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Human-Augmented Technology Interaction for Improving Construction Quality Control and Task Monitoring: An Application of Augmented Reality for Visualization and Remote Project Management Support

December 2022

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16. Abstract
Construction projects often require effective communication between project participants dispersed across various physical locations. Traditional methods of communication might rely on site visits or telephone calls. However, site visits can lead to wasted time traveling to remote sites, and phone calls can omit critical site details due to limited visual context. Augmented Reality (AR) can, in theory, support site communication by offering a visual understanding similar to site visits but with the efficiency of telephone calls. The goal of this research was to study AR efficiency in active construction sites (i.e., uncontrolled settings). The research team used video recordings, interviews, and feedback from NDOT practitioners who used AR and those who have not yet used it. The team also studied users' behaviors and perceptions which influence communication efficiency and effectiveness through the use of two methods of AR: the Trimble XR10 and mobile computing devices (i.e., cellphones and tablets). After analyzing twenty recorded video calls and follow-up interviews fourteen factors were revealed, which were categorized into four categories: technology, people, process, and environment. Recommendations were made to overcome some environment and technology-related factors, creating a framework to help users choose the recommended AR communication application depending on particular scenarios and conditions. In addition, the authors conducted a series of Delphi panel reviews, which aimed to elicit input from experts and targeted users about their understanding of AR.

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HUMAN-AUGMENTED TECHNOLOGY INTERACTION (HATI) FOR IMPROVING CONSTRUCTION QUALITY CONTROL AND TASK MONITORING: AN APPLICATION OF AUGMENTED REALITY (AR) FOR VISUALIZATION AND REMOTE PROJECT MANAGEMENT SUPPORT

FINAL REPORT AND USER GUIDE

Prepared for

NEVADA DEPARTEMENT OF TRANSPORTTION (NDOT)
Project AGR P676-19-803

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SUMMARY

This report is the final deliverable for the research project sponsored by the Nevada Department of Transportation (NDOT), which introduces the application of Augmented Reality (AR) technology for visualization and remote communication to support inspections. AR is a technology that allows users to see the real world with virtual objects superimposed upon, or composited with, the real world.

The report includes two main parts: the research report and the user guidebook.

- The research report documents how the study was conducted; it presents the motivation behind this study, the research methods used, the results, a discussion of the findings, and a conclusion to summarize major contributions.
- The user guidebook is the practitioner-oriented document and is included as Appendix A of this report; it includes the recommended steps to set up an AR application using the necessary tools and recommendations documented by the authors based on the research findings. It also includes a helpful framework to guide potential users of AR to choose the right tool based on the project site, context, and technological needs to support communication. At the end, helpful tips are included for users to avoid initial difficulties when first using AR.

Construction projects often require effective communication between project participants dispersed across various physical locations. Traditional methods of communication would rely on site visits or phone calls. However, site visits lead to wasted time traveling to remote sites, and phone calls might omit critical site details due to limited visual context. AR in theory can support site communication by offering a visual understanding very similar to site visits but with the efficiency of phone calls. The goal of this research is to study AR efficiency in active construction sites (i.e., uncontrolled settings). The research team used video recordings, interviews, and feedback from NDOT practitioners who used AR and those who have not yet used it. We also studied users' behaviors and perceptions that influence communication efficiency and effectiveness through the use of two methods of AR: the *Trimble XR10* and mobile computing devices (i.e., cellphones and tablets).

On-site personnel from NDOT were invited to study their monitoring and communication processes through the use of Augmented Reality applications. These on-site users conducted AR remote calls with off-site users to discuss, inspect, and monitor site activities. After analyzing twenty recorded video calls and follow-up interviews, fourteen factors were revealed. Some of these factors posed challenges while others provided benefits. The research team categorized these factors into four categories related to technology, people, process, and environment. This classification allowed the team to propose recommendations to overcome some environment and

technology-related factors. Also, it allowed the authors of this study to extend their research and create a guiding framework to help users choose the recommended AR communication application depending on particular scenarios and conditions they are facing.

In order to verify the structure and wording of the developed framework, the authors also conducted a series of Delphi panel reviews, which aim to elicit input from experts and targeted users about their understanding of this tool. NDOT practitioners, with and without AR experience, participated in these sessions. Those with experience offered verification and input to ensure that the authors' results accurately reflected their AR experiences. Participants without experience offered insights into how the developed framework would be understood and used by new AR users to guide decision-making. Collectively, participants' inputs offered important suggestions to enhance the developed framework to ensure it may be useable by other NDOT users in the future.

The results of this study are synthesized in this document. The intent of this work is to help users successfully deploy AR technology to address issues that emerge on-site and decide when this mode of communication applies and offers value.

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Project Motivation and Background

1.1 Project Motivation

State departments of transportation (DOTs) often are faced with the challenging task of closely monitoring construction activities for sites that may be at distant locations. It can take hours for individuals to travel from project to project to monitor and inspect specific elements. This can be especially challenging when said tasks must be monitored by experienced managers from the DOT. Currently, DOTs typically handle construction challenges that arise through site visits and phone discussions. Site visits can lead to high-quality decision-making, but often require experienced (and typically highly paid) individuals to spend valuable time traveling to and from distant sites to provide their insights. Conversely, phone calls can enable experienced individuals in remote locations to quickly provide insights into construction situations but may not effectively support detailed visual-based communication between field and office personnel. Communicating site information through verbal descriptions alone can be prone to misunderstandings or omissions of critical site details that can impact decision making. For this reason, the research team leveraged Augmented Reality (AR) to target the efficiency of a phone call with the effectiveness of an in-person visit, in order to provide a valuable new tool for NDOT to use for communication between on-site and offsite personnel.

1.2 Background

It is known that the construction industry highly impacts the economy. In most countries, this industry constitutes three to eight percent of the Gross Domestic Product (GDP) (*1*). Challenges related to communication affect the productivity of the construction industry despite its high impact (*2,3*). Like all industries, communication is an effective tool to overcome challenges and production problems. While it takes years to develop expertise, communication is key to ensure informed management decision-making (*4,5*). This shows the importance and the need for effective communication between all stakeholders of a given project to support the construction process and outputs by allowing informed decision-making (*4,6*).

Like most operations across many industries, construction procedures are supported by traditional communication means such as face-to-face meetings facilitated by site visits and phone calls (*7*). Although face to face conversation can be the best communication due to intuitive understanding and site visuals, traveling to sites can take a lot of time and may sometimes be inefficient. In addition, phone calls can promote misunderstanding due to omission of important and critical details due to limited site vision. Moreover, considering the workforce shortage in the industry, particularly highly experienced personnel retiring in droves, these challenges are being further exacerbated affecting the monitoring process of remote projects (*8)*; this means that individuals with less experience are often asked to do a job that usually demands more expertise. This highlights the need to explore innovative communication methods that allow adequate visualization of the site's environment, a clear transmitted verbal communication and a better way to share knowledge and expertise between different site practitioners.

Augmented Reality is a technology that allows virtual objects to be superimposed on the real world to offer physical context to the virtual content and is a subset of Mixed Reality (MR) (*9, 10*). AR has the ability to superpose models, drawings, or annotation forms (e.g., text, arrows, circles, lines) onto a site view, enabling on-site and off-site users to see an augmented version of the construction site in a highway construction context (*11),* similar to the yellow or red "first-down" line on televised football games. AR allows participants in remote areas to communicate in real-time and exchange relevant information without wasting time physically traveling to sites, which may support some of the benefits of in-person meetings combined with the efficiency of phone calls.

Researchers have thoroughly explored the potential of AR to support design visualization and comprehension; however, minimal research on the use of AR for construction communication has been performed. The studies that have explored AR for construction communication have largely been conducted in controlled laboratory-like settings (*12, 13*). The research team used this existing knowledge offered by the literature investigating AR in controlled environment to influence how they deployed AR in this study in uncontrolled settings (i.e., NDOT active construction sites).

For example: Imagine sending many new personnel to a large number of sites, each with their own device, while one experienced person sits at the office from a distance and advises them on what to inspect and how to inspect it. The goal here is to extend the impact of the experienced personnel available, who can now monitor many more projects than they were traditionally able to monitor, due to a reduction in their travel time needed, while also training newer personnel on what to look for and how to inspect projects because they are guiding them and literally seeing through their eyes.

The previously identified literature, as well as the new data collected through this study, will inform how this vision may become a reality at NDOT and beyond.

CHAPTER 2

Research Method

The methodology consists of five phases: user interface definition, iterative AR development, field testing, Delphi panels, and reporting the findings. In the first phase, the team focused on findings documented in the literature and obtaining feedback from NDOT users. The second phase is based on identifying the available tools and conducting initial internal testing to develop a user guide. The third phase consists of field testing, inviting users from NDOT willing to test the application, as well as revealing findings related to their behavior and perception. The fourth phase is based on what we learned in the third phase and consists of developing a guiding framework to help the users choose the AR device that best supports decision-making based on existing site conditions and device specifications. The fifth and last phase consists of reporting all the findings in a form of research publications, start guide, and AR guiding framework, which are all included in this document as shown in Figure 1.

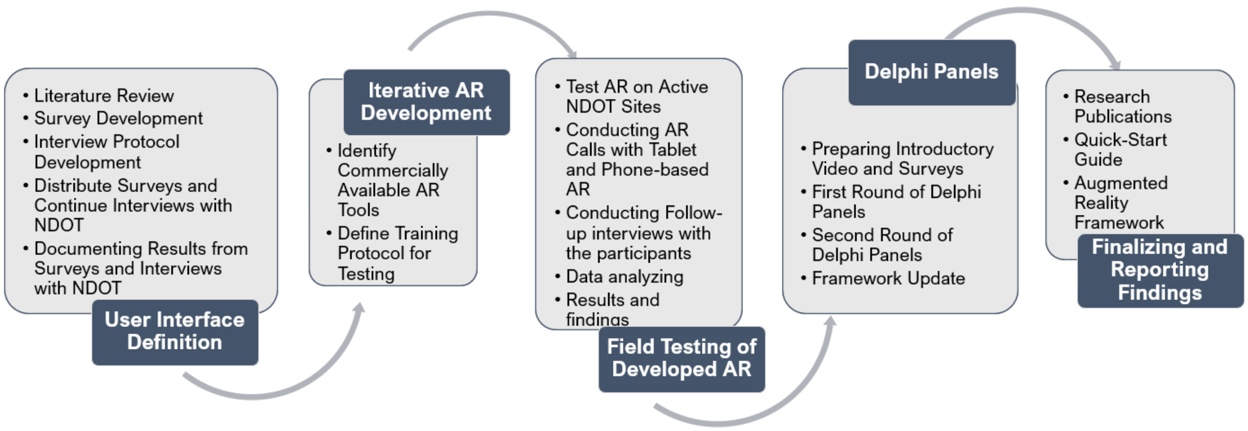

Figure 1: Methodology Key Phases

2.1 User Interface Definition

Literature Review: The team analyzed 70 leading publications on Augmented Reality (AR) and related technologies in the construction domain. This effort helped to allow the research team to build on the research findings generated by others and learn from their collective expertise when defining an effective AR user interface for NDOT.

Survey Development: The team developed and validated a survey for data collection with NDOT practitioners, using the Qualtrics web-based survey software. These questions elicited critical feedback about their background, experience, and perceptions of other relevant communication technologies.

Interview Protocol Development: The team has defined an interview protocol to elicit discussion from NDOT practitioners about various AR-related use-cases for supporting office-to-site communication. It also includes several specific high potential use-cases that have been developed in collaboration with NDOT in order to understand the value that various NDOT practitioners envision in these applications.

Distribute Surveys and Continue Interviews: The research team distributed the survey to the participants. After collecting the results from the survey, the research team conducted interviews with the same participants to collect their perception. The findings produced from these surveys and interviews allowed the research team to tailor the targeted AR user interface to maximize the potential gains stated by interviewees while avoiding some of the identified potential pitfalls.

Documenting Results from Surveys and Interviews: A journal paper has been published for this part of the work. In short, this paper identifies AR application contexts for office and field users where current practitioners envision benefits and drawbacks. These findings helped in guiding our plan for field implementation in order to test and validate the contexts perceived to offer value, while potentially avoiding contexts that were perceived to lead to drawbacks (*14*).

2.2 Iterative AR Development

Identify Commercially Available AR Tools: The team identified various commercially available AR tools to support their development efforts. The team analyzed these various tools available and elected to use the *Trimble XR10* AR device and *Microsoft Dynamics 365 Remote Assist*, which is tailored to the *HoloLens 2* and *XR10* platforms. The team has also begun exploring options for handling inevitable challenges that could arise in field conditions related to heat and glare from sunlight. These efforts helped in defining workflows and best practices that enabled the research team to select AR-based communication strategies that work in realistic conditions that may be present on active NDOT construction sites. In addition to exploring *XR10*-based AR, the team also explored options for using tablet- and phone-based AR. This enabled a broader range of AR tools to support subsequent field testing. It also helped elucidate the specific advantages of more expensive *XR10* devices over more accessible phones and tablets supporting downstream technological investment decisions for NDOT. The results of the AR user interface development for NDOT are documented in a 'Quick Start' guide to support NDOT users.

Define Training Protocol for Testing: In order to support NDOT personnel who tested our developed AR communication approach, we developed a straight-forward 'Quick Start' guide to enable these individuals to understand how to best use *Remote Assist*. To further support NDOT personnel, a graduate student involved in this work provided live feedback via phone to ensure that technical difficulties are minimized and addressed in real-time. The types of feedback provided by the graduate student have been documented in the Quick Start guide to support future NDOT use.

2.3 Field Testing of Developed AR

Test Trimble XR10 AR on Active NDOT Sites: The team successfully conducted 16 *Trimble XR10*-based AR calls during the duration of this research with 3 teams. These calls related to inspection, follow-ups, on-going activities, and collaboration with other NDOT members.

Conducting AR Calls with Tablet and Phone-based AR: The research team successfully conducted 4 AR calls with NDOT's Las Vegas and Fallon teams using phone- and tablet-based AR.

Conducting Follow-up Interviews with Participants: After testing the use of AR in real construction sites, semi-structured interviews were conducted with the same practitioners to obtain an understanding of their perceptions. These interviews offered the participants the opportunity to express their assessment on the use of AR and elicit considerations to influence when to use, or avoid, the use of AR.

Data Analysis: The video recordings provided observational data, which was analyzed using thematic analysis. This thematic analysis approach makes it possible to reveal important codes and repetitive distinguished patterns to draw meaningful conclusions.

Results and Findings: Factors affecting AR application in active construction environments were generated from observing the performance of users, and were also informed through follow-up interviews that elicited the perceptions of participants. These factors were classified into categories spanning technology, people, process, and environment. This documentation of factors identifies conditions in which AR may be or may not be a communication support for on-going construction projects. A journal paper has been published for this part of the work (*17*), in addition to two conference papers (*15, 16*).

2.4 Delphi Panels

Preparing Introductory Video and Surveys: The research team prepared an introductory video to explain the main objectives of the research with their impact on the findings (available here: https://www.youtube.com/watch?v=PGvMqkwWIL8). The video was edited, and necessary graphics and pictures were included to ensure a full comprehensive of all the given information. The video was included as a first introduction to the survey given to the participants in this phase.

First Round of Delphi Panels: In this phase, the research team used the Delphi technique to obtain the consensus of qualified and carefully selected experts on a particular subject or uncertain issue by exposing them to a set of updated questions combined with opinion-based feedback. Two surveys were prepared, one for users who have previous experience using AR, and the second survey for users who have limited experience with AR. The survey links were then distributed via emails to all participants who were given two weeks to complete it. This step constituted the first round of the Delphi panels.

Second Round of Delphi panels: The second round is based on live discussions with both groups (i.e., experienced and inexperienced AR users), where questions were updated based on the answers from the first round and initial feedback from the panelists. The second round was conducted via *Microsoft Teams*.

Framework Update: The two rounds of Delphi panels allow the update of the framework that guide the decision making on live construction sites. This framework helps the users choose which type of tools supporting AR for communication should be chosen based on site conditions and tool specifications.

2.5 Finalizing and Reporting Findings

Research Publications: At the time of this writing, the research team has authored four papers that have been published (or accepted for publication) related to AR implementation. The first paper, focused on the feasibility of AR for contextually relevant communication in the industry, and was published in the journal of Advanced Engineering Informatics in 2021 (*14*). The second paper, focused on technological processes for AR implementation, and was published and presented at ASCE's Computing Conference in Orlando, Florida (*15*). The second paper, focused on procedural workflows for field use of AR, and has been published and presented at ASCE's 2022 Construction Research Congress Conference (*16*). The third paper, focused on behaviors and perceptions observed by practitioners during field testing, and has been presented at the Transportation Research Board 2022 Conference, and published in Transportation Research Record Journal in 2022 (*17*).

Quick-Start Guide: The team has developed a guide to help new AR users quickly learn how to interact with AR when completing calls from either on- or off-site.

Augmented Reality Framework: The team has developed a decision-making framework to help NDOT practitioners select the right AR device (Cellphone-based AR or *Trimble XR10*) for a given context. The research team has solicited feedback from NDOT about this during the 2022 Resident Engineers conference in Fallon, NV. In addition, a modified-Delphi method was implemented to develop and validate this framework. The framework was well-received and also obtained a number of constructive suggestions that were incorporated into subsequent revisions. The final resulting framework is presented later in this report.

C H A P T E R 3

Results and Discussion

The outcomes of this study are the summary of the results from the initial survey conducted during the first phase, the recorded video calls of practitioners using AR, the follow-up interviews with users during the third phase, and developing the decision-making framework in phase four of the methodology.

3.1 Envisioned Concerns and Opportunities

The survey and the interviews illustrated the type of opportunities and concerns that participants envisioned for using AR on NDOT projects before implementing AR on site. The insights gained from the analysis indicated practitioners' perception of the effectiveness of current modes of communication (i.e., emails, phone calls, video calls). This first phase of the methodology provided an important baseline, and information that the research team used in later phases of this project to compare perceptions reported during field implementation. Envisioned concerns and opportunities expected to be faced on site during AR application reported by potential NDOT personnel are presented in the following sections.

3.1.1 Off-site beneficial situations

Given the opportunity for off-site personnel to be more involved remotely in site activities, AR also allows off-site professionals to handle multiple projects at the same time without physically being present on site. They can practically solve issues for multiple sites while sitting in the office. However, it was noted that the type of decisions to solve issues using AR depends on the complexity of the problem and the site itself. Based on off-site users' perceptions, the research team noted the following:

- Only simple problems (e.g., helping relatively new staff members on-site in solving an issue by pointing out the right documents for them) could be solved using AR. Complex problems would require a site visit. An example for a complex problem as provided by a participant is an issue on site that might require multiple parties to be present (e.g., when a resident engineer, contractor and subcontractor must be present on site to look at something at the same time and come to a decision.)
- AR has the potential to act as a training tool for less experienced on-site staff.

Based on a designer's perception, AR offers value by being more involved in site progress and getting a better understanding of site issues and daily challenges. This would also potentially save the design team the time required to travel to a particular site, especially when considering that many sites can be in remote locations.

3.1.2 Off-site non-beneficial situations

Non-beneficial situations were also reported by off-site practitioners, and include the following:

- Site conditions, especially on rural projects where internet and signal connectivity are unpredictable. Although AR supports communication and inspections for remote sites and saving time driving to said locations, the application could be limited by the internet connectivity and availability.

- Extreme light conditions, such as high sun brightness or very low light conditions, can be problematic.

This highlights the importance to define an efficient workflow and understand where AR does and does not apply, to address challenges related to the device and site conditions.

3.1.3 On-site beneficial situations

For on-site situations, beneficial factors were reported as follows:

- Eliminating the communication gap between architects or engineer and construction site personnel, by providing visual aids reducing misinterpretation.
- Troubleshoot on-site testing equipment with the help of online testers.
- Training new on-site staff.
- Reducing travel time to go from the office to the site to solve a simple problem.
- Saving time traveling also saves money allocated for travel, and experienced professionals can thus manage multiple sites in less time.

3.1.4 On-site non-beneficial situations

Similar to the finding reported for off-site situations, on-site non-beneficial situations mentioned that AR might not be adequate for complex projects. In addition, some participants identified factors related to safety such as:

- Bulkiness of the device in use
- Ensuring onsite users do not experience new hazards from wearing or focusing on AR device.

3.2 Observed Value of AR

Unlike the previous section that illustrates perceptions by NDOT practitioners without substantial AR experience about how AR may impact their workflows, this section focuses on what was observed when AR was actually used. The following sections present descriptions of the devices in use, the testing data using each type of device and an example narrative of on-site and off-site users for a specific case and context.

3.2.1 Description of Devices and Participants

The observations are based on AR technology that is likely to be available for use by other practitioners. More specifically, the research team chose to use "*Microsoft Teams*" and "*Microsoft Dynamics 365 Remote Assist*" to facilitate AR application between the two users. The on-site participant interfaced with the off-site participant using a *Trimble XR10*, a head-mounted visor based on *Microsoft's HoloLens 2* incorporated with a hard hat or using a cellphone or tablet, while the off-site user interfaced through a standard laptop. These tools are considered the most robust and commercially available AR devices at the time of this study.

When conducting a call between the two users, an individual from the research team joined the call to observe and record the communication process for further analysis. After conducting a number of AR calls, the research team interviewed the participants to record their perception about their AR experience. Both on-site and off-site users did not have previous experience using AR for communication. They both acquired more than 300 minutes of first-hand exposure to AR on site.

Using the *Trimble XR10*, on-site participants used hand gestures and voice commands to manipulate the interface during the conversation and generate virtual annotations to support communication. Both users were engineering technicians and had around 20 years of experience in highway infrastructure projects.

3.2.2 Field testing using *Trimble XR10*

Using a *Trimble XR10*, 14 AR calls were recorded. The purpose, time, date, duration, and number of codes revealed during each call are shown in Table 1.

Table 1: *Trimble XR10* Video Characteristics

Video	Purpose	Time	Date	Duration (Minutes)	New codes identified
1	Test call	10:13am	02/17/2021	20:04	24
2	Steel rebar around vent opening	12:30pm	02/26/2021	7:22	10
3	Stress head location around steel rebar	9:30 am	03/02/2021	3:03	5
4	Stress head location around steel rebar	10:59 am	03/02/2021	5:44	3
5	Steel plates holes drill	10:09am	03/03/2021	7:47	1
6	Concrete pouring plan	10:17pm	04/03/2021	8:01	1
7	Test call	12:08pm	08/17/2021	9:00	0
8	Road base material laying	07:30am	08/18/2021	21:47	0
9	MEP road items execution follow-up	07:37am	08/23/2021	16:50	0
10	Concrete walls patching	08:16am	08/31/2021	25:16	1
11	Slabs steel bars coring inspection	07:53am	09/08/2021	23:58	0
12	Follow-up call	01:05pm	09/17/2021	02:23	0
13	Side-way concrete edge inspection	07:36am	09/22/2021	15:35	0
14	Wall concrete pouring	07:43am	10/06/2021	12:38	0
15	Testing call, sidewalk	12:30pm	05/27/2022	58:39	0
16	Testing call, road inspection	12:00pm	06/22/2022	21:56	1

3.2.3 Field Testing using Cellphones / Tablets

Using cellphone and tablet, four AR video calls were recorded. The purpose, time, date, duration, and number of codes revealed during each call are shown in Table 2. All the videos were recorded on different days and times.

Table 2: Cellphones Video Characteristics

Video	Purpose	Time	Date	Duration (Minutes)	New codes identified
1	Concrete wall cracks inspection	8:30am	05/26/2021	11:14	3
2	Under bridge beam span inspection	9:30am	06/04/2021	6:08	2
3	HVAC opening steel bars bending	8:00am	06/15/2021	8:59	3
4	Road Inspection, testing call	12:30pm	06/22/22	9:22	1

3.2.4 Narrative of individual calls or use-cases

During phase 3 of this study, video recordings from actual AR calls were conducted between users on-site and others off-site. Section 3.2.2 shows the different videos that were recorded using *Trimble XR10* by the on-site user. In this section, Table 3 shows the narrative between two users. This narrative is taken from the video V2, subject: Steel rebars around vent. During this video, the on-site user explained the problem of the steel rebars running over the vents where they should not have been. The off-site user was able to clearly see the site and the steel rebars. In addition, he made sure that he understood the problem by the use of virtual annotation (i.e. arrows) to point to the issue. The two users discussed the solution together and came up with a decision that effectively addressed the problem. Table 3 shows observations noted by the research team when watching the video recording. Codes were revealed from these observations, and these codes were then classified and regrouped based on similarities under themes and sub-themes. The themes identified are referred to as "factors" affecting AR application on active construction projects.

Table 3: Narrative Sample from One Video

On site	Off site	Observations	Codes
Hey, this will be per cap reinforcement steel number 4 on structure i-48, we will use the rebar spacing		Drilling noise in the back	
	Do you have the pdf for that?		Desire for extra visuals
I know it took me a while to open a file, I have to break them down to smaller files, it is still showing me the signing-in stuff, but I know you guys can pop it up and open it on your screen because it is on the teams group sharing files		3 clicks on the desire file	Time to insert a file to be opened
	Right we need to get that pull it over on your files for me to see it going at the same time, but we will get that taken care of	9 clicks on the chat box	Difficulties in clicking
Yea I should be able to take care of that later in today or anything tomorrow it is just an issue we are having with the desktop computer			
	Rodger that		
I'm kind going away from these guys			Ability to move
	Okay, what are we looking at?		Visualization

On site	Off site	Observations	Codes
So they got the vents in, and our reinforcement steel on our soffits runs right over it and they didn't count for it, so talking with the teams, what we are going to do, is cut the square out 2 inches spacing around axe hatches and then put-in extra bars. The bars that we cut out and put them back in all over the corners for reinforcing around the axis hatches			Explanation of problem / more involvement
	So hang on 1 second I will start editing, what we are looking at, I need to see if we are talking about the same thing.		Desire to edit / no misleading
	we are talking about this area, in here, right?	Trying to annotate	
I'm not seeing anything on my screen			Visual is not clear
	Hang on, just bear with me	Drilling noise in the back	
No worries			
	Let me get a different color		Colors are not clear enough
	I will place an arrow instead		use of arrow
Oh I see			
	You are taking about these rebars in these areas that are crossing over the top		No misleading
Yes			
	Okay, can you see my arrows?		
Yes, I can see them perfectly			Clear annotations
	Okay, so what you are talking about is taking the transversal rebars that goes across the vent areas, and you are going to cut those off at these areas and give us a 2 inches clearance around the complete circumference of the extruded metal		Solution given

On site	Off site	Observations	Codes
That is correct			
	Okay, well that is an acceptable fix, we have actually already dealt with that fix on an earlier issue, so good I think we can apply the same	Drilling noise in the back	Solution confirmation / decision-making
Okay that sounds perfect			
	Before we hang up, are you satisfied with the solution?		
Yes, absolutely it seems the best way to go with it, and it's a great idea			Showing satisfaction
	Okay, well I confirm and say that this issue is resolved		
Alright			Go back to the interface
	Bye	Stop recording	
Bye		2 clicks to hang up	

3.3 Perceptions of AR Compared to Traditional Communication

3.3.1 On-Site Practitioner Perception

After testing the AR application, the on-site users reported willingness to implement this technology especially during remote work. They are confident of its usability and described it as a "moderately efficient communication method". It supports decision-making and helps solving site problems.

Some of the challenges reported by on-site practitioners were related to the *Trimble XR10*:

- Being head-mounted, the device is heavy on the head especially after prolonged hours of use.
- The attached headphones are uncomfortable even when alternative positions are attempted and can result in headaches.
- These headphones are not noise cancelling, so when walking around noisy and heavy machinery, it becomes hard to clearly hear the conversation. Planning the duration and the location of the call could help in reducing this challenge.
- The *Trimble XR10* promotes the overlay of annotations or drawings exchange. When using the device in broad daylight, these virtual elements were nearly impossible to see. However, adding a shading device like the tinted film provided by the research team helped overcome this issue.
- Opening large files to share documents or drawings can take too much time during a call.
- The use of hand gestures is necessary to manipulate the device. This could be difficult for users who are not familiar and are using the *Trimble XR10* for the first time. Training and using the virtual interface could be eased with time and after many repetitions.
- The internet connection is another problem faced by all forms of AR either using the *Trimble XR10* or Cellphone. Without having good signal coverage and internet connection, the call would be impossible.

- Battery and headphone chargers are another challenge for which on-site users should be aware. It is recommended to always fully charge the device before use to avoid call interruption.

Although these challenges were reported during the post-interviews conducted with the users, the users also reported some strategies and easy solutions to overcome them.

In addition to the challenges reported during the interviews conducted with the on-site users, benefits also have been reported:

- The users showed openness to the application despite all of the challenges. They believe that AR devices can be developed with time and all of the challenges related to the tools could be overcome, even the manipulation becomes easier with practice.
- The on-site users believe that AR application offers great opportunities in communication as they can communicate with people located in their offices and work remotely without traveling to remote sites.
- They also reported appreciation toward the 3D visualization and overlapping augmented systems that the application offer, in addition to the virtual annotations and the drawing exchange that they apply during discussion.

3.3.2 Off-Site Practitioner Perception

Similar to the on-site users' perception, the off-site practitioners described the application as an efficient communication tool supporting effective decision-making. They also reported the following challenges:

- The wind noise affected the clarity of the sound transmitted.
- The internet connection is another problem reported.
- The color of the annotations can sometimes be unclear based on the background. The user should strategically choose the color of the annotation drawn, based on what is visible for a given scenario.
- The off-site user reported that the on-site user wearing the *Trimble XR10* should have experience with virtual manipulation so he can successfully operate the interface and perform hand gestures.
- The off-site users reported factors that mainly resulted from site conditions and manipulation challenges.
- They also reported that their manipulation through the laptop interface was relatively easy and did not report any challenges.

Off-site users also reported the following benefits for the AR application:

- The ability to work online and save time and money associated to travel.
- Doing annotations and exchanging documents during a discussion that would support the communication process and decision-making.
- The ability to detect and predict mistakes by providing instant solutions while having a clear vision of the site shared by the on-site user.
- Off-site users also reported the benefit of the application during construction conducted at night.
- Off-site users also expressed the importance of directly resolving issues without going through the Request for Information (RFI) process, thus saving time needed to submit RFIs and waiting for responses. They reported that AR promotes real-time collaboration enhancing effective decision-making.

3.4 Developed framework Illustrating Observed Factors

3.4.1 Factors related to technology, people, process, and environment

After decoding the video recordings of the calls between the on-site and off-site users, the factors uncovered from the videos were confirmed by the factors decoded from the post-interviews performed by the research team with the same users. The research team organized the factors revealed from the data collected into categories of technology, people, process, and environment related, as shown in Table 4. Factors related to the devices and tools used by the users and how they operate were considered to be technology related. Factors related to users' behavior, performance, and actions were considered to be people related. Factors related to procedural steps followed before and during AR calls were considered to be process related. Finally, factors related to the site conditions, such as weather, time, and location were considered to be environment related. Figure 2 shows the different categories of factors and their respective icon.

Figure 2: Table Legend

Table 4: Classification of Codes and Factors

Codes Generated	**Category**				**Factors**
The use of hand gesture virtual manipulation	X	X			Virtual Manipulation
Repeat hand gestures to move the interface	X	X			
Repeat in finger-clicking gesture	X	X			
Moving with the virtual interface		X			
Instant drawing exchange	X	X	X		Visual Aid
Use of arrow to annotate	X	X	X		
Use of pen to annotate	X	X	X		
Desire for extra visuals, drawings			X		
Request for visual clarification			X		
Desire to measure		X			
Expressing that the annotations are not clear enough	X				
Time to insert a file	X				
Description of the situation with vision			X		Share Action Plan
Provide instruction			X		
Give Solution			X		
Point to objects with a finger	X				Hands-free
Do other activities	X				
Moving objects around the site	X				
Agreeing into solution / decision		X	X		Decision-Making
Confirmation of understanding		X	X		
Report the ability to hear each other	X	X			Site Interaction / Site Involvement
Report the ability to see the person talking to	X	X			
Showing satisfaction about the solution		X			
+4 person call configuration	X		X		
Expressing the situation as doing inspection	X	X			Working Remotely
Expressing gratitude when remotely solving a problem	X	X			
Appreciation of recording		X			Repetition and Back-up Information
Recording the call	X		X		

Codes Generated	Category				Factors
Moving around the site	X	X			Locomotion
Moving with the virtual interface	X	X			
Moving objects around the site	X	X			
Testing call			X		Performing Different Types of Jobs
Sharing live vision of concrete pouring activity			X		
Expressing the situation as doing the inspection			X		
Expressing concerns with the device weight	X	X	X		Device Discomfort
Expressing issues with the comfort of using the headphones	X	X	X		
Relocation due to near background noise				X	Background Noise
Repetition of statements due to wind sound				X	
Making calls at night				X	Lighting Conditions
Use of tinted film (i.e., shading device)	X	X			
Expressing concerns due to sun glare	X			X	
Bluetooth disconnection	X				Disconnection in Hardware Components
Battery disconnection	X				
Internet disconnection				X	

Virtual manipulation is a factor related to the *Trimble XR10* device supporting AR. This factor has been deduced after the repetition of the same patterns related to: "The use of hand gestures"; "repetition of finger movement for clicking"; "repetition of hand gesture"; and "moving with the virtual interface". These codes were observed in the video recordings by the research team and confirmed after, during the interview with the on-site user when expressing the challenges related to manipulating the virtual interface and keyboard by hand gestures during a call. However, these manipulation difficulties shown in the video recordings during the early stages were eased each time the same on-site user conducted a new call. Expressed also by the users during the interviews, training and practice helped the users to get more familiar with the manipulation. This highlights the importance of practicing or conducting prior sessions where the on-site user can train and get familiar with the device before direct application of AR in real live construction sites.

Exchanging drawings and documents, in addition to annotation of virtual lines and arrows over the real view of the space are patterns related to Visual Aids. Fig. 3 show a virtual shop drawing and document opened from the on-site user. These visual aids were reported as benefits offered by AR, except when practitioners have lack of familiarity on how to use these features. Some problems might be faced at the early stages of the application when trying to use these visual aids. Sharing large files, for example, is not possible due to the long time needed to load. During the first two videos, the users noted this challenge and tried to reduce the size of the shared documents. This shows how users were able to adapt to AR application and its requirement.

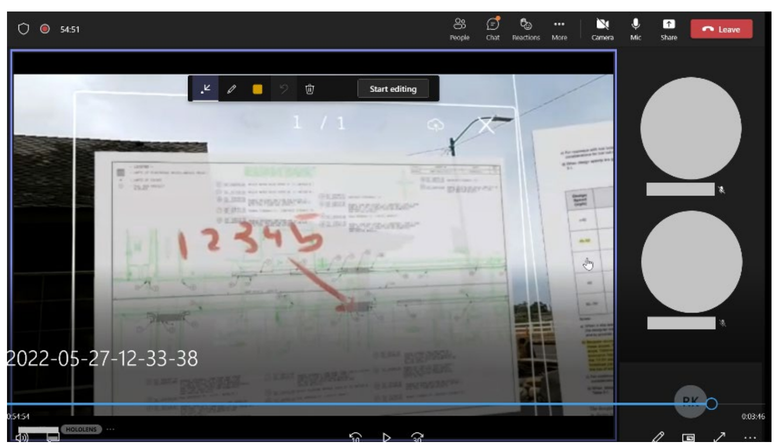

Figure 3: Document Exchange

Sharing an action plan, decision-making, and working remotely are factors pointed out by the users and observed during the recorded videos. Considered to be an added benefit to AR application, these factors show an important characteristic of the application such as the ability to describe the situation with a live vision of the site and discuss and provide direct solutions without the need to travel to site. Also, having the ability to open the camera and see the person you are having the conversation with and sharing the site view during the call is another beneficial feature that helps the off-site practitioners to be more involved in the site activities. Similar to conducting meetings with a group of stakeholders on site, AR has the ability to conduct a group call with more than one person and accommodate a meeting setup to improve the interaction between all callers.

The action of recording the call for repetition and back-up information purposes is another factor revealed by decoding the videos. The devices in use offer the option to record the conducted calls for future reference. The process of recording problems and documenting the solutions may help to prevent future problematic site situations. Similarly, locomotion is another factor that is beneficial to the application. This provides the ability to move around the site during a call, which can help to not only resolve problems that emerge on site during construction, but also conduct inspections, troubleshoot equipment issues, and even test site procedures. This diversity of AR application goals shows the added value of the application not only as an exchange of information method but also as an innovative method to conduct other sorts of site activities like inspections.

Hands-free is also another beneficial factor related to the *Trimble XR10.* As a head-mounted device, the *Trimble XR10* device allows the user to have free hands to perform other activities during the calls. Fig.4 shows how the on-site user is trying to remove a steel bar using both of his hands. This factor is an advantage to the technology offered only with the use of the *Trimble XR10*. However, this device tends to be uncomfortable and heavy on the head. The on-site users reported that the device can lead to headache and neck pain especially after prolonged hours of use. However, they also reported that by planning the duration of the call and establishing an efficient agenda to be discussed can minimize the issue.

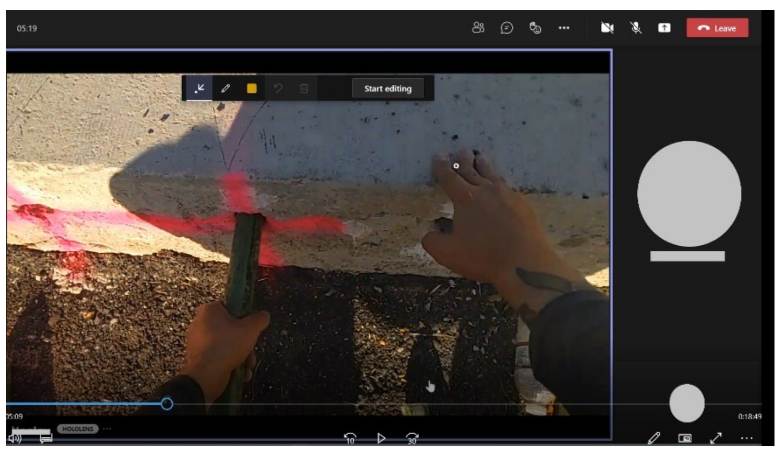

Figure 4: Handsfree to Measure

Environment related factors are often considered a challenge to AR application. Background noise is a challenge that affects the quality of the conversation. Users are often required to repeat the discussion which often increases confusion and misunderstanding. On-site users expressed the importance to distance him or herself from heavy machinery or loud activities and strategically choose where to stand during the call. Based on the observations reported from the recorded videos, users show direct adaptation to face such problems by simply relocating themselves. Similarly, to avoid disconnection of the tools in use due to battery life or headset life, the users showed adaptation by charging the devices prior to use and by planning the duration of the call.

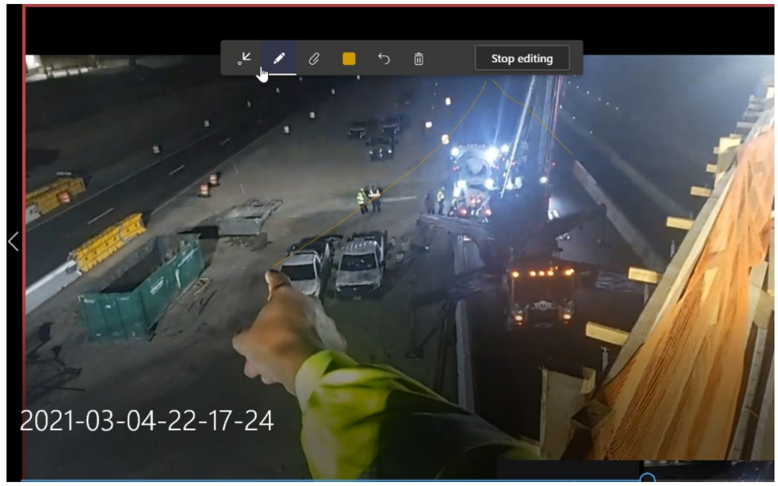

Figure 5: Call Conducted at Night, with Yellow Annotation (Arrows)

Lighting condition is another environment factor considered to be a challenge for the *Trimble XR10* reported by the on-site users. This challenge was also recognized during the internal testing done by the research team during phase 2 of the research. The research team explored the use of a low-cost mask crafted by tinted plastic film to cover the front area of the visor. The on-site users reported that the sun brightness affecting the vision of the virtual elements and the interface can be reduced by the tinted film. Thus, future studies focusing on these factors could be developed to overcome these challenges. In addition, on-site users expressed satisfaction about the use of AR during the night, such as during recording V6. Figure 5 shows the use of AR during nighttime construction activity with overlayed annotations.

3.4.2 Framework development for decision making.

After the field-testing phase and documentation of the findings, the research team was able to develop a guiding framework for AR decision making. This framework was first built on the factors revealed by the observations from the recorded videos of actual calls between on-site and off-site practitioners and their perception toward this technology. Then, the framework was tested through Delphi panels, which is a research approach intended to form consensus from experts (i.e. NDOT practitioners who may use this content). Two types of panelists were involved in these Delphi rounds; the users who actually tested the application, and new users who had never used AR or had limited experience. Users without previous experience are the targeted audience of this framework.

The first round of the Delphi panels was conducted through an online survey of panelists. The two types of users (experienced and inexperienced) were each sent a different survey. The questions asked in the survey related to the understanding of the framework. Four realistic scenarios were given to the users to test their ability to understand and apply the framework in order to choose an appropriate AR device based on specific contexts and needs. Other questions were related to the format of the framework, the workflow involved in using the framework, and its comprehensiveness. Eight users without previous AR experience and five users with AR experience completed the survey. All responses were noted and taken into consideration for analysis and updating the questions to be asked during the second round.

A second round of Delphi panels was done after the completion of the survey phase. Five practitioners from NDOT joined the meeting via *Microsoft Teams*. This group of five participants included four individuals without AR experience and one with AR experience. Those without experience offered insights into the ways in which they would plan to use the framework for decision-making. The individual with experience offered insights into the ways in which the framework does, or does not, effectively present the findings based on the individual's prior experience. This configuration of panelists helped in answering the research team's questions and providing additional feedback about how to enhance the developed framework.

After the two rounds of Delphi panels, the research team conducted a deep review of all of the answers given during the first and second rounds. Based on the answers, the participants were able to choose and justify the device choice for each scenario given based on the framework. They also expressed their opinion towards the application and the factors mentioned in the framework. In addition, they agreed on all of the factors that are present in the framework and mentioned that no factors need to be removed. They also suggested some new factors to be added. For the new factors suggested, the research team added them to the framework if they related to the decision-making process for the targeted users of AR on active construction sites. Conversely, if the suggested factors did not relate to these users or related to higher-level strategic AR decision-making, the feedback was included in this report, but not incorporated into the framework. For example: one of the mentioned factors was the cost and the related budget needed to use AR on site for each device. While this is undoubtedly important to consider, it would need to be considered in advance, rather than at the moment when a situation emerges where someone considers using AR. It also would likely be addressed by a different audience of users (likely executives within NDOT). To be clear, this content is still included in this report in section 3.5 "The Business Cases", but maintaining the focus of the decision-making framework to only factors that relate to AR application allowed the developed framework to remain broadly usable for NDOT.

The factors that emerged during the Delphi panels that would impact AR decision-making included:

- "Requires previous coordination" is a factor that has been added into the framework after the second round conducted with the practitioners. Using AR supported by either the *Trimble XR10* or the cellphone requires coordination between the on-site and the off-site user to make sure that the off-site user is ready and in front on his laptop awaiting the on-site user to call him.
- "Requires around 10 minutes set-up time" is an added factor to the framework. It shows the difference between starting up AR calls using a *Trimble XR10* or a Cellphone. The audience for this factor is the on-site user, and it directly affects the decision of which device to use.
- "Safety awareness" is another factor suggested by the users. While wearing the *Trimble XR10*, the user could potentially be distracted, which could potentially impact safety. This highlights the need to be cognizant of concerns about a particular scenario before engaging in an AR call.

Based on this feedback, the research team updated the framework to add these new factors and make edits to existing factors. The final framework produced is included in Appendix A.

3.5 The Business Cases

While many benefits and drawbacks of AR have been defined in this work, it is important to discuss the cost of such an application. We will do so by presenting relevant costs related to AR communication. Table 5 shows some of the costs associated with AR as compared to traditional in-person site visits. Admittedly, this table makes various assumptions about exact costs and travel times. In reality, exact costs would depend on a number of factors like the type of construction, personnel traveling, location of the site, distance traveled, type of car, availability of the devices, or type of cellphone. Rather than illustrating an exact return on investment (ROI) that NDOT may expect, this table is intended to show the types of factors that may lead this ROI in the future.

Table 5: Cost Example

	In-person Site Visit	*Trimble XR10*-based AR	Cellphone-based AR
Time required to drive to site	Varies based on project location	No additional travel time required	No additional travel time required
Cost of fuel (assumed)	$30.00/hour	No additional travel funding required	No additional travel funding required
Cost of AR hardware	N/A	$3,500.00	Not required if personnel already have smartphones
Cost of software (per month)	N/A	$65.00/month	$65.00/month

From the table above, it is clear that the business value of AR is derived from using it to avoid spending resources on traveling to and from remote sites.

- Assuming a NDOT employee may cost $100/hour and fuel may cost $30/hour, using AR to avoid that employee traveling 30 minutes per month for a site visit would cover the software costs associated with cellphone-based AR. For sites located 15 minutes or more away, this savings could be achieved on a single AR call per month. Any additional use would directly result in a savings over what would have been spent on travel.
- Similarly, if a *Trimble XR10* was used, avoiding the same 30 minutes of monthly travel time would cover software costs, and using the device to avoid another 27 hours of travel time would cover hardware costs. Depending on the specific sites targeted and associated travel times, this break-even number of hours could be reached within weeks or months of regular use. Any additional use would directly result in savings over what would have been spent on travel.

While there can be an economic value to using AR, the more compelling reason to use it may be to allow the experienced individual to spend his or her travel time addressing other situations at other project sites, rather than focusing on driving to and from a single remote site.

CHAPTER 4

Conclusion

This report identifies the communication scenarios in which current transportation industry practitioners envision possible value to using AR to support and replace some in-person site visits to resolve construction challenges. It also defines contextual factors that would impact the willingness of construction practitioners to adopt AR for supporting remote communication in construction environments.

In this report, the research team identified factors that impact AR communication between on-site and off-site practitioners. The factors were generated from field observations of users' performance in uncontrolled construction environments, as well as asking about their perceptions. Forty-four codes were extracted, revealing 14 key factors that could impact the success of AR. The team was able to classify them into technology, people, process, and environment categories. This classification enabled the team to identify ways in which AR technology may, and may not, immediately support site-based communication for construction applications.

Identified challenges related to AR application are associated with the type of tool used, its features, and its surroundings. Some of these factors were addressed by simple solutions suggested by the authors, such as the tinted film; others were overcome by repetition and practice by users. These factors were used to create a guiding framework targeting the users who may not have used AR application on construction sites. This framework is intended to support their decision-making regarding AR use.

Several other findings were identified. The research team found benefits from the use of AR, including the possibility of having more meaningful involvement of the design team and the efficient leveraging of experienced staff's expertise. Participants also indicated that, while AR might not be suitable in some instances specific to complex problems, it can likely offer value for most of the issues faced on a daily basis. Collectively the findings documented in this report are intended to support broad decision-making by NDOT executives regarding the use of AR, as well as practical decision-making by AR users.

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APPENDIX A

Augmented Reality User Guide

Augmented Reality (AR) is a technology that allows users to see the real world with virtual objects superimposed upon or composited with the real world. The AR user guide represents all the information and the processes needed by the person who is willing to use this application to conduct remote calls. This guide is developed by the research team and intended to be used by practitioners on-site and off-site. All the information observed, and the findings explored by this study were captured and documented to create this instructional guide.

For on-site users AR application is based on the choice between two devices:

1. A head mounted device (in this research the research team elected *Trimble XR10*, based on *Microsoft's HoloLens 2* head-mounted display)
2. Cellphones or tablets

In addition, a specified platform (*Microsoft Dynamics 365*) should be used as software supporting the AR application by the on-site caller. For the off-site user a standard laptop to receive calls from sites is needed. During a preliminary study, the research team explored both devices and platforms and explored the process of conducting remote calls. Some benefits were notes as well as some challenges. Simple solutions were tried to overcome these challenges.

The first part of this guide represents the steps needed to set-up the platforms, and some supporting tech-solutions explored by the research team and then implemented by Nevada Department of Transportation's practitioners to overcome some challenges related to the device in use.

The second part represents some recommendations based on documenting challenges related to the factors explored during the calls conducted by on-site and off-site users and the follow-up interviews done with them.

The third part of this user guide represent a guiding framework to help the users choose which type of communication tools (including AR) should be chosen based on site conditions and other specifications.

The fourth part represent a quick start guide for both on- and off-site users to help them prepare the device in use, initiate the platform, and launch the call.

The fifth and the final part is a helpful tips and tricks section for an optimal use of the application.

A1.1 AR Set-up

In this section the necessary pre-requisites are presented before conducting AR calls. In order to set-up any technology, some IT requirements are involved to ensure that the platform and the device in use are functioning. The first part of this section explains the requirements for the platforms in use by both users. The second part explains some technological requirements that could be used to support the device in use.

A1.1.1 Technological Architecture (*Microsoft* Requirements)

Onsite Set-up

The on-site user will be using *Microsoft Dynamics 365 Remote Assist* as a platform to contact the offsite user. *Microsoft Dynamics 365 Remote Assist* allows the connection between people in remote location with each other. This platform requires a license in order to be used beyond the trial time. Based on, the IT department is required to choose a license package and associate it to the elected on-site user through his NDOT email address. After buying the necessary license, the user is required to download the platform on the desired device using either the "Apple Store" for *Apple* based phones / Tablets, or the "Play Store" for *Android* based phones / Tablets, and sign in using the same email address associated to the license. The on-site user will be able to directly search, find, and contact any other NDOT member from the same domain.

Offsite Set-up

The off-site user will be using *Microsoft Teams* as an online platform to contact the on-site user. Off-site user is required to install the software on the laptop in use, sign in using NDOT email address, and make sure the status is shown as available.

A1.1.2 Supporting Architecture (Research Team Developments)

During an internal testing which the research group conducted at the begin of this study, some potential solutions to overcome many technological issues related to the use of the *Trimble XR10* as a device were explored in order to solve these drawbacks.

1. Tinted Film:

Five sheets of tinted glass film adhered together, installed on the front area of the *Trimble XR10* by small 3M Velcro, as a shading device, to block out the sun glare. This film is removable and the choice between light or dark sheets is made based on the user needs. (Check Appendix B)

2. Charges with External USB Battery to:

Power banks (or similar) can charge the device even during activity, to extend the duration of the utilization to overcome the battery loss challenge. External USB charging can be used on both devices *Trimble XR10* and Cellphones / Tablets.

3. Hot Spot Device:

Wi-Fi signal cannot always cover the whole area of an on-going project, especially infrastructure projects that can be in remote areas. Using a Hot Spot device like "MiFi" to create a mini wireless broadband cloud or hotspot, users are able to have a stable connection to overcome problems related to internet connection. Hot Spot Device can be used on both devices *Trimble XR10* and Cellphones / Tablets.

4. Noise Cancelation Earbuds:

Noise cancelation earbuds are suggested to overcome on-site noise generated from heavy machinery and on-site sounds. Those earbuds can protect the on-site user to be able to hear the called person.

A1.2 Recommendations

Based on the finding of the research study, some recommendations help potential users strategically plan the use of AR in real time applications. One such practical finding is understanding the challenges, as well as potential solutions proposed and introduced in this section. Table 2. presents possible solutions to overcome some of the identified challenges, and groups these solutions in three types or categories: low-cost, training, and to-do strategies.

Table 6: Recommendations and Possible Solutions to Identified AR Challenges

Recommendations	**Solution type**
Tinted film	Low-cost solutions
Manipulation practice Annotation practice	Training
Be aware of the noise Do not use the device near heavy machinery sound equipment Do not use the device during heavy wind Ensure quality of internet connection and Wi-Fi signal coverage Make sure of the Bluetooth connection Charge the battery device Charge the headset Plan AR use time / call duration	Strategies to-do

A1.3 AR Framework

This framework represents a tool for planning communication with different stakeholders located each in different locations. On-site and off-site practitioners planning to use AR for communication can base their choice of device based on this framework for a better understanding of each device type based on its specification and site condition. In addition, this framework shows the different factors affecting the use of devices supporting AR for communication. The devices in use are: 1) Cellphones or Tablets, 2) *Trimble XR10* based on *HoloLens 2* (a construction specific head-mounted hard hat with a visor in front). This framework is divided into three categories.

The first category is related to pre-requisites that are required be present for each form of AR to make it work. The second category is related to site conditions that can affect effective or ineffective uses of AR based on the 2 devices (i.e. cellphones/tablets or *Trimble XR10*). This category is organized by common site parameters, such as temperature, day lighting, weather conditions, and congestion on site, that will guide decision making for future users at NDOT. The third category is related to AR devices and their specifications regarding what they can or cannot do. The organization of this category is related to operational parameters such as sharing drawings, recording calls, having free hands, etc. This framework is intended to guide decision making for the users who have not used AR before, so they can use this technology where is effective, and avoid its use where it is not beneficial.

	Factors	Cell-phone/ tablet based AR	Trimble XR-10- (HoloLens 2-) based AR
	related to pre-requisites		
1	Requires internet connection (i.e., WiFi or hotspot)more than 1.5mbps up/down	YES	YES
2	Requires training sessions before use	NO	YES
3	Requires safety training	NO	NO
4	Requires previous coordination	YES	YES
5	Requires around 10 minutes set-up time	NO	YES
6	Requires hands handling to the area of call	NO	YES
7	Requires protective safety awarness	NO	YES

Figure 6: Framework First Category - Pre-requisites

	Factors	Cell-phone/ tablet based AR	Trimble XR-10- (HoloLens 2-) based AR
	related to site conditions		
8	Functions at high temperatures above 86°F	●	⚠
9	Functions at high temperatures above 95°F	⚠	⚠
10	Usable in bright sunlight	●	⚠
11	Usable in bright sunlight with shading device *	NA	●
12	Usable in low light condition (night)	●	●
13	Usable in high wind	⚠	⚠
14	Usable in light rain	⚠	●
15	Usable with light dust	●	●
16	Usable in crowded areas	●	●

Figure 7: Framework Second Category - Site Conditions

	Factors	Cell-phone/ tablet based AR	Trimble XR-10- (HoloLens 2-) based AR
	related to AR specifications		
17	Shares virtual drawings	⚠	●
18	Hands free operation	⚠	●
19	Supports communication while moving around site	⚠	●
20	Supports discussions about far and unreachable object of interest †	●	⚠
21	Can record calls	●	●
22	Supports calls with more than 2 users	●	●
23	Charges with external USB battery to extend operation time	●	●
24	Protects and secures collected data	●	●
25	Software supported by the device can be upgraded	●	●
26	High memory capacity to store data	●	●

Figure 8: Framework Third Category - Device Specifications

Legend	
●	Effective
⚠	Ineffective

NA: Not Applicable.

* Shading device: Crafted tinted film mask, installed at the front area of the holoLens.

† Object of interest: This refers to the location of the built element(s) or object(s) that are relevant to the discussion. For example, for a concrete column inspection call, the concrete column itself would be the point of interest.

Figure 9: Framework Legend

A1.4 Using AR

The on-site users have the choice to choose between two types of devices for supporting AR calls. This section represents a quick start guide to help the on-site callers to set-up the *Trimble XR10*. In addition, it also provides support to off-site users to enable them to receive or launch a call.

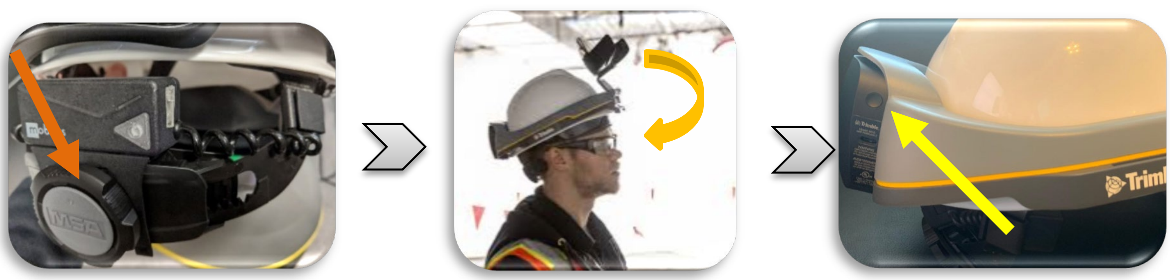
A1.4.1 On-site Users

QUICK START GUIDE: **On-Site Users**

Open the *Trimble XR10* case. Remove the *Trimble XR10* with its charger. Charge it for a minimum of 30 minutes (if it has not been charged yet).

Clean the interior area of the helmet with sanitizing wipes. Clean the *Trimble XR10* glass with the dry glass wipe.

Put the *Trimble XR10* on your head and adjust it with the rotating wheel on the back for your comfort. Drop down the glass. Push the start button on the back.

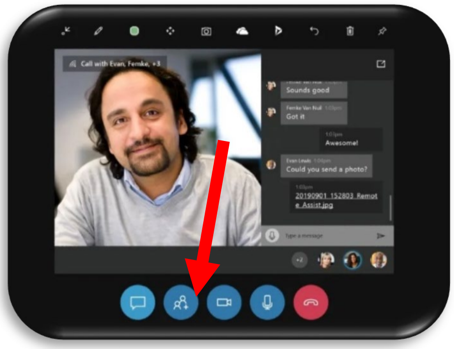


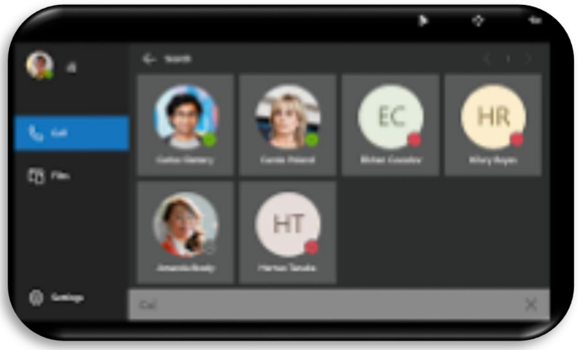
Connect the device to an Internet Wi-Fi connection using the Settings function. Turn the Headphone's Power On. Connect the Headphones using Bluetooth connection, if it has not been connected automatically.

Enter the given Pin Code to access the device. Watch the tutorial video for quick manipulation instructions of the *Trimble XR10*. Make sure that *Microsoft Dynamics 365 Remote Assist* is downloaded on the device, if not, you can download it from the *Microsoft Store*.

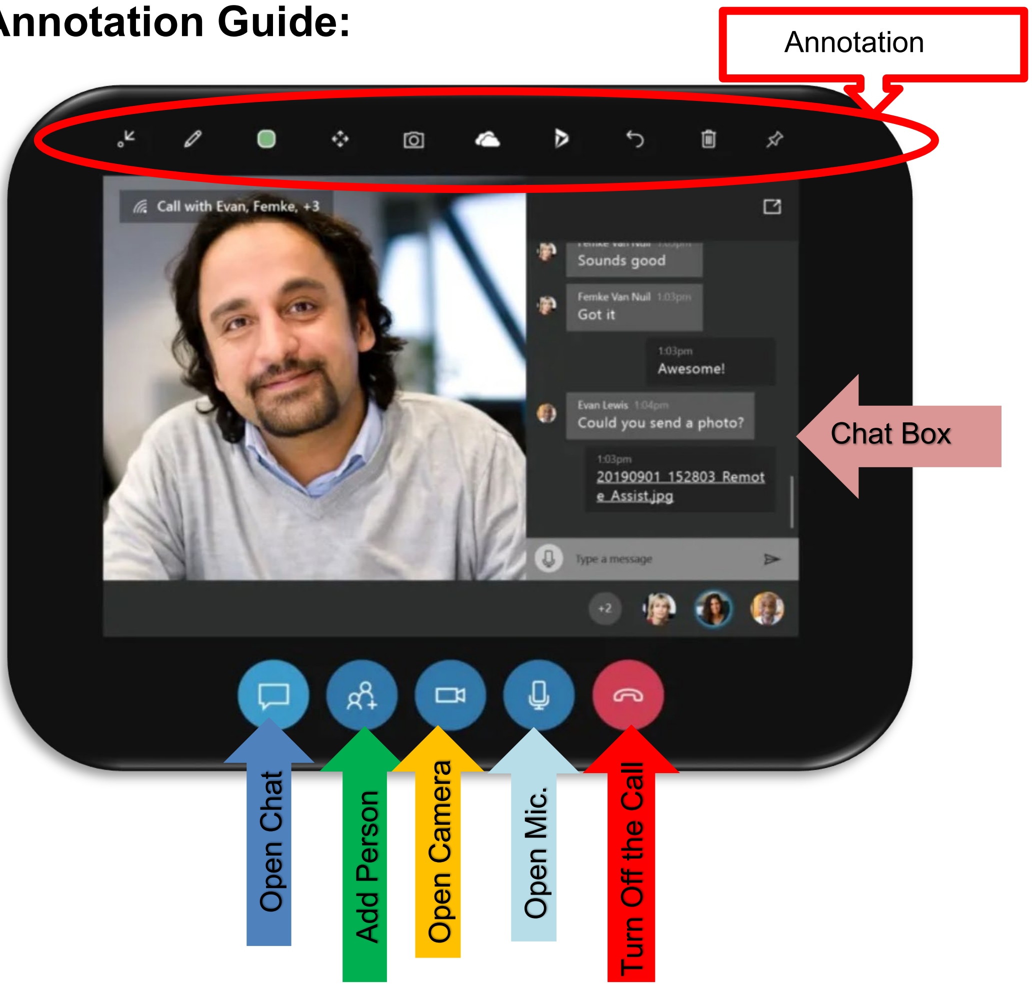
Before launching any calls, make sure that the person you want to call is online or available on *Microsoft Teams* on their computer. Click on *Microsoft Dynamics 365 Remote Assist* and launch the application on the device. Search your contacts to find the off-site person you want to call and launch the call.

After calling the person off-site, click on the "add contact" icon for the possibility to more people on the call. Search in your contact and click on their name and call them.





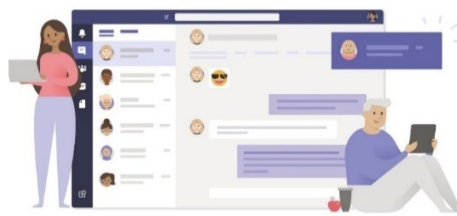
Annotation Guide:



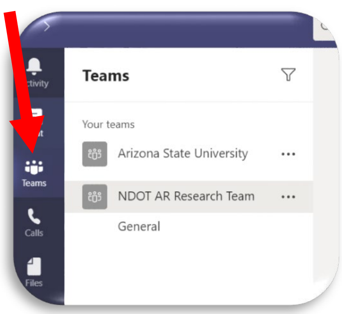
A1.4.2 Off-site Users

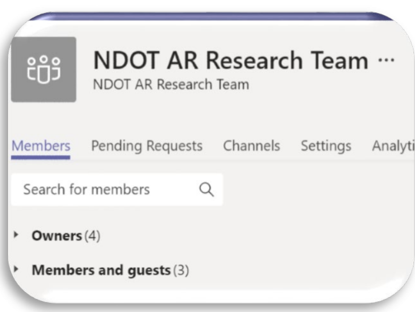
QUICK START GUIDE: **Off-Site Users**

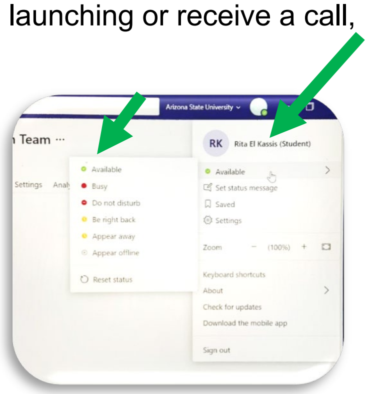
The off-site participants should have *Microsoft Teams* installed on their NDOT Laptop or computer that will be used for the call.



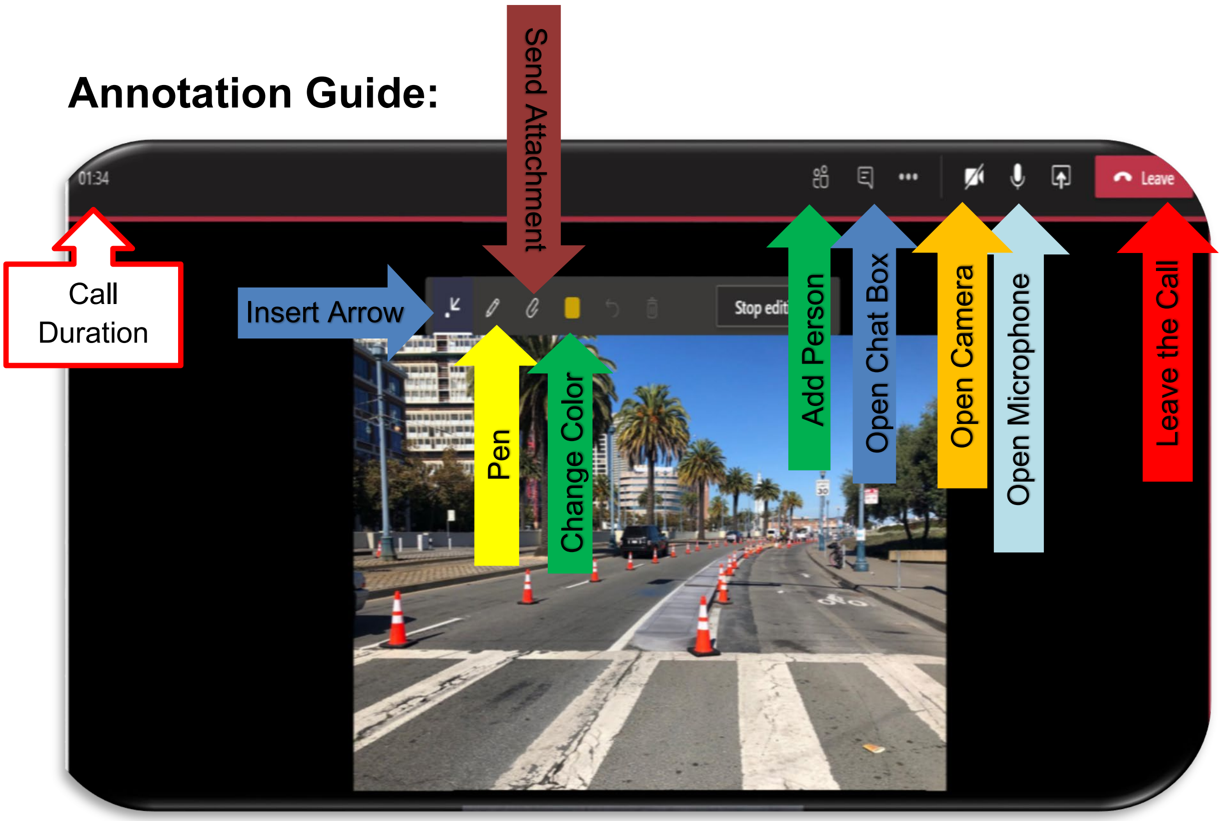
Make sure you are in the right group on *Microsoft Teams*. Before launching or receive a call, make sure your status is shown as available.







Annotation Guide:



A1.5 Helpful Tips and Tricks

- After finishing the call, please make sure to turn off the device the same way you turned it on. Clean the interior of the hard hat with wipes and charge it again for the next use.
- If you require extended power while using the *Trimble XR10*, you can connect the included power bank via USB cable and store the power bank in a back pocket while in use.
- While making annotations, the image captured from the on-site user will freeze allowing the off-site user to annotate on a static image. Make sure to inform the on-site user that annotation will occur, so he or she will notice the annotation.
- After annotations are completed by the off-site user, the image from the on-site user will return to a live video feed.
- When a video call is launched a conversation box will be opened directly between the two contacts. Annotations created during a call can be saved in the same chat box.
- For your safety, please do not use the *Trimble XR10* during extreme heat events.
- While inserting annotations of both lines and arrows, current site conditions should be considered. For example:
  - ➢ Yellow is not ideal under sun glare.
  - ➢ Red is not a good color to use while annotating on a red object.
  - ➢ When inserting an arrow, make sure to widen the scale of it in order to become visible for both users. Use a hand gesture to widen the arrow.

- While sharing files its always recommended to place the open content in a shaded area. Use a hand gesture to move the file into the desired area. In instances when no shade is present, it is better to open files away from the direction of the sun to avoid washout from the sun’s backlighting.
- For outdoor usage under the sun glare, use the tinted-film glass cover:
  - Lighter tint for moderately sunny days.
  - Darker tint for very sunny days.

APPENDIX B

Tinted Film Template

Use the following template to map the tinted film mask.
Cut the edges and stick as many as tinted paper as you want. The higher number of tinted paper film the darker it becomes.
Use small, rounded Velcro on the tinted mask and at the front area of the visor so the mask could be attached to it.
See a picture of the result behind the template

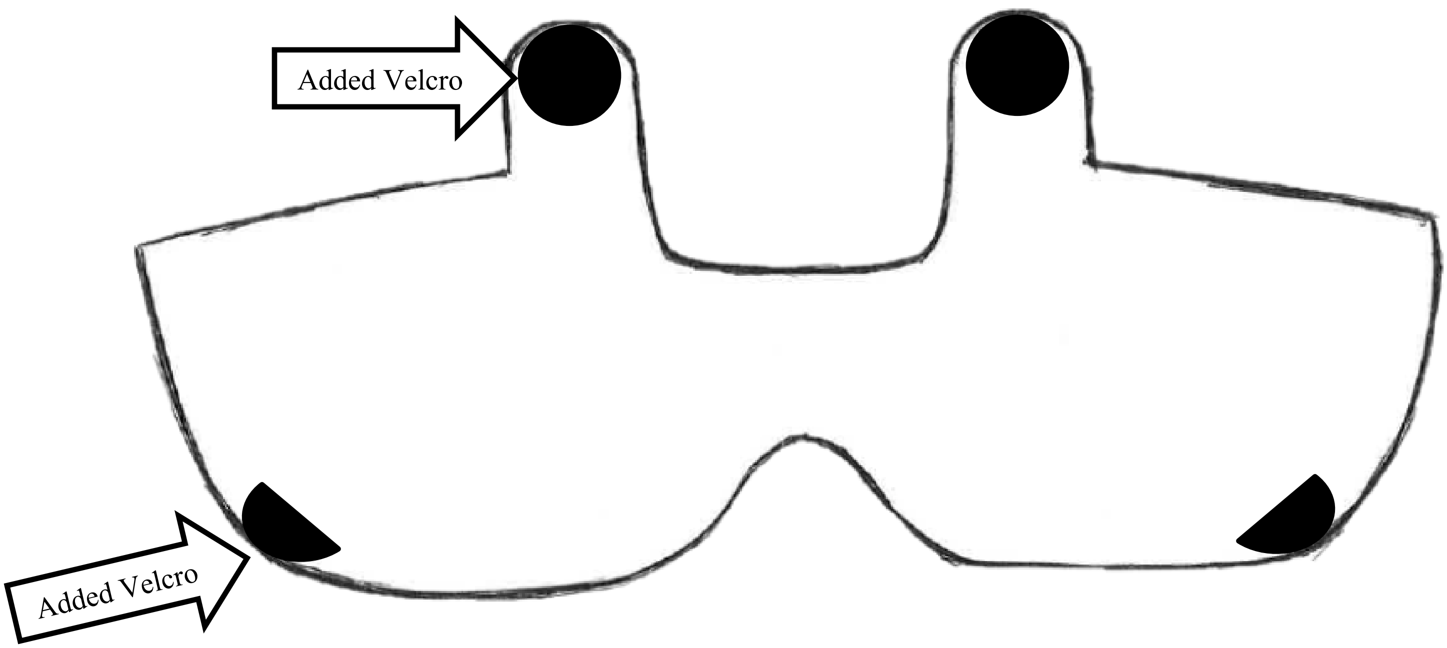


Figure 10: To Scale Template

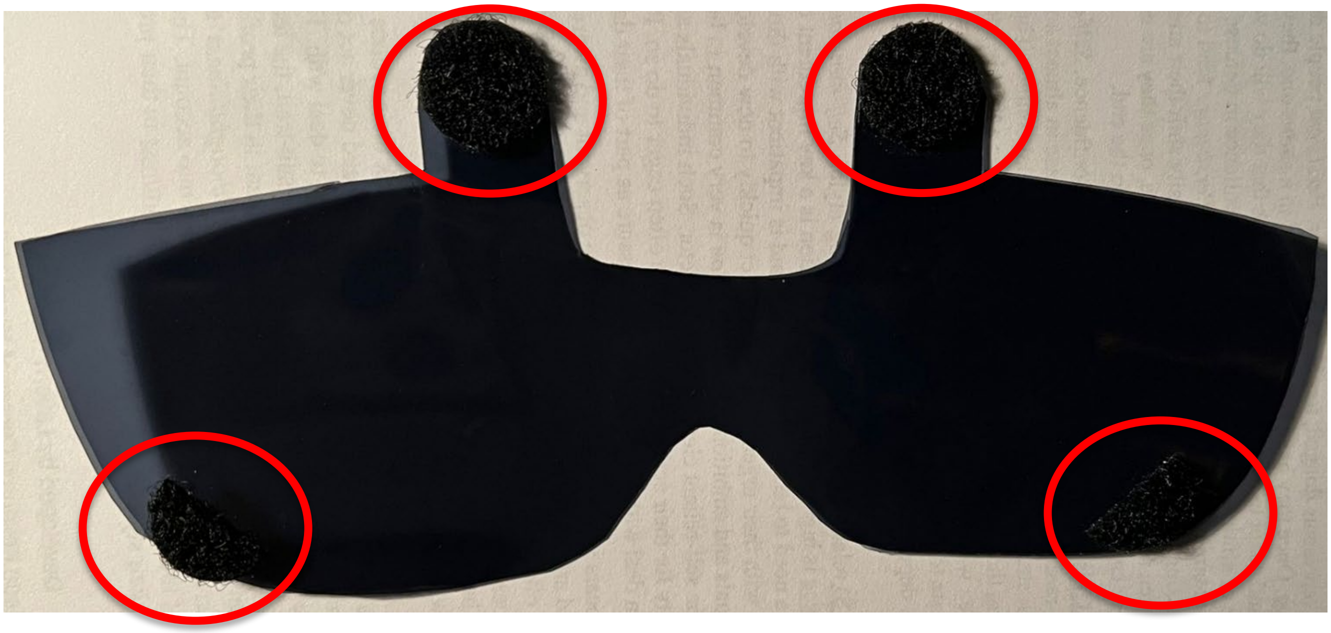


Figure 11: Tinted Film Mask with Velcro (Red Circles)

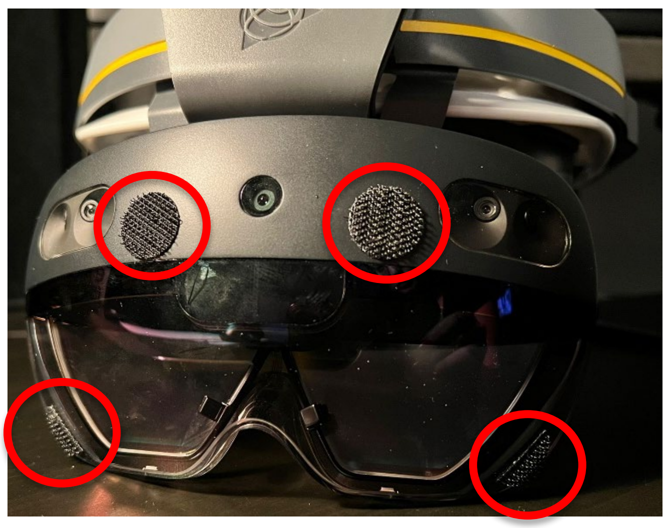


Figure 12: Velcro on Visor

Figure 13: Visor with Mask On

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