the qualitative survey, where 5 participants suggested improvements for the drawing tool. On the other hand, 90% of users felt that the rectangular selection was capable of accurately selecting symbols. In the qualitative questions, one user suggested that this option should come with a variety of shapes, rather than simply the rectangular option. These results suggest that while the drawing selection needs some more work in order to become more usable, the rectangular selection is already quite convenient.

The majority of participants (80%) thought the virtual lamp was a useful tool when examining the stone, however 20% scored it a 2 out of 5. One of those who gave the lamp a low score suggested that the lamp did not provide enough contrast between the raised and lower parts of the art. This suggests some additional work on the virtual light feature such as offering more control on the virtual lighting conditions (e.g., changing the intensity or the colour of the light, etc.).

The qualitative results have some interesting trends. None of the users had previously used a HoloLens or any other mixed reality device. 40% were less than 30 years of age, 40% were aged between 30-50, and 20% were more than 50 years old.

20% of respondents felt that none of the features required significant changes, 10% were unsure, as they felt they did not have enough time to truly test the application. 70% suggested changes that could be made to various features. There were a total of 8 suggested changes from all of the surveys. Two suggestions relate to the ability of the HoloLens to identify and respond to hand gestures. As this is a feature of the HoloLens rather than MAAP Annotate, it is not something that we can address. Moreover, it is very likely that hand recognition will be much more precise and efficient in the future versions of such MR devices. Finally, it is possible that the users may have required more time to become accustomed to the HoloLens.

The other suggestions were directly related to features we had designed. Three comments focused on the selection tools, with two relating to the drawing selection and one to the rectangular selection. As mentioned above, one user felt that there should be a choice of various shapes in the rectangular selection option, which would allow the user to choose the shape to suit the feature they were annotating. The other two users suggested improvements needed to be made to the drawing selection. One simply commented that it was a little awkward, while the other suggested that the user should have the option of different line thicknesses to draw with. In this way, they would be able to select a line which suited the symbol they were annotating, as the width of symbols can vary greatly from stone to stone.

Two suggestions were related to the scaling option. One user felt that it should be possible to enlarge the stone greater than 200 percent, while the other commented that when the stone was large, the menu options disappeared behind the stone. They felt the menus should move with the stone.

The final suggestion was not related to any of the features currently implemented, and rather suggested the creation of a feature which would allow successive stones to be viewed in order. This feature would allow the user to view stones, located next to each other in passage tombs. It would be a carousel of sorts, and the user could simply drag the current stone forward to view the one behind. This is an idea that could go into future work, and will be discussed below.

The next question asked the participants if they had general comments, unrelated to specific features. One comment suggested that the drawing selection tool required a pointer or pen nib of some kind to make it easier to use. Another suggested that the lamp should be stronger, to increase the contrast between light and shadow, and allow more of the art to be viewed. A response suggested that the annotation box should be located above the stone, rather than next to it, to allow the user to view the stone and the text as they are speaking. All of these suggestions will be taken into consideration.

The other comments were more general, with one respondent suggesting that a demo video should be created for users to view prior to using the tool. Another respondent suggested that the tool should be made available for use with other archaeological models, particularly artefacts. Finally, one user commented upon the usefulness of the voice to text annotation, as it allows the user to analyse the stone without breaking their

TABLE I

QUANTITATIVE QUESTIONS OF THE SYSTEM USABILITY STUDY OF MAAP ANNOTATE. THE SCORES ARE MULTIPLIED BY DIFFERENT FACTORS TO GIVE AN OVERALL VALUE IN PERCENTAGE (80.75% HERE). ACCORDING TO RECENT RESEARCH [16] THIS CORRESPONDS TO GRADE A OF USABILITY.

Questions	Score					Average
	1=strongly disagree	2	3	4	5=strongly agree	
I thought that using MAAP Annotate was natural & logical	0%	10%	0%	30%	60%	4.4
I felt physical discomfort while using this application	40%	30%	10%	20%	0%	2.1
The movement feature was well designed	0%	0%	0%	60%	40%	4.4
I thought the rotation feature was too complex/difficult to use	40%	60%	0%	0%	0%	1.6
I felt the scale bar was a simple & effective option	0%	0%	10%	50%	40%	4.3
I felt the rectangle selection was incapable of accurately selecting symbols	30%	60%	10%	0%	0%	1.8
The hand scale option was easy to use and understand	0%	10%	0%	30%	60%	4.4
I found the drawing selection feature very cumbersome/awkward to use	20%	20%	60%	0%	0%	2.4
I thought the lamp was very useful when examining the art	0%	20%	0%	20%	60%	4.2
I would not like to use MAAP Annotate in my future archaeological research	40%	60%	0%	0%	0%	1.7
Total Usability Score						80.75%

flow to write notes.

The final question asked the participants if they felt that this tool would be useful in future archaeological research. All participants agreed, with the majority commenting upon the usefulness of this in situations where objects which are not easily accessed. Another aspect that was popular was the ability to use a tool like this to collaborate with other archaeologists around the globe, while the final comment related to the use of such a tool in public outreach. However, one user commented that the cost of a HoloLens is currently outside of the budget of most archaeologists. This is an important point, as the HoloLens is quite expensive. It is hoped that, as mixed and augmented reality devices become increasingly popular, the price of such devices will drop and more archaeologists will be able to access them. Until then, this tool is not feasible on the HoloLens, and must instead be utilised on a desktop computer, laptop, or tablet.

V. DISCUSSION

It was incredibly insightful to test MAAP Annotate on archaeologists – as they are the target audience who will be using this application in the future to assist in their annotations and analysis of megalithic art or other archaeological artefacts. The test confirmed that this application is usable and that archaeologists view the HoloLens and the MAAP Annotate tool as an excellent way to annotate megalithic art. They also appreciated the possibility of being able to view a stone and take notes simultaneously without being interrupted by the necessity to write on paper. However, it is also clear that there is still work to be done to make this application practical.

Firstly, none of the archaeologists consulted had previous experience with a mixed reality device. As a result, it would be necessary to create a quick educational tutorial, teaching

the gestures and explaining the features. Secondly, quite a few people had problems with the drawing selection feature. This feature can be difficult to get used to, and this was reflected in the feedback. While none of the participants thought it was extremely cumbersome, the majority gave it a mark of 3 out of 5, suggesting that some improvements need to be implemented. Thirdly, the lamp will require some adjustment. While the majority thought that it was very useful, two participants suggested that it should be stronger, in order to give more contrast. One participant also suggested that it would be interesting to have multiple lights to place in different positions. This is something that will require more investigation. Finally, several suggestions were made about the placement of the annotation box and the menu. While this is a purely cosmetic issue, it is important that this tool is as easy to use and navigate as possible. For this reason, the suggestions about the placement of these items will be implemented.

Future work will also involve creating a database in which all of the stones in Ireland and Northern Ireland will be stored. Eventually, it is intended that 3D models collected in other countries will also be available on this project. When this database is created, users will be able to select any country for which 3D models are available. After choosing a country, they may choose an archaeological site, and all the stones with megalithic art from that site will appear on the screen. They will then have the option to select the stone that they wish to annotate. Having opened the first model, it will be possible to select additional stones and view them all simultaneously. It may be possible to view these stones in a carousel, as suggested by one of the participants. This would allow a user to explore a site without having too many models present in the room at one time. Of course, one of the challenges associated

with this is that the memory on the HoloLens cannot support such a database. It will be necessary to store everything online, meaning that it will not be possible to use this application without internet access.

It will also be possible to save annotations to this database, and to access all of the stones and annotations using MAAP Annotate. This will facilitate collaboration between archaeologists using this application, and will allow previous annotations to be fully implemented. "Previous annotations" includes both notes made by archaeologists, and the areas which they have highlighted. When users are viewing previous annotations, the area that is being discussed will automatically be highlighted. However, it will be possible to turn off this emphasis in order to better view the art itself.

When implementing the previous annotations option, notes will be ranked by expertise of the author possibly through a system of upvoting or accreditation. This will ensure users that the information they receive is legitimate. Upon selecting an annotation the user will be presented with the option of either reading or listening to it. In the final MAAP database, only verified archaeologists will be able to annotate. This will prevent non-specialists from adding inaccurate information that would decrease the value of the database.

The high scores given to MAAP Annotate by archaeologists are significant because they imply that in the future MR tools, such as the HoloLens, can be accepted and will be more widely used in an archaeological context. Applications such as MAAP Annotate facilitate archaeological research in a safe and comfortable environment, and assist in allowing more people to access and contribute to archaeological research.

VI. CONCLUSION

MAAP Annotate, although currently incomplete, provides an interactive and useful way to annotate 3D models. Currently, it is possible to manipulate a 3D model, and to create annotations. The results of our SUS demonstrated that the features implemented thus far are, for the most part, ready for use. There are some improvements to be made - the light and the drawing selection were the two most commonly criticised features. However, there remains work to be done to make this tool fully functional and usable by archaeologists.

The main focus for future work will be to create a database into which annotations can be saved, and from which previous annotations can be accessed. In addition to this, a method of viewing multiple stones will need to be developed. The SUS was useful in this regard, as it provided confirmation that this was perceived as important by archaeologists. The suggested carousel of megalithic art is an interesting idea, and is something that will be investigated. The largest obstacle to this is the lack of memory available on the HoloLens. It is likely that the database will be stored in the cloud, and will be accessed via the HoloLens connected to Wi-Fi. There are some other issues that need to be addressed, however these are mostly cosmetic - placement of menus for example - and are not the top priority for the completion of this program.

One of the primary motivations for this project was to create an annotation tool which could be used to annotate models for a queryable database of megalithic art. When the application is complete, the MAAP project will utilise this tool to start annotating these models. This will allow further, more intensive, analysis of megalithic art by archaeologists. It is interesting that 7 of the survey participants (70%) commented upon the potential of this tool for access and collaboration. This suggests that the database, which has similar goals, will be welcomed by the archaeological community.

Of course, this tool could be used on any 3D model, and not simply megalithic art. Although the primary aim of this tool is to aid archaeologists studying megalithic monuments in their research, it could also be used in other fields. This will be explored once MAAP Annotate is complete and accessible. Annotating in MR is an interactive and straightforward method of sharing knowledge and adding information to 3D models. It is hoped that MAAP Annotate will be an aid to archaeological research, teaching, and public outreach.

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