Cartography M.Sc.

Master thesis

A Comparative Study of 3D Visualization versus Immersive Visualization

(*HoloCave*) – Knowledge Discovery Redefined

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"**A Comparative Study of 3D Visualization versus Immersive Visualization (*HoloCave*)**"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Munich, 09.09.2019 Irhamillah, Khamsim

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Abstract

Visualization in modern cartography follow the formalization new computer and multimedia technique. 3D visualization is a method commonly used for visualising while immersive is a fairly new approach. The same interaction is provided for both visualizations but in different mechanism. This research is about comparing the knowledge construction in two different visualizations. An application for implementing immersive visualization with point cloud laser scanning data of Gua Damai in West Malaysia as a case study of this research. Since the point cloud data is already in 3D it is easy to import to any other software which can works with point cloud. However, to create the immersive environment in visualization, HoloLens is one of the devices to produce a hologram which named "*HoloCave*". Based on two different types of visualizations, a simple task experiment is set up in order to measure the time taken for knowledge construction between them. 17 respondents participate in this experiment from beginner, intermediate and expert level in climbing skill. Drafting and planning climbing route from two different visualization on 2D orthophoto, proves their understanding in transforming information from eyes to brain and measure any different in decision making via qualitative and quantitative method.

Keywords: 3D, immersive, visualization, knowledge construction.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
ANOVA	Analysis of Variance
AR	Augmented Reality
CEPCoS	Center for Experimental Psychology and Cognitive Science
HC	*HoloCave*
LTM	Long Term Memory
LTVM	Long Term Visual Memory
MR	Mixed Reality
MRTK	Mixed Reality Toolkit
STM	Short Term Memory
STVS	Short Term Visual Store
UAV	Unmanned Aerial Vehicle
UI	User Interface
VR	Virtual Reality
VRML	Virtual Reality Markup Language

1 INTRODUCTION

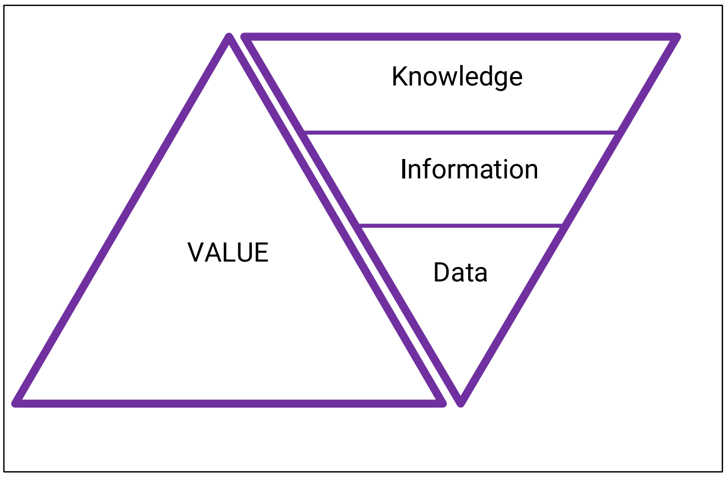
1.1 BACKGROUND OF STUDY

Imagination and mental map for each individual is different even if they are visualizing the same map. It is because the interpretation of the information depends on the cognitive ability of the person. Kaiser (1991) stated that humans are naturally spatial thinkers. According to Peterson (1994), humans process the information into three different stores; (i) sensory register, (ii) short-term memory (STM) and (iii) long- term memory (LTM). In order to visualize the information, these three memory stores are referring to short-term visual store (STVS) and long-term visual memory (LTVM). In general, in visualization processing information, it begins with iconic memory which is thought to hold information in sensory form about 500ms, long enough to be recognized. (Humphrey and Bruce, 1989). Figure 1.1 shows the relation between data, information and knowledge. Data is broad. Data refers to the collection of the facts through observation, experiments or process. Data may consist of numbers, words or images particularly as measurements or observations of a set of variables. Data is often viewed as the lowest level of abstraction from information and later on, from the information the knowledge is derived. Information is one of the processes to discover knowledge, indirect or direct through experience either it comes from themselves or others. Meanwhile, knowledge is an extraction of information's theory. So, in which part of this process does visualization play a role? Visualization process takes part mainly in between data and information. It is because through the eyes (retina) the data will be extracted into information via cognitive process and later become the knowledge based on what they are looking for. For example, if the person is looking for the shortest route, he or she will only focus on the road network and real time traffic.

In cartography perspective, Taylor model (2.1.2) represents the concept of modern cartography in a triangle where the visualization is in the center. There are three basic things in Taylor model, cognitive and analysis, communication visual and non-visual, and formalization new computer technique. Visualization can be enhanced by the advanced of computer technique following the trend of modernization. Visualization is defined by Hornby (1985) as to make it visual and "to bring something as picture before the mind". Through the innovation of immersive visualization, the perception is created in front of the user. People can interact and communicate with objects virtually in front of them. The benefit of the feeling being in the situation itself, helps a person to create imagery image or iconic memory in his or her mind faster. In general, visualization in augmented reality (AR), virtual reality (VR) and mixed reality (MR) have more advantages but how much knowledge users can gain from it is still doubted in cartography but not in medical field. According to healthimaging.com:

"OpenSight specifically utilizes the Microsoft HoloLens headset that allows simultaneous visualization of the 3D patient images in AR and the actual patient and their real-world surroundings. The technique may decrease operative times and improve surgical planning and the understanding of anatomic relationships."

Thus, this research will discuss if there are any changes in knowledge discovery while a person is having the immersive visualization versus visualize the object on the screen. Are there any details in information that can be extracted when they interpret the object virtually? What is the limitation of using immersive visualization?



[1]

FIGURE 1-1: RELATION BETWEEN KNOWLEDGE, INFORMATION AND DATA (Redrawn)

1.2 PROBLEM STATEMENT

Reading 2D maps requires more time to generate the iconic memory, compared to 3D map. Different level of cognitive makes everyone a unique spatial thinker. According to Hoffman (2011), there is a theory that men are on average in spatial intelligence involving the ability to mentally process shapes, patterns and images, while women are better at social, emotional and verbal tasks. However, this theory has postulate. It is because this research mentioned about nurture and not naturally. So, visualization technique plays important roles in order to generate an iconic memory especially for women. Since the evolution of the technology, we can measure the trend or pattern of visualization technique in a more advanced manner. From the 2D map in printed hardcopy on paper, it transforms to digital form such as Big Map, google map, Open Street Map which can overlay so many layers inside a computer with a better interface design like a case study for crime analysis by Roth, Ross & MacEachren (2015). Users also have an opportunity to interact with the map using many interaction tools

[1] https://brianreynaldo.files.wordpress.com/2009/12/data-informasi-knowledge.jpg Retrieved on 8 July, 2019

that have been developed as well.

Peterson (1991) mentioned that cartographers are now viewing a computer not only as a tool to make a map on printed paper, but also as a medium of communication that renewed interest in mental process and later gain the knowledge from interpretation of information. As a result, it goes back to cognition again which gains a greater insight into visual mental processing that dynamically displays associated with visualization. Clarke (1990) believed that cartographers in the 1990's must be a data base expert, a user-interface designer, a software-engineer who retain the sense of a map aesthetics and still produce a map. This is a very good advantage in cartography because without these new tasks, the cartographer profession would have already died based on what he believed. Through the invention of merging the real environment with virtual object visualization in front of users, there might be changes in cognitive processes in generating iconic memory that later influences the knowledge and decision making outcome. Cognition is defined as the "intelligent process and product of human mind" (Flavell, 1977, page 28). The cognition process includes mental activities such as perception, thought, reasoning and mental imagery. With the help of immersion visualization, the perception is already created in front of the user in virtually. It is supported by Peterson (1991) where:

" *Computer visualization can create images of complex things beyond the capabilities of the human minds*"

According to Sprinarova et al.,(2015) :

"*In the geographical data displaying it is constituted the question in which way the type of visualization technology affects the user performance on cognitive and behavioural level*"

Immersion itself is defined by "feel in presence" Bailenson et, al (2006). Thus, this thesis is to investigate on how the knowledge is discovered with the two different techniques of visualization, between 3D visualization on screen versus immersive visualization where both of them are having the same interaction mapping tool.

1.3 Objective and Research Questions

Cognitive process involve perception and have a relation with visualization. With the advance level in visualization of modern cartography, it gives the impact on interaction among users in knowledge discovery and decision making. Therefore, the main objective of this thesis is to investigate between two different geo-visualizations; 3D visualization versus 3D immersive visualization in knowledge discovery.

The main objective is supported by two sub-objectives where the other elements that control the study are manipulated as well.

i. To investigate on how user interprets the information between two different visualization techniques with the same mapping tool interaction provided.
   a. How do users interact with 3D visualization?
   b. How do users interact with immersive 3D visualization?
   c. How do users interpret the information if he or she already has an experience?
   d. Is there any different in making a decision between two of these visualizations?

ii. To compare what is the benefits and limitations between these two different visualizations?
   a. What are the advantages of using 3D visualization?
   b. What are the disadvantages of using 3D visualization?
   c. What are the benefits of using immersive 3D visualization?
   d. What are the limitations of using immersive 3D visualization?

1.4 HYPOTHESIS

1. There is a significant difference in time taken in knowledge construction in 3D visualization and 3D immersive visualization (*HoloCave*). 3D visualization takes longer time than *HoloCave*.

2. Knowledge can be gained deeper and, better understanding, when using 3D immersive visualization.

1.5 RESEARCH STRUCTURE

This thesis is structured in seven chapters. Chapter one is the introduction where it discusses the general overview of the topic and points out the problem statement, what is the purpose of conducting this research. The objective and sub-objectives are carried out with the research questions corresponding to the factors that influence the outcomes of the research.

The hypothesis is generated from the understanding and overview of an idea, but it will be tested and observed in methodology either it is falsifiable or accepted.

Chapter two is literature review or state of art, the related theory in this thesis. Dibiase's view (2.1.1), Taylor's view (2.1.2) and map use cube (2.1.3) are discussed. The model on how the information process in extracting the knowledge in general will be discussed as well. In this chapter also deliberate about how the visualization task has a relationship with the human cognitive that lead to change in making a decision. This chapter also gives the overview on how the knowledge is discovered in different visualization in 2D, 3D and immersive visualization.

Chapter three is methodology. There will be a discussion on the implementation on how to construct the research technically based on the existing literature review. In order to observe the knowledge in two different visualizations, the interaction mapping tool should be constant between two of them. In chapter three also, it discusses about how to create the immersive visualization and what is the device used. In order to test the hypothesis, the evaluation of user study will be conducted. There are many user study methods. So, which method is more suitable to this research will be considered. The task is pointed out as well.

Chapter four is case study of this research. The case study of this thesis is about the wall cave of Gua Damai which a famous cave in East Malaysia in rock climbing activities. The wall of the cave has been scanning by Jurukur Perunding Services Sdn Bhd using the Unmanned Aerial Vehicle (UAV) in 2017.

Chapter five discusses the result from the task that have been conducted with user study. The statistical graph will be used to generate the result and analysis. Result will be interpreted and statistically significant will be describe.

In the chapter of six, discussion part, the result and analysis will be summarized and relate to any other existing look alike research. Further implication based on result will be made. Assessment of the hypothesis either rejected or not will be point out as well.

In the last chapter of seven, which is the outlook, where it highlights the recommendations and suggestions if any other researchers are interested to conduct the extend of this research.

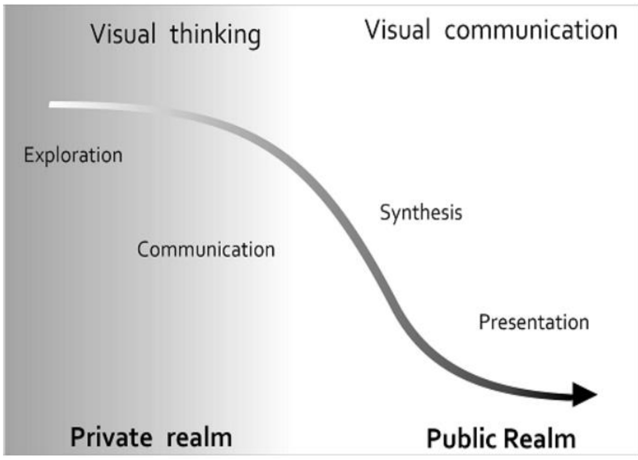
2 LITERATURE REVIEW

2.1 THREE DIFFERENT VIEWS ON GEOVISUALIZATION

There are three different views of geovisualization which are familiar in cartography field. Geovisualization plays important role in communication and interaction either between user to object or among user itself. These three different views of geovisualization follow the transition of the innovation in computerization. From the different view, the researchers relate the visualization with the information extraction that finally, leads to discover the knowledge. With the transition of modern technology in geovisualization, it is not only reducing the workload in cognitive, but it helpful to gain more knowledge.

2.1.1 DIBIASE'S VIEW

There are three different views in geo-visualization. The earliest model of visualization is Dibiase's view. Philibrick (1953) said "a picture worths a thousand words". However, the visualization on a map depends on the interpretation of geographical phenomena (MacEachren, 1994). Figure 2.1 shows Dibiase's view model on visualization. Dibiase (1990) proposed a framework for thinking about geographical visualization, in context of scientific research. He highlighted a map as a role in research sequence. He defined map based on scientific visualization including all aspects of map beginning from initial data exploration, hypothesis formulation until final presentation of result. For example, a student created a 3D city model and use many layers of map. Once the output is presented to the audience, it has become public visual communication. From Dibiase's view, the important thing is a distinction is made between private visual thinking and public visual thinking. In early research process, private visual thinking is made, then after the output comes out, it facilitates public visual communication.



[2]

FIGURE 2-1: DIBAISE'S VIEW

Visualization is not a new aspect in cartography, but an approach for one application of communication and visual thinking. From Dibiase's view, it clearly distinguishes between perspective of map maker (visual thinker) and user (visual communicator). Dibiase does not focus on geovisualization formulation. Later, Taylor improvised the model to include geo-visualization as the main core inside the triangle model.

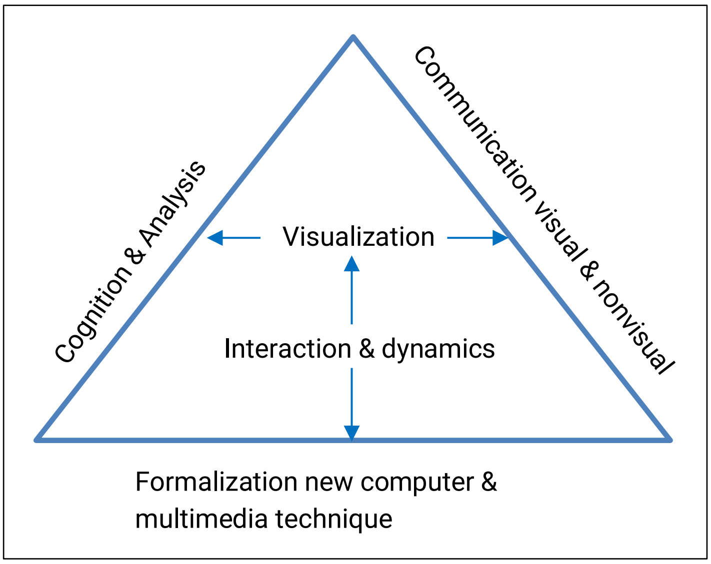
2.1.2 TAYLOR'S VIEW

Another model of geovisualization is Taylor's view. Figure 2.2 shows the triangle of Taylor's view where the visualization is located in the middle. Taylor (1991) puts the three components outside the triangle. At the sides of the triangle, he puts cognition and analysis and communication of visual and non-visual thing which means these two perspectives are the main content of modern cartography and mapping. From the cognition and analysis, it derives from the data to information and later it become the knowledge. Meanwhile, communication of visual and non-visual refer to the communication among people and between people and environment. The base of the triangle is formalization new computer and multimedia technique. All of these three main components are connected together with the visualization in the middle of the triangle. In 1994, Taylor added interaction and dynamics as the main characteristic of geo-visualization. Every step forward of the new technologies always promote the development of the visualization. He also stresses out that underlying content of geo-visualization is not equal to whole view of cartography. The terminology of geo-visualization was introduced by Kraak (2003) as:

[2]https://gistbok.ucgis.org/bok-topics/geovisualization Retrieved on 12 July, 2019

"the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions and construct knowledge"

As mapping already changes following the transition of technology in computer, Peuquet and Kraak (2002) suggest maps need to change as well. Krisp (2006) believed that map should be best used as visualization tools for exploring digital geographic databases, and as interactive aid on experiencing the world, decision making, and solving spatial problem. Since visualization with the support of computers is going to get more advanced from time to time, it also affects cognition and communication. Taylor did not mention further on how the cognition process is going on in different visualization that lead to knowledge discovery behind it.



[3]

FIGURE 2-2: TAYLOR'S VIEW

Redrawn

2.1.3 Map Use Cube

MacEachren and Kraak response on geo-visualization is different from Dibiase and Taylor. Taylor and Dibiase imply that visualization is the same thing as cartography and does not create something new. Meanwhile, Kraak and MacEachren have different perspective of geo-visualization and disagree with them, that they propose a new model which is called 'cartography cube' in 1995, but in 2005 it changes the name to map use cube (figure 2.3). Cartography cube defines geovisualization in terms of map use. In this conceptual, the cube is divided by three axes. The first axis represents the usage of the map from private (an individual using the map for its own needs) to public (someone create the map for audience's

[3]https://sites.google.com/site/rzcartography/publications/three-different-view-on-geovisualization Retrieved on 9 July 2019

need). Second axis shows the map as a way to reveal something unknown versus something that already known, where the user is attempting to access particular spatial information. For example, from the visualization on the map, user gain the knowledge after interpreting the image behind it. The last axis is human-map interaction. Interaction either can be among the user to user itself or user to the object which is map. A high human-map interaction means the user can change the map in a practical way such as merging map in many layering, make time slider to see the change of the map in different years and something as simple as rotating, panning and scaling the map. Meanwhile, low human-map interaction means that user has limitations in manipulating the map (MacEachren and Taylor, 1994).

MacEachren believes that many maps are designed to communicate particular messages. So, he disagrees if people say the research on cartographic communication is irrelevant and there should not be a clear dividing line between visualization and communication. He mentioned communication is a component of all map use, even when visualization is the main object. He thinks that even the most mundane communication-oriented map still can serve as a prompt to mental visualization. Consequently, it allows the user to emphasize the difference in designing goal principle for a map. Since the primary function of the map is to facilitate in transferring the knowledge from a few people (expert) to many people, hence, the primary use of the map is to help individuals to think spatially. Towards human-map interaction, there is no single map without having some level of interaction even it is a printed 2D map. According to him, higher level of interaction does not solely depend on the computer, user can draw lines of maximum gradient on topography map then visualize the runoff pattern of drainage basin mentally. However, interactive computer tools expand the possibilities for interaction with map and thus increase the possibility to facilitate visual thinking and knowledge discovery.

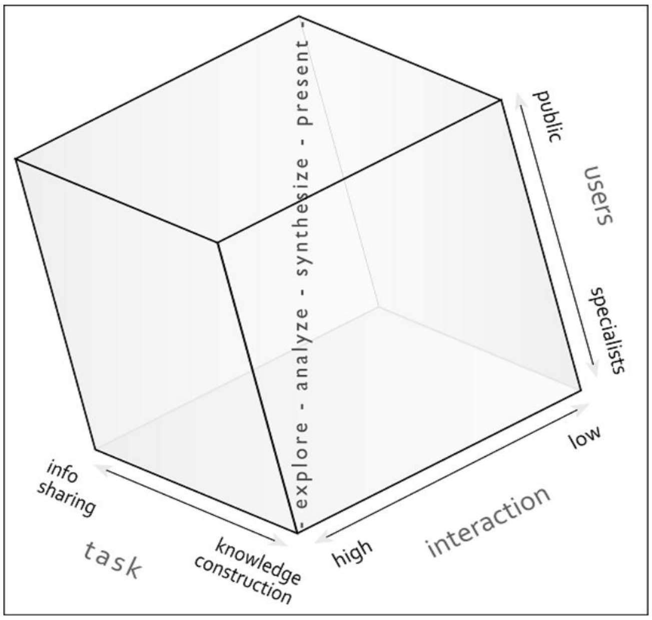


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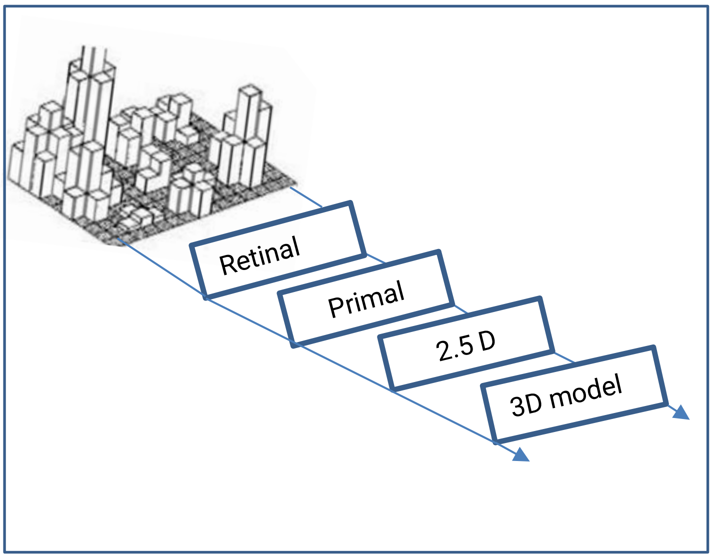
FIGURE 2-3: MAP USE CUBE

2.2 VISUALIZATION TASK

In everyday experience vision and cognition are interrelated to each other. It is very critical to understand how vision and cognition work in any context MacEachren (1995, page 27). Understanding the representation through the visualization is more to how the eye-brain system works. According to David Marr's (1982) approach to vision has a dramatic impact on understanding both vision and information processing system at numerous level of analysis that later comes out with the knowledge construction. From philosophical perspective, he suggested three linked processing modules it starts from retinal image, primal sketch, 2.5D sketch and finally highly structed 3D model representation.

[4]https://gistbok.ucgis.org/bok-topics/geovisualization Retrieved on 12 July 2019

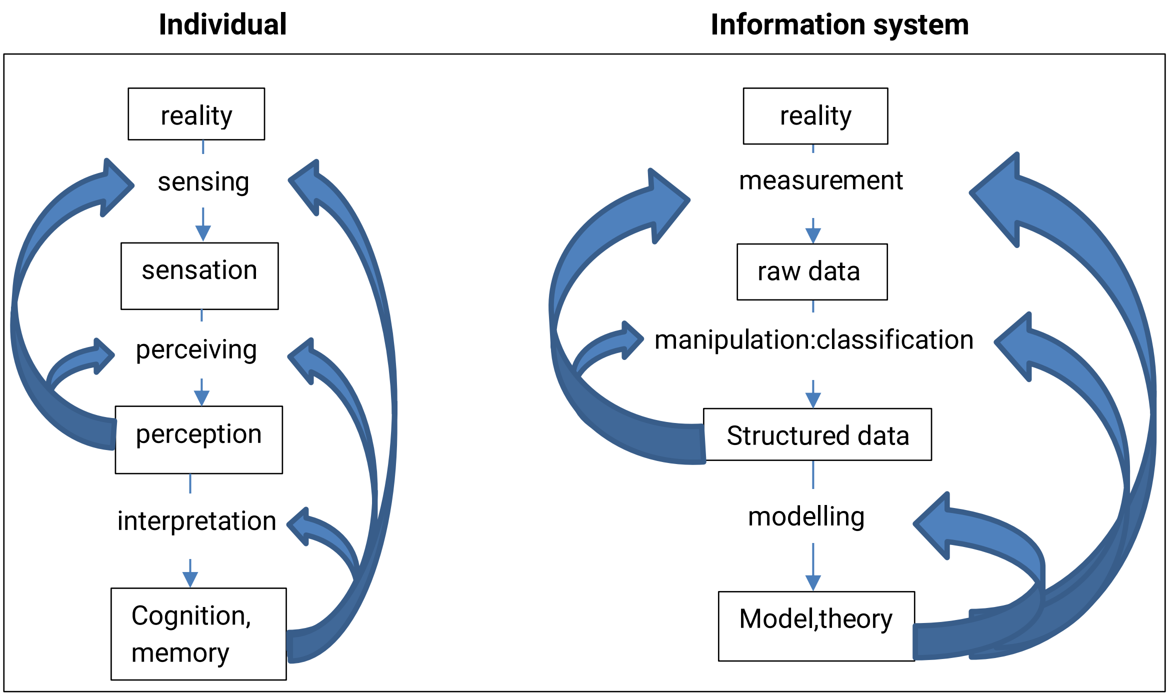


[5]

FIGURE 2-4:MARR'S (1982) STAGES OF VISION. Redrawn

2.2.1 Observation

Observation is an activity to increase our knowledge (Lindholm and Sarjakoski, 1994). Visualization is a part of observation which can add user's prior knowledge through finding pattern of the data and then generating hypothesis of them. Figure 2.5 is an analogy between observation processes of an individual and how information system is depicted. Boxes represent information, while arrow indicate information flow.



[6]

FIGURE 2-5: OBSERVATION PROCESS AND INFORMATION FLOW Redrawn

[5] Vision and Visual Cognition. How Maps Work. The Guilford Press. New York London (page 29)
[6] Designing a Visualization User Interface. Visualization in Modern Cartography (page 168)

According to Lindholm and Sarjakoski (1994), they believe that a person does not only passively monitoring incoming data, but he or she is also paying attention depending on earlier observations and relates new data to what is already known (Neisser 1980) such as their own experience. Both Lindholm and Sarjakoski consider visualization will happen when an individual is perceiving and interpreting and at the same time manipulating and modelling stages of information level. The modelling stage in an information system observation process includes simulation and interaction, which are common tools in visualization. Their thought will derive a new structured observation from existing model and theories. The corresponding individual process is called imagination. Since Petterson (1994) categorized information process in three different memory stores; sensory register, short-term memory and long-term memory, the individual level is closely related to this. Lindolm and Sarjakoski extend on what Petterson said by saying that the sensation is stored in the sensory register and the process of perceiving happens in visuo-spatial scratch in short term memory and the result of object recognition is made in perception. Thus, when this perception is given an interpretation which is linked to the observer's prior knowledge, so that it can be stored in long term memory. Once the user performs a visualization action, information system and individual are merging together. In the basic requirement of visualization system there are two stages; (i) data manipulation and (ii) modelling. At data manipulation, user perceiving meaningful structures in the data aided through user interface while in modelling stage, the system should provide easy way to connect perceptions to the model of reality.

2.2.2 INFORMATION FLOW IN VISUALIZATION

Figure 2.6 shows a model of the information flows in visualization situation. The system here consists of information coded in different language, then it translates into another language among them. The main part of user communicating is with database.

Lindholm and Sarjakoski (1994) define the database in here as a collection of available data whether it is structured or not. The database is created by capturing data in reality world. The figure shows the logical division to identify languages that user have to deal with. Human can receive a message through perception and send message back via physical action. The database receives messages as queries and then maps the result of the queries into output such as menus, icon, sound or possibly a map. Input from user can affect both in query and mapping process which means how the data are supposed to be displayed, for example flow maps. There are three different levels that can be considered for each message in a model (map display). Based on semiotics (sign action) and information theory by (Morris 1938; Nauta 1972) the three different levels are (i) syntactic, (ii) semantic and (iii) pragmatics. The three different levels are discussed further by Lindholm and Sarjakoski (1992):

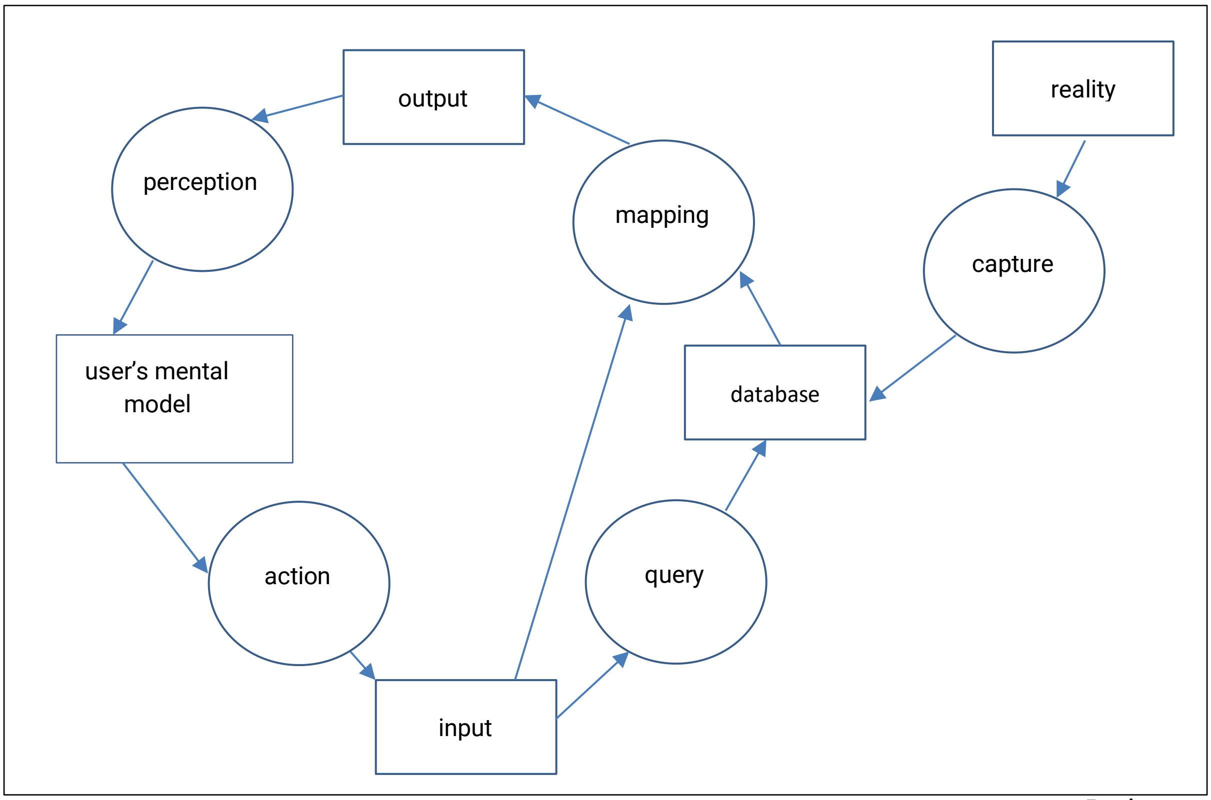
- *"Syntactic aspect of information relates to coding and transmission of message. The amount of syntactic information in a message is inversely related to the frequency of communication channel appearance. The compressed file in a disk is measured by syntactic information of its contents.*

- *Semantic information is the general meaning of the messages. The amount of a message is depending on how precisely it defines the state of things (Carnap and Bar-Hilel 1952)*

- *Pragmatic information is the personal meaning of a messages to the receiver. If the receiver already knew the things are, the pragmatic content of the message would be nil. There are no clear theories of pragmatic information.*

  "

  Only syntactic level is operated by computer, while semantic and pragmatic values are evaluated by user.



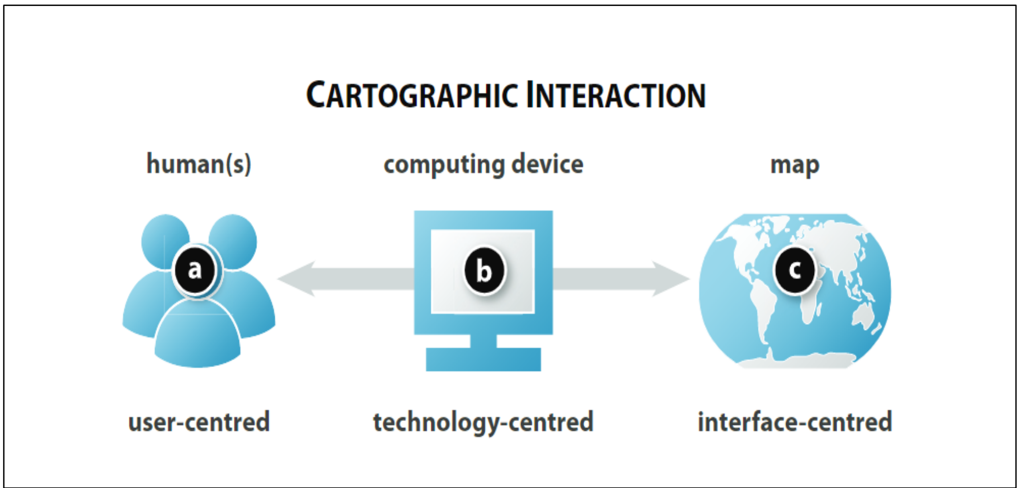
[7]

FIGURE 2-6:INFORMATION COMMUNICATION IN GIS. RECTANGLE REPRESENT INFORMATION SET, CIRCLE INDICATE PROCESS WHILE ARROW MEANS INFORMATION FLOW. Redrawn

[7] Designing a Visualization User Interface. Visualization in Modern Cartography (page 170)

2.3 User Interface (UI) as map interaction tool

Geovisualization is not a passive process which solely seeing or reading a map. It is an active process which an individual engages in sorting, highlighting, filtering and transforming data in search of patterns and relationships (MacEachren, 2001 b). Computers allow user to have an interactivity at a certain degree such as clicking button, zooming, rotate, panning and etc. Peterson (1994) believed when the object is rotated the mental image inside our brain is rotating as well. The ability to rotate an image is important in map rotation. Steinke and Lloyd (1983) examined the mental rotation of the map while Goldberg et al. (1992) looked at image transformations of three-dimensional terrain map. The effect of orientation on the map and the result after it is rotated, is considered in both cartography and psychology (Shepard and Hurwitz 1984; MacEachren 1992). Llyod (1989) examined how mental images in the form of cognitive maps are used to estimate distance and direction. Finally, MacEahren (1991) viewed the role maps and images in spatial knowledge. Figure 2.7 shows the interaction between human to map connected with computer as a device for interaction. Digital environment allows wider array of interaction forms for manipulating cartographic representation such as an interactive map. The objective of interactive map is not only limited to the map user, but it also requires high skill from developer to design, process and display the data with the suitability of the capability of the hardware as well. (Gahegan, 1999). The term cartographic interaction is defined as the dialogue between a human and a map through computing device to emphasize digital interaction (Beaudouin-Lafon 2004; Cartwright 1999; Peterson 1998; Roth 2011; Yi et al 2007).



[8]

FIGURE 2-7:CARTOGRAPHIC INTERACTION MODEL

[8]https://www.semanticscholar.org/paper/Interactive-maps%3A-What-we-know-and-what-we-need-to-Roth/f73c77363fdc90a27da86a599a949e19cdd76f7d Retrieved on 13 July 2019

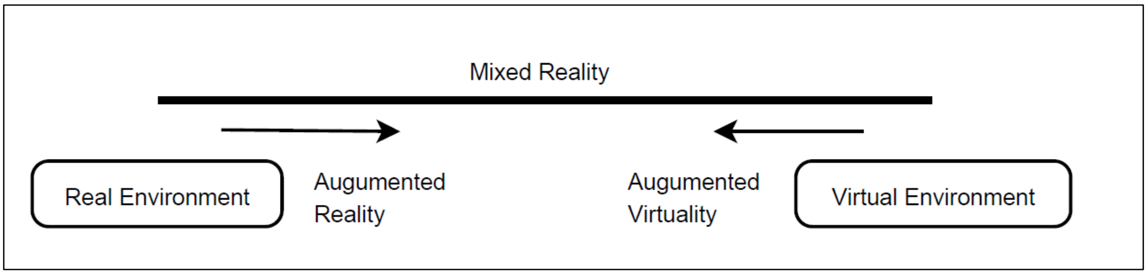
Bowman (2012) explained on how the interaction technique is clarify by considering the technological contexts to find 3D interaction including:

- **Desktop computing**: For example, users of modeling software can directly specify the 3D orientation and position of an object using a mouse in conjunction with 3D manipulation techniques.
- **Virtual environments**: For example, a user can “fly” through a virtual world through 3D pointing in the desired direction of motion.
- **Augmented reality**: For example, a physical card can represent a virtual object, allowing the object to be selected, moved, and placed in the physical world.

2.4 KNOWLEDGE DISCOVERY IN 3D VISUALIZATION AND IMMERSIVE VISUALIZATION

Mental imagery relies heavily on existing knowledge (Wood, 1994). Immersion is a perception, feeling of being presence by Šašinka et, al (2016). Immersion is also described by the technology in computer to display and deliver an inclusive, extensive, surrounding and vivid illusion of reality to the sense of human participant. Inclusive specifies the extent of physical reality is lock out. Extensive defines the range of sensory spatial accommodated. Surrounding indicates the extent of the virtual reality in panoramic view. While, vivid refers to the resolution and fidelity within particular spatial (Slater & Wilbur, 1997). In order to create immersive environment there are two ways of possibilities; (i) virtual reality and (ii) augmented reality. Virtual reality addresses the construction of artificial worlds with clear spatial dimensions (Unwin & Fisher, 2001). In virtual reality, database can structure and store data using the method that trying to minimize spatial abstraction. Computer system is able to combine the mixture of real world experience with the simulation of real world representation that has been generated through modelling algorithm in programming language. Virtual reality markup language (VRML) enable human to incorporate virtual reality with geographic datasets. According to Dykes and Moore et al. (1999) cartographers used VRML to add interactivity to their maps and explore the potential for realistic representations. Cammack (2003) agree that Quicktime Virtual Reality (QTVR) where it transform the virtual reality from photorealistic 3D in case study in Little Sac River, Unites States, helps public in understanding the base geomorphologic structure of the river. Krisp (2006) supported the idea of implementing geographical data in virtual reality system but he also mentioned that it is very complicated to handle geographical data, for example, it is difficult to alter or enhance data. This problem may affect the importance of the reference system for the data. There is always pro and cons for each technology. However, augmented reality (AR) interaction helps user in interpreting 3D topographic and make the orientation more easier to determine goal location (Canrera and Asensio, 2016)

Augmented reality and mixed reality are interdisciplinary fields involving signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, computer network, distributed computing, information access, information visualization and hardware design for new displays and sensors (Krisp, 2006). Krisp (2006) believed that mixed reality and augmented reality concepts are applicable in a wide range of application. Figure 2.8 describes the taxonomy on how the augmented reality and virtual reality works according to Milgram and Tamura et. al (1994).



[9]

FIGURE 2-8:REALITY – VIRTUAL CONTINUUM BY MILGRAM

From the figure, at the end of the line are real world and virtual environment while in the middle, between them is mixed reality (MR). Augmented reality lies close to real world and predominate perception being the real world augmented by computer generated data. Hedley (2002) explored the use of hybrid user interface with the geographic data visualization collaboration. From the cartographic point of view, combination of modern computing technology with extensive digital coverage of the earth at multiple scale in particular form of cyberspace, give the effect of blurring distinction between reality and representation (Peuquet, 2002 : Peuquest and Kraak, 2002). The boundary between direct and indirect experience becomes fuzzy and it is difficult to distinguish between real and created one in cyber world. Krisp (2006) questioned if the virtual representation can ever replace the graphic and textual representation in geographic space, then Peuquet and Kraak (2002) answered it is clearly no

[9] https://www.researchgate.net/publication/259756809_Mobile_Augmented_Reality_The_Potential_for_Education/figures?lo=1 Retrived on 18th August 2019

because map is a symbolization abstraction of reality. But Krisp (2006) believed that the combination of realistic and virtual components might have advantages in the understanding of the phenomenon. The motivation of the development of virtual reality to geography is providing a realistic view (Unwin and Fisher, 2001) and at the same time help human to understand the simulation such as flood modelling or terrain height contour in cartography view. How the knowledge is discovered through different types of visualization relates to observation task that has been discussed in (2.2.1).

The immersive environment helps user in term of iconic image creation through virtual perception using the head-mounted device. Thus, it is able to reduce the cognitive workload compared to normal 3D virtualization on screen. Visualization in virtual environment can create better experience for users particularly to the public (Brainbridge, 2007). By merging the virtual environment with geographic concept such as regional features, geographic coordinate and geographic scale, it helps the user to get better understanding in geography information through multi-sensory interaction. Thus, it clearly improves understanding of real-world patterns and process. In this case, it provides convenient manipulation and communication that further contribute to attract more users and gain more geographic knowledge (Lin et al., 2013).

In order to extract the knowledge from interpretation of different visualization, a task has to be given to the participants. According to Robinson et al. (2011) one of the user-based method which is good for conducting the task in this research is by using surveys method through questionnaires. According to them, survey method can be questionnaires, entry/exit surveys, blind voting, or cognitive workload assessment. This method is good when the characteristics of the target audience are fully known, and the participants do not require long time to provide feedback. In cartographic perspective, conducting a survey through questionnaire is pretty good regarding the cartographic interface evaluation where the questions are related to the cartography representation and interaction. While participants completing the task, participants will be observed. Based on Robinson et al. (2005) the user study through observation is good when evaluator want to build strong connection with particular set of users about how the users currently work. Unstructured interview also good in cartography point of view. It is where the user provides map example from discussion and demonstrate existing visualization related to the study. They also clarify how they can extract the information from the existing map. (Slocum et, al. 2004). Figure 2.9 below shows the technique that has been used in this research which modified from the previous research on the case study of learning the contour and flood modelling by Šašinka and the group of research platform Center for Experimental Psychology and Cognitive Sciences (CEPCoS), Faculty of Art, Masaryk University of Prague, Czech Republic.

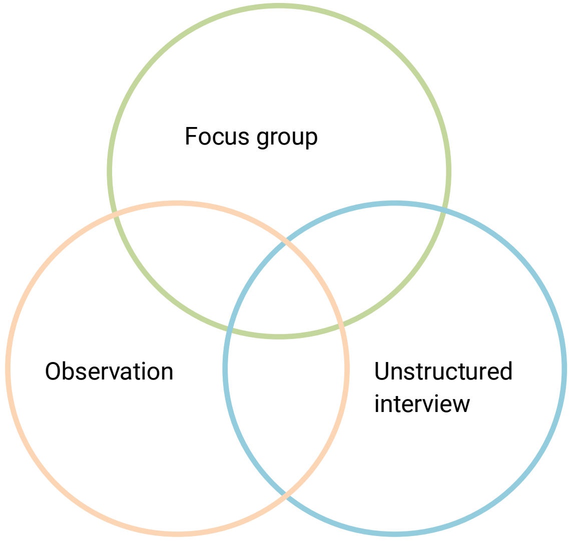


FIGURE 2-9:TRIANGULATION RESEARCH TECHNIQUE FOR ANALYSIS MODIFIED FROM ŠAŠINKA ET, AL (2016) Redrawn

3 METHODOLOGY

Flowchart explain the methodology in this research.

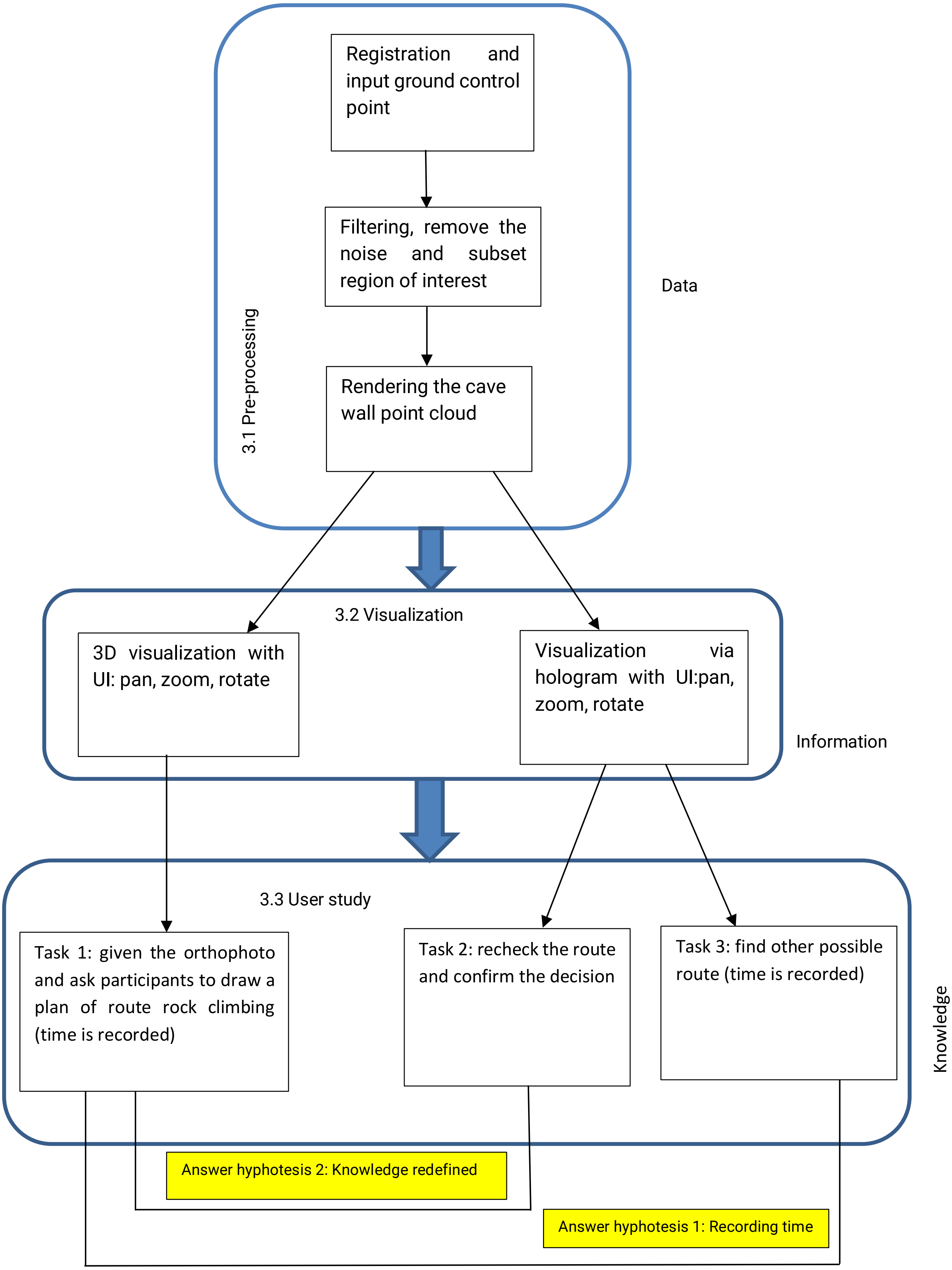


FIGURE 3-1:METHODOLOGY WORKFLOW

3.1 DATA (P RE-PROCESSING OF POINT CLOUD DATA)

3.1.1 POINT CLOUD REGISTRATION

Point clouds are often aligned with 3D models or with other point clouds, a process known as point set registration. All the points have to be registered to produce one of the complete objects. During the registration process the geometry correction is performed as well. Registration process is a crucial part because when the targets are not registered correctly the points do not blend in the same plane. For example, when the laser scans the wall of the room, the scan position of the laser device is moving from one place to another in order to have the complete scanning of the room. But if all scan positions are not registered correctly, it will produce two layers of wall plane instead of one plane of wall of the room.

3.1.2 FILTERING

Once the point clouds are registered, the filtering process will take part. In filtering process, the noise of the point clouds are removed. During the filtering process too, user can subset the area that is useful only, depending on the application of the study. As the point clouds are well known as a big data, the subset process is really important since not all of the point cloud software can manage big data of point smoothly.

3.2 RENDERING POINT CLOUD IN TWO DIFFERENT VISUALIZATION

3.2.1 3D VISUALIZATION AND USER INTERACTION TOOL

Point cloud data around 11 067 009 millions of points are rendered in 3D visualization using normal point cloud software. Figure 11 shows the point cloud data of the wall cave in rotation mode. Interaction tool using mouse is like normal usage of mouse. Right click to pan the wall cave, wheel button to zoom in and zoom out, while left click button to rotate the object.

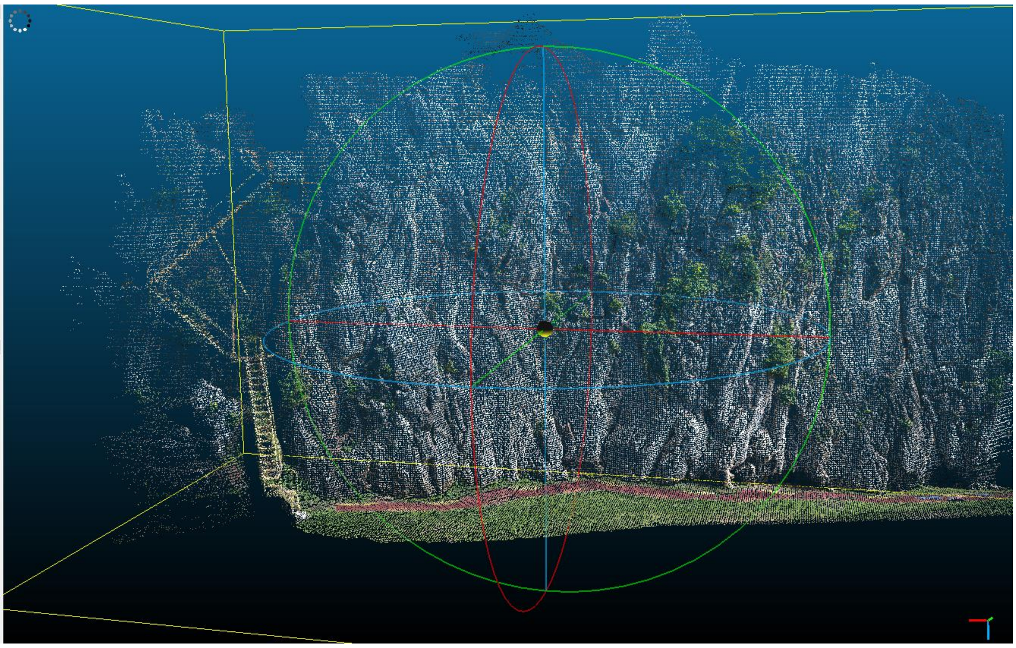


FIGURE 3-2: MAP ROTATION 3D CAVE

3.2.2 IMMERSIVE VISUALIZATION *HOLOCAVE* AND USER INTERACTION TOOL

Due to the big data issue of point cloud, proper package of point cloud importer source code is required to deploy the hologram inside the HoloLens device. From the github searching, kejiro point cloud data importer source code is used. The original point cloud data format which is .las have to converted to .ply data format in order to use pcx package created by Kejiro Takahashi. In order to deploy the point cloud in HoloLens device, mixed reality toolkit is imported as well.

*the link of the source code in github account is attached: [10]

*the link of the mixed reality toolkit package is attached: [11]

[10] https://github.com/keijiro/Pcx/tree/master/Assets
[11] https://github.com/microsoft/MixedRealityToolkit-Unity

FIGURE 3-3:AIR-TAP GESTURE RESCALE BY ADJUST WHITE COLOUR AT THE EDGE OF BOUNDING BOX BLUE IN COLOR

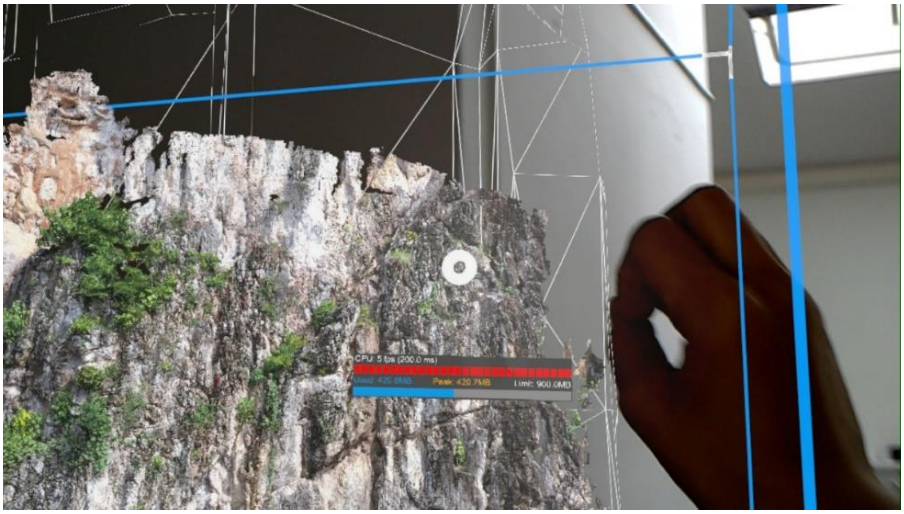


FIGURE 3-4:TAP GESTURE TO PAN AND ROTATE

3.3 CONDUCTING USER STUDY

In order to measure how much knowledge users can gain from two different types of visualization; a simple task is created. The target group of this research are people who have experience in climbing either rock climbing or bouldering. Participants are categorized in beginner, intermediate and expert level in climbing. They are given the printed 2D orthophoto of cave wall in A3 size. Before the experiment start, participants can have their own time as much as they can to get familiar using the mouse interaction tool for 3D visualization and air tap gesture for interacting with *HoloCave*. Time is recorded for each of the task. The details of the task are :

Task 1 : Plan and draft the climbing route on 2D printed orthophoto with a marker while having or after first visualization

Task 2 : Checking the existing climbing route with the second visualization. If user want to make changes, use the different marker to make the route in more details.

Task 3 : Using the second visualization, mark another possible route if they spot another interesting route.

Figure below shows on the right picture, user is checking the route after having 3D visualization as first visualization (location in dorm). On the left side, expert climber is learning how to use the air tap gesture (location in climbing gym). While image at bottom shows the climber planning and drafting the route (in eye tracking lab cartography)

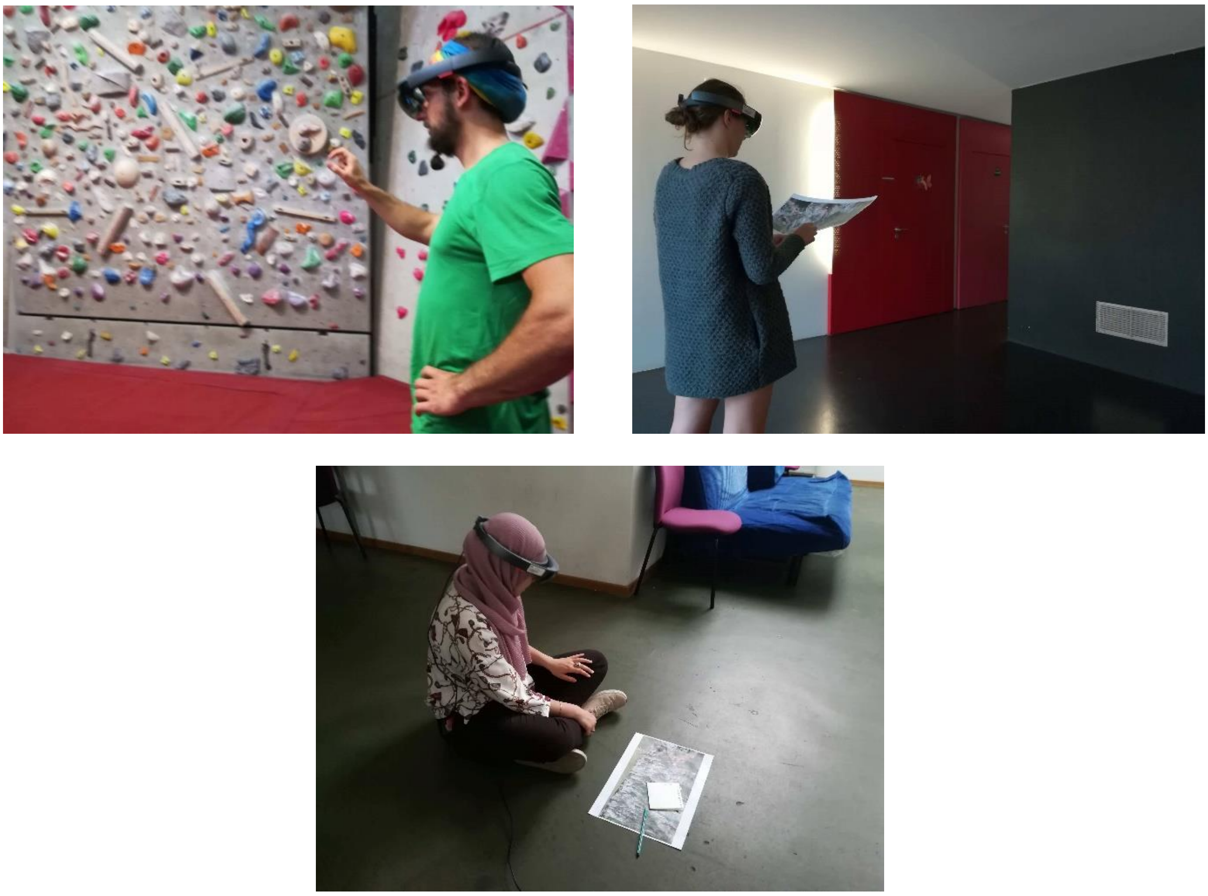


FIGURE 3-5:EXPERIMENT ON PROGRESS IN DIFFERENT PLACE AND DIFFERENT LEVEL OF CLIMBER

The pre-user study is conducted first before the real experiment. The participant of the pre-user study is an expert climber who has experiences in 3D point cloud. He also familiar with air tap gesture interaction through HoloLens device. From the pre user test finding, the existing orthophoto is flipped in order to provide the same orientation with 3D model and

HoloCave. The whole pre user test experiment takes around 30 minutes to complete all the task.

FIGURE 3-6: FLIPPED ORTHOPHOTO AFTER PRE- USER TEST

4 CASE STUDY

The case study of this research is one of the cave walls located in West Malaysia. The cave is called “Gua Damai”. Gua is Malay Language meaning cave, while “damai” is peace. The location of the cave is 3.2481° N, 101.6874° E. Gua Damai is in Batu Caves district and takes around 20 minutes by car from capital of Malaysia, Kuala Lumpur.

Gua Damai provides an eco-recreational and educational outdoor activities which include the obstacle rope management. Gua Damai extreme park also provide services for trekking and learning about traditional herbs. Gua Damai is situated behind Batu Cave hill. Batu Caves is one of the popular attractions among tourists where it has an old Hindu temple where worshipers come to pray aa well as celebrate Thaipusam. Gua Damai’s wall has more than 120 bolted routes with grade from 5 to 7’s, making it suitable for newcomers to climbing sport. It also has 2 other natural protection routes which is good for learning how to use natural protection device in rock climbing. Gua Damai is the first and only place in Malaysia where all base jumpers can jump from the height of 316 feet (96m) from its cliff and landed in the football field. The point cloud cave wall of Gua Damai is captured by Jurukur Perunding Services Sdn Bhd in 2017 using the drone Unmanned Aerial Vehicle (UAV) brand eBee second generation. During the flight planning the end lap is about 80-90% while the side lap is about 40 -60%.

FIGURE 4-1: ORIGINAL ORTHOPHOTO GUA DAMAI WALL

5 RESULT AND ANALYSIS

The result and analysis of the thesis are divided into three small parts as referred to (2.4). Referring to figure 10, there are three different results in this thesis which are; (i) observation (quantitative and qualitative); (ii) result and analysis from questionnaire (quantitative) and (iii) unstructured interview (qualitative).

5.1 OBSERVATION

Participants from target group (people who has experience in climbing) had been observed by recording the time when they are transforming the information from each visualization through drafting any climbing route on hardcopy orthophoto in A3 size. All the participants are categorized by their level in climbing because the prior knowledge may affect the decision making in planning a climbing route. The time is recorded in minutes for every task. In order to test the hypothesis 1 (1.4), time is recorded when the participant is planning and drafting a route while or after having visualization one and two. Each participant does not start with the same visualization. Some participant starts with 3D visualization then *HoloCave* and vice versa. Table 1 shows the time recorded for every climber in minutes. Certain climber does not perform the task in making any possible route in second visualization. So, the time will be recorded as zero minute.

T-test is one of the statistical analysis used in this research in order to check whether hypothesis null is accepted or rejected. The hypothesis null of the research is the same with the first hypothesis which is no difference in time taken in planning and drafting a route for climbing in 3D visualization and *HoloCave* as an immersive visualization. If the hypothesis null is rejected, the alternative hypothesis will be accepted, where there is a difference in time taken for 3D visualization and *HoloCave*.

Ho: $\mu 3D - \mu HC = 0$

H_1: at least one of the means is different.

Where:

Ho = hypothesis null

H_1 = alternative hypothesis

μ3D = mean time (minutes) in 3D visualization

μHC = mean time (minutes) in *HoloCave* (3D Immersive Visualization)

TABLE 1: RECORDED TIME TAKEN IN PLANNING AND DRAFTING ROUTE IN 3D AND *HOLOCAVE*

	Time Taken (minutes)	
Climber	3D	HC
1	6.28	2.72
2	4.09	1.87
3	2.6	3.47
4	0	4.57
5	10	7
6	0.38	0.87
7	8.1	4.68
8	0	2.18
9	2.88	3.6
10	7.92	4.17
11	6.28	0
12	0.58	2.27
13	0	1.17
14	1.97	0
15	1.73	0.93
16	0	2.63
17	4.52	1.08
sum	57.33	43.21
mean	**3.37**	**2.54**

The table shows that four climbers do not make any drafting of the possible route in 3D after they are having *HoloCave* as first visualization. Four of them already felt confident using the route in *HoloCave* visualization. Only two climbers who do not make any possible route in *HoloCave* because of one beginner climber having trouble using air tap gesture in HoloLens, while the other already satisfied using the same route planned in 3D even though he did make little changes in that route after using *HoloCave*.

TABLE 2:T-TEST PAIRED TWO SAMPLE FOR MEAN

	3D	*HC*
Mean	3.37	2.54
Variance	10.84	3.51
Observations	17	17
Pearson Correlation	0.48	
Hypothesized Mean Difference	0	
df	16	
t Stat	1.18	
P(T<=t) one-tail	0.13	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.26	
t Critical two-tail	2.12	

From table two, it shows that mean for time in 3D is 3.37 minutes while for *HoloCave* is 2.54 minutes. But there is a huge different in variance for 3D and *HoloCave* where both of their recorded time is 10.84 minutes and 3.51 minutes. If t Stat < -t Critical two-tail or t Stat > t Critical two-tail, the null hypothesis is rejected. Based on the t Test the value of t Stat is 1.18, while the t Critical two tail is 2.12. Thus, null hypothesis cannot be rejected. In simple statistical form is:

$$\boxed{-2.12 \leq 1.18 \leq 2.12}$$

Conclusion : Do NOT reject hypothesis null.

Ho is accepted.

The observed difference between the sample means (3.37 – 2.54) is not convincing enough to say that the average time taken for climber in planning and drafting route using 2 factors (two different visualization 3D and *HoloCave*) differ significantly.

Since prior knowledge is related to knowledge construction, further statistical analysis of two-way ANOVA without replication is tested by comparing the performance of each climber based on their skill in climbing either beginner, intermediate or expert.

TABLE 3:TWO WAY ANOVA WITHOUT REPLICATION

Anova: Two-Factor Without Replication

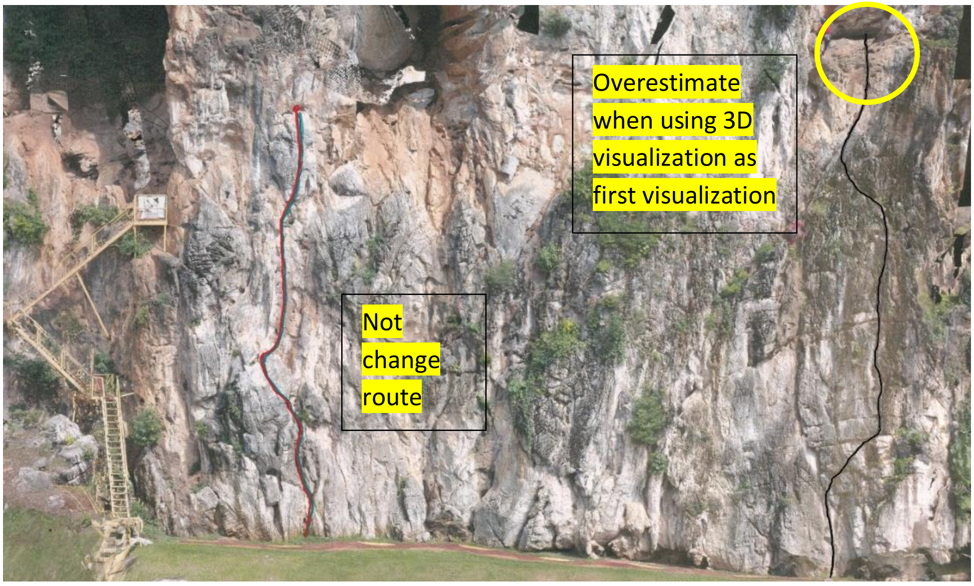
SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	2	9	4.5	6.3368
2	2	5.96	2.98	2.4642
3	2	6.07	3.035	0.37845
4	2	4.57	2.285	10.44245
5	2	17	8.5	4.5
6	2	1.25	0.625	0.12005
7	2	12.78	6.39	5.8482
8	2	2.18	1.09	2.3762
9	2	6.48	3.24	0.2592
10	2	12.09	6.045	7.03125
11	2	6.28	3.14	19.7192
12	2	2.85	1.425	1.42805
13	2	1.17	0.585	0.68445
14	2	1.97	0.985	1.94045
15	2	2.66	1.33	0.32
16	2	2.63	1.315	3.45845
17	2	5.6	2.8	5.9168
3D	17	57.33	3.372353	10.84023
HC	17	43.21	2.541765	3.513878

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	162.3055	16	10.14409	2.41	0.04	2.33
Columns	5.863953	1	5.863953	1.392858	0.26	4.493998
Error	67.36025	16	4.210015			
Total	235.5297	33				

From the table 3, ρ value in row (each climber) is 0.04 which is less than 0.05, it concludes that there is statistically significant difference in time taken based on their prior knowledge of climbing. But no significant difference in time taken between 3D and *HoloCave* visualization.

From the observation, participant who are eager to learn air tap gesture normally takes a longer time to get familiar with that interaction. For pan the *HoloCave* is seem really easy for them even they are not familiar with it. All of the participants do not have any trouble to pan the *HoloCave*. But for the rotation and rescale, only five participants are successfully control the *HoloCave*. To rotate the HoloCave they have to use the both hands to tap and rotate the object slowly because the massive data of the point cloud do not work so well with the first generation of HoloLens. To rescale it is very tricky and quite difficult because they have to use two hands as well and tap the white edge of the blue bounding box which hold the *HoloCave* inside. One of the expert participants flipped the object during the experiment and the evaluator has to stop the time and reset the hologram again. Most of the participant who are enthusiastic with the new technology of AR do not complaint about air tap gesture interaction through HoloLens device. However, the unstability of the *HoloCave* is still a problem during the experiment. Here are a few samples of orthophoto that have been marked by respondents. There is one expert climber who make mistake during interpretation by marking the route that is not in 3D or *HoloCave*. Another one is intermediate level who made changes during *HoloCave* visualization.



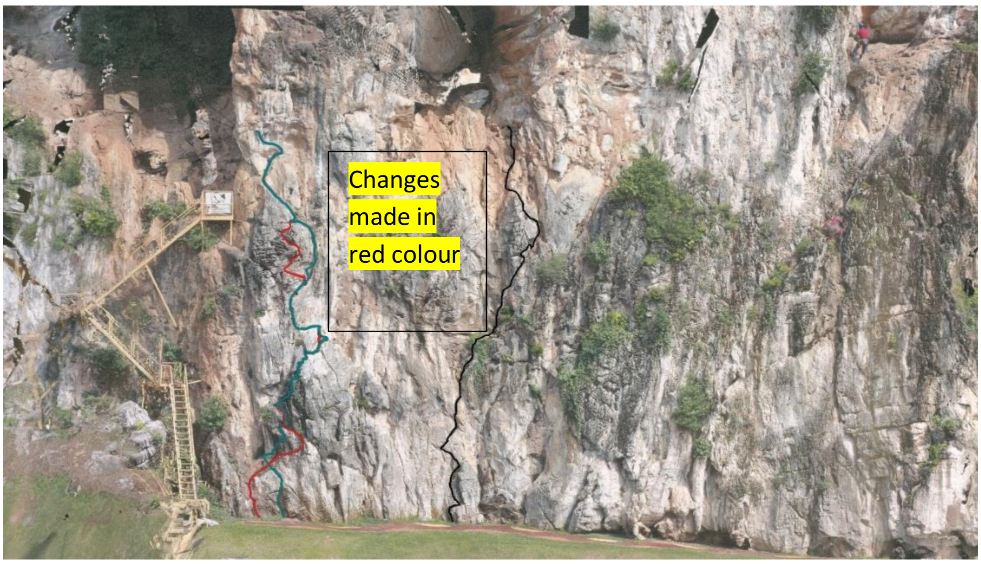


FIGURE 5-1: SAMPLE MARKED ORTHOPHOTO

The remaining orthophoto draft has been uploaded in the DVD attached in hardcopy thesis. In total, there are three participants out of seventeen participants who are overestimate route. All of overestimate cases is from 3D visualization. However, there is only one overestimate case from *HoloCave*.

5.2 QUESTIONNAIRE

This section divides by three different parts; (i) demographic questions which has 7 questions; (ii) 5 questions relate to human understanding and knowledge construction with both visualizations and (iii) 3 open questions where the user has to give the opinion, reason and suggestions.

5.2.1 DEMOGRAPHIC QUESTIONS

The sample of demographic question is about the age, gender, level of climbing, how familiar their interaction with mouse in 3D visualization, how familiar they are interacting with air tap gesture in HoloCave, how often they do rock climbing and whether they have ever seen 3D point cloud data before or not. Total of the participants is 17, where 9 males and 8 females. There are 8 people of each age range between 18-24 and 25-34 years old, with only 1 person in the range of age between 35-44 years old.

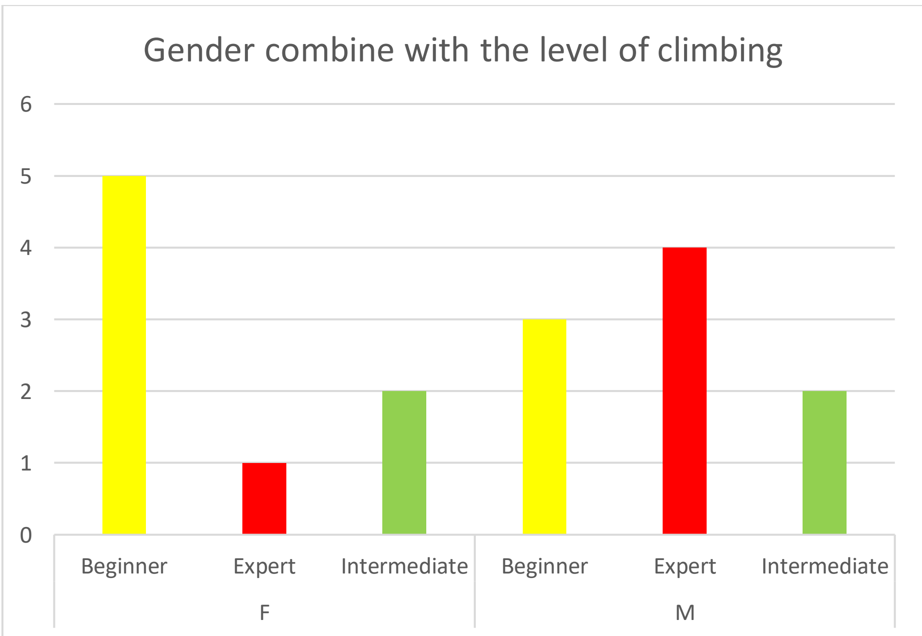


FIGURE 5-2: GRAPH LEVEL OF CLIMBING IN GENDER CATEGORIZE

From the figure 5.2, it shows that 5 female respondents consider themselves as beginner, 2 is intermediate and 1 is expert level. From the male group, 3 of them are considering themselves as beginner, 2 people consider as intermediate while 4 of them are experts.

The color for level is based on colour coded in rock climbing gym. Normally, stone with the yellow and blue colour are considered as easy and it is a good start for the beginner level. For those who want to challenge himself or herself a bit will take a route with green code, while the red colour is for expert. Usually the red and black color coded the wall in the rock climbing gym is not a 90 degree vertical anymore, it is very tilt which is around 45 to 60 degree. Thus, before the respondents identify themselves in which level of expertise, the evaluator asks the questions of which color code they usually follow when climbing in indoor climbing gym. Certain climbing gym use the color coded to level the hardness of the route, while certain climbing gym use the number as grade. In outdoor climbing usually people use the grade.

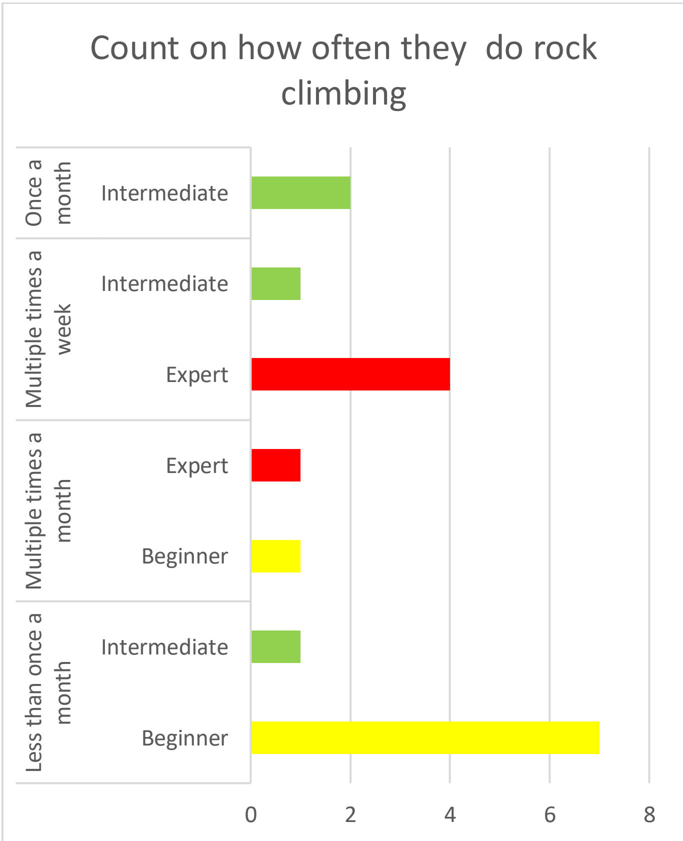


FIGURE 5-3: LEVEL OF CLIMBER AND HOW MANY TIMES THEY CLIMB IN A MONTH

From the figure 5.3, it shows evidently majority of the experts go climbing multiple times a week while most of beginners only climb less than once a month. How often they do rock climbing is highly represented in their level and it is positively related to the alpha value in ANOVA result (Table 3:two way anova without replication), where the performance in time taken to perform the task based on 3D and *HoloCave* is statistically significant on the prior knowledge of each person.

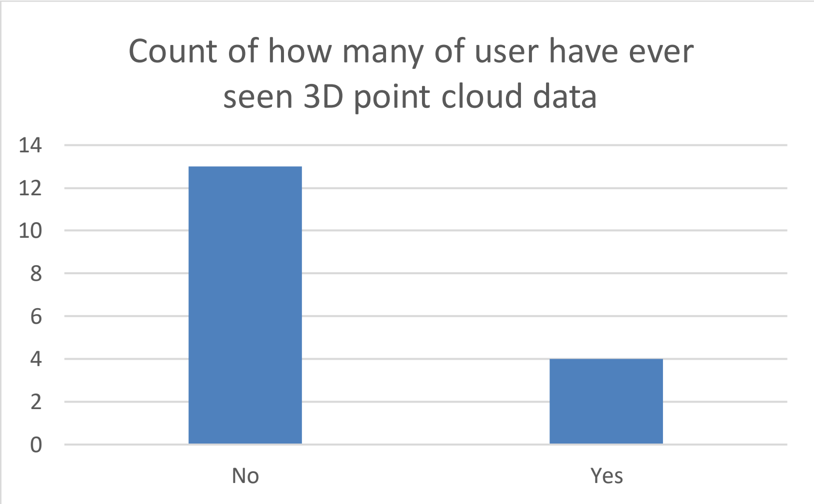


FIGURE 5-4: HOW MANY USERS HAVE EVER VISUALIZE 3D POINT CLOUD

From the figure 5.4, only 3 participants have visualized 3D point cloud data before while the rest said it was the first time they saw the point cloud. From the observation, the time they took for planning and drafting the route is not correlated whether they have experience with point cloud data or not. Certain people who have never experienced in visualizing point cloud data before only takes 56 second (fastest time among users whosaw point cloud data for the first time) to complete the first task. While the person who has experience in point cloud data took 7 minutes (longest time among the other two persons who ever seen point cloud). So that, it can be assumed that prior knowledge of point cloud data does not give any affect in knowledge construction in planning climbing route.

For the demographic question (4) about have they ever had experience using HoloLens before. No one has ever experience using the HoloLens. Even they had a briefing about how to use air tap gesture interaction, it takes time and need to practise to click with air tap 2 fingers. In order to analyse how familiar they are using two different interactions with two different visualizations, it has to relate with their understanding and the knowledge that they gain from first and second visualization.

5.2.2 HUMAN UNDERSTANDING AND KNOWLEDGE CONSTRUCTION

Since the interaction is related to the knowledge construction while performing the task (Figure 2-3: Map use cube). Thus, the scale of how familiar the participants are in controlling 3D object using mouse is measured in 7 scale (question 5a) will be relate to the question number 11 where they have to scale their opinion about better overview and understanding the structure of the wall. The answer in question number 11 also have 7 scale.

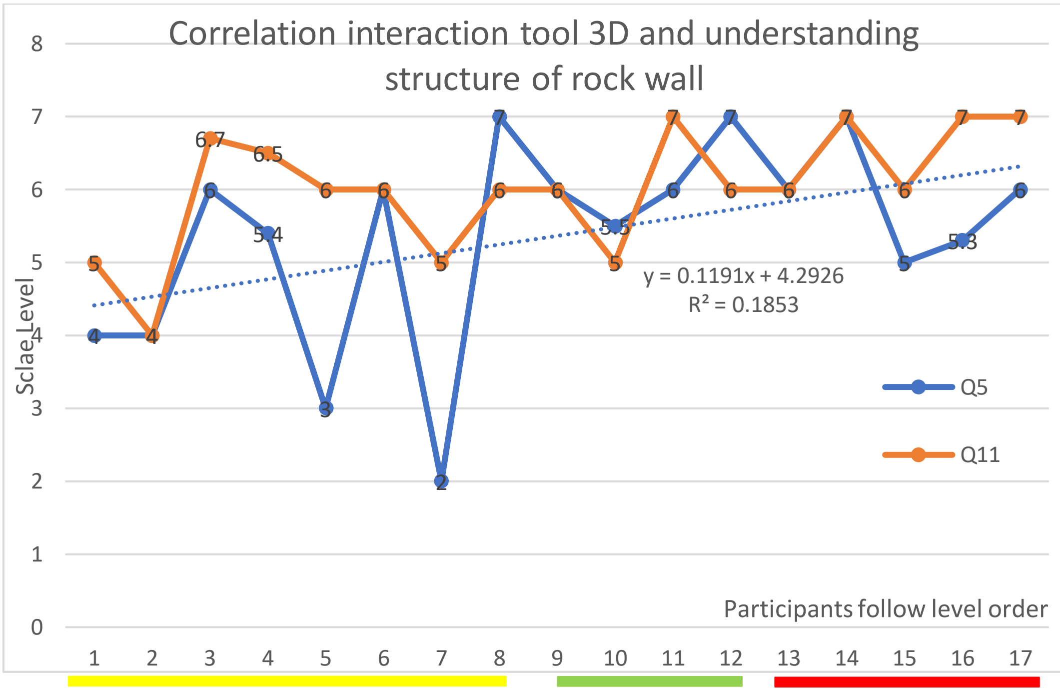
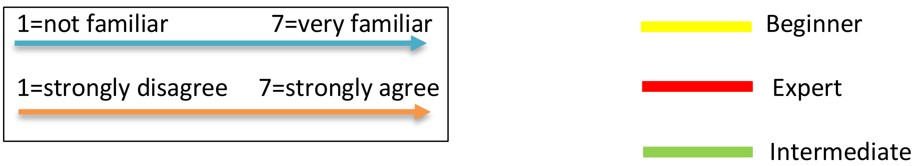


FIGURE 5-5: CORRELATION INTERACTION IN 3D WITH UNDERSTANDING



From figure 5.5, it shows that there is a linear positive correlation which fits the regression model of R^2 20% between the familiarity in controlling mouse as interaction tool for 3D visualization and better overview and understanding of the structure of the wall following the order of the climbing level among participants. The calculation of square root of R^2, give the r value or is called as correlation coefficient is 0.42. It is a positive moderate correlation. It means people who are most familiar in controlling the interaction with mouse get better overview and understanding of the structure of the wall during the experiment. The result is not promising enough because the sample size is considered small in statistic view.

Question 9 is about how helpful 3D visualization in planning a route and it will be related to the familiarity in controlling interaction tool using mouse click.

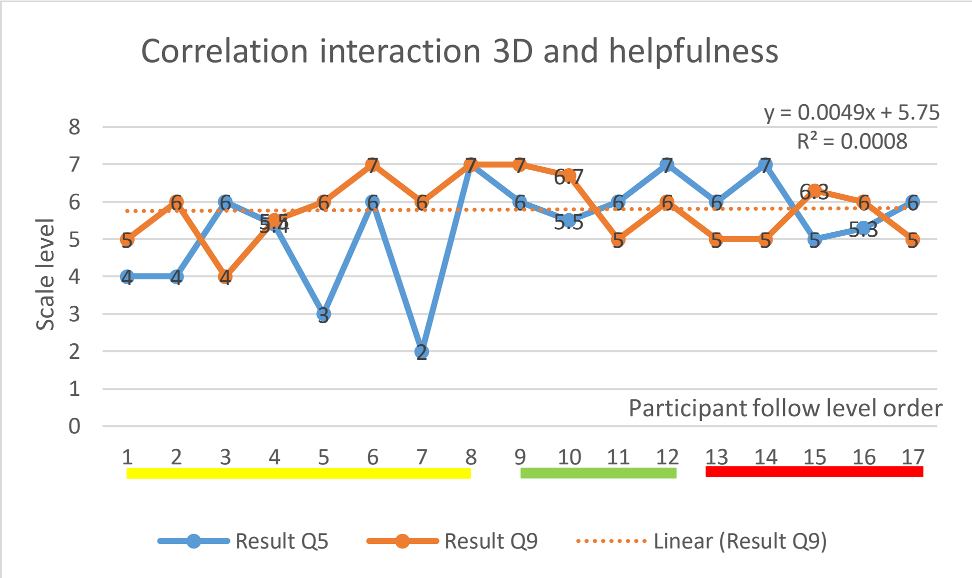


FIGURE 5-6:RELATIONSHIP INTERACTION 3D WITH LIKERT SCALE OF HELPFULNESS

Figure 5.6 shows the graph of the relationship between how familiar the user measures their interaction using mouse in 3D visualization and scale on how much they agreed 3D visualization is helpful in planning climbing route. The correlation between two variables is positively correlated, but the value R^2 is almost 0% and it gives the correlation coefficient value, r value is 0.0. It is means that there is no correlation between two variables. Thus, how familiar in controlling 3D visualization through mouse is independent variable. To conclude, between the (Figure 5-5: Correlation interaction in 3d with understanding) and (Figure 5-6:Relationship interaction 3d with likert scale of helpfulness), the higher the scale of familiarity in interaction influences the understanding of the structure of the wall. However, it is not too much helpful in planning route for climbing. It is because of the prior knowledge of climbing is considered as the main factor. Nevertheless, the result might be different and much more convincing if the respondents is more than 17.

Since none of the respondents have experiences using the air tap gesture through HoloLens device, no analysis of the relationship between familiarity's scale in air tap gesture interaction to helpfulness level or understanding view. But, the Likert scale of helpfulness through *HoloCave* visualization can be relate to how much scale they agreed for better overview and understanding structure of the wall. In order to measure the relationship of the two variables (helpfulness) and better overview and understanding, regression model is calculated again.

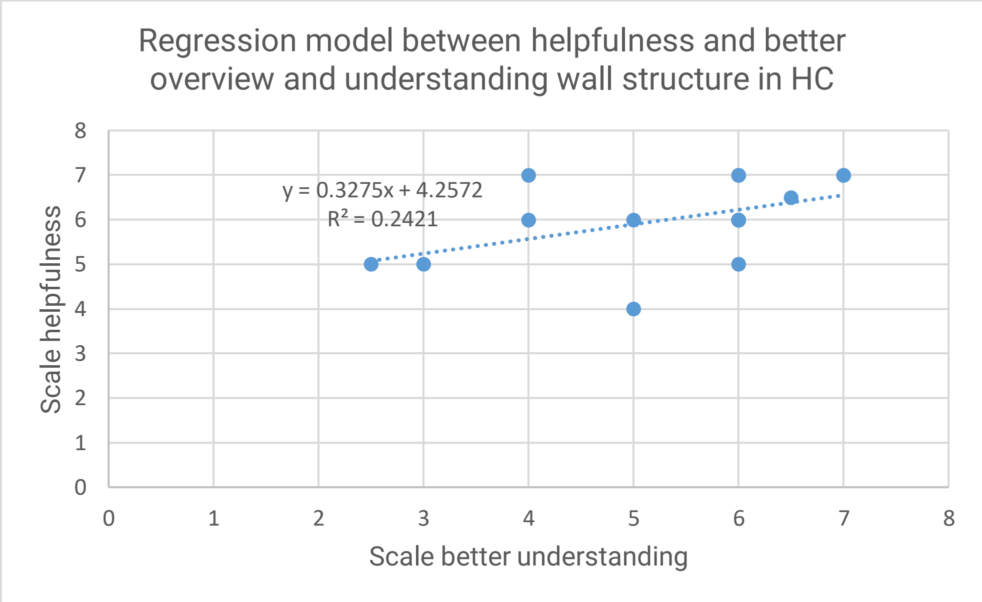


FIGURE 5-7:RELATIONSHIP IN HC BETWEEN 2 VARIABLES

From figure 5.7, it shows the regression model between helpfulness scale and better overview and understanding structure of the wall. From the regression model above, R^2 value is 0.227 while the square root of it gives the r, correlation coefficient value of 0.49. It means that there is a positive correlation between helpful level scale and better overview and understanding of the rock wall structure. Due to the small sample of respondents in statistical view, the result of correlation is not promising enough to prove. However, it is clearly shows positive correlation among them and 0.49 is considered as moderate positive correlation. To conclude that figure, helpfulness level in *HoloCave* has a moderate relation to better overview and understanding of the wall structure. Therefore, participants who vote for high level of helpfulness are getting more understanding and better overview of the structure while they are performing the task.

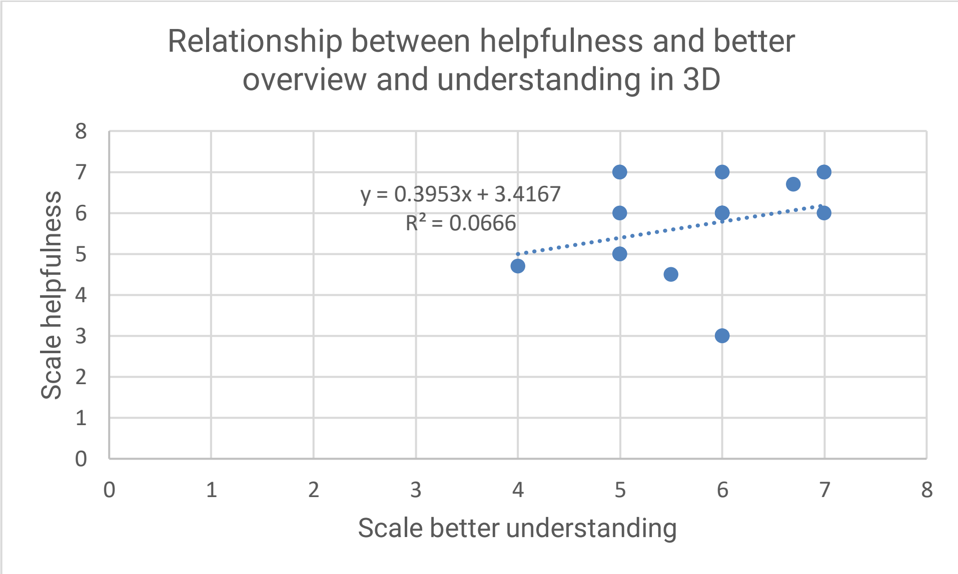


FIGURE 5-8:REGRESSION MODEL BETWEEN 2 VARIABLES IN 3D

Figure 5.8 above shows the relationship between helpfulness scale and better overview and understanding in 3D visualizations. Helpfulness scale is considered as one variable or a factor. While better overview and understanding is the other one. The purpose of measuring the correlation between these 2 factors is because of some respondents did not get better overview and understanding of the cave wall structure while using the 3D visualization even if they claim 3D visualization is more helpful than *HoloCave*. From the graph it shows that R^2 value is 0.06 and it is lower than R^2 of *HoloCave* regression model. The correlation coefficient, r is calculated, and it gives the value 0.26. By comparing the (Figure 5-7:Relationship in hc between 2 variables) and (Figure 5-8:Regression model between 2 variables in 3d) it shows that the correlation coefficient in *HoloCave* which is 0.49 is much higher than 3D which is 0.26 and it is almost half in difference. In conclusion, *HoloCave* has stronger relation between helpfulness scale and better overview and understanding of the wall structure compared to the relationship in 3D visualization. People think *HoloCave* is helpful and they get better over view and understanding. Meanwhile, 3D is helpful too, but they do not get better overview and understanding the structure of the wall cave which is proven by the lower r, correlation coefficient value. However, due to the small number of samples, r value, is not convincing enough in statistical.

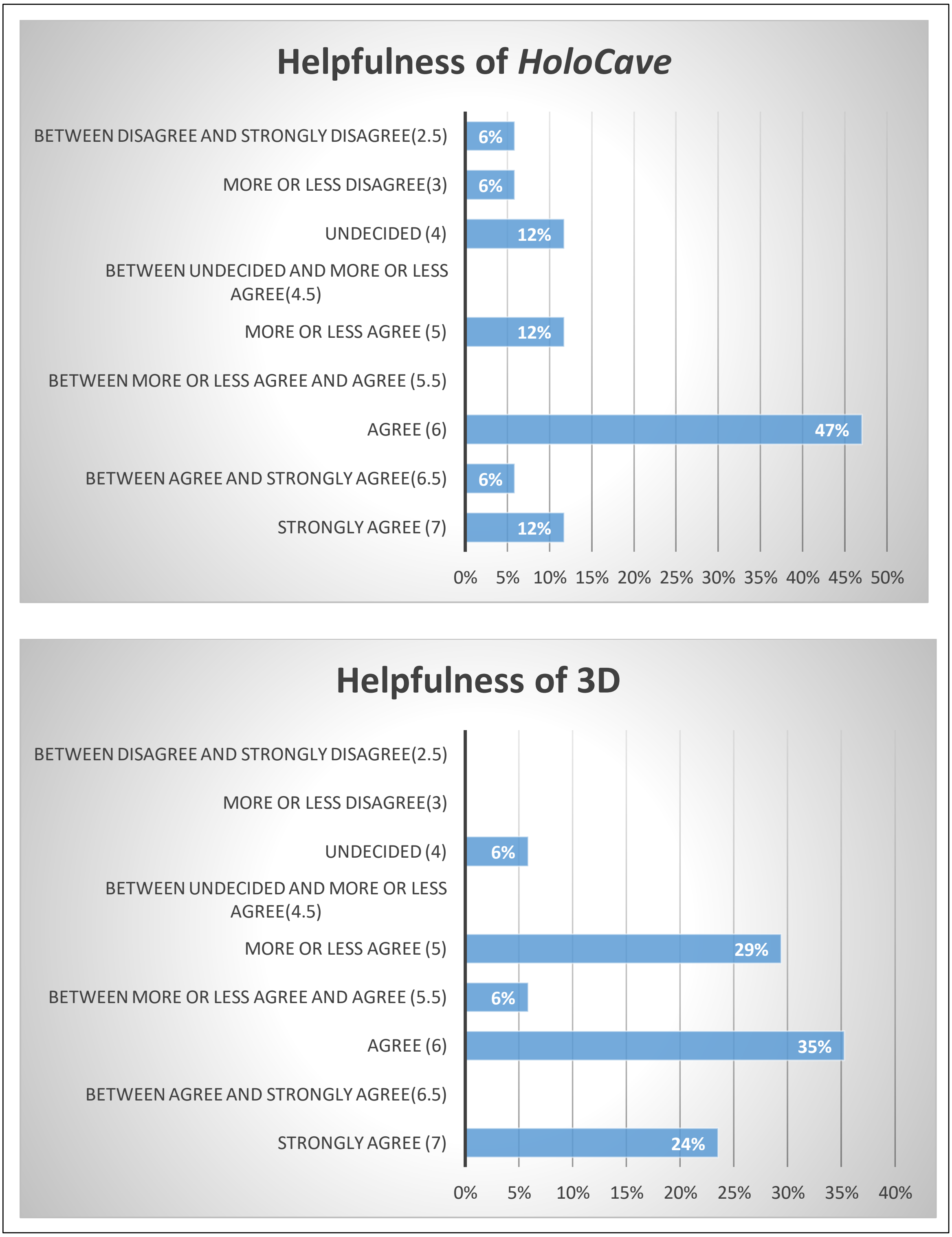


FIGURE 5-9:COMPARISON HELPFULNESS LIKERT SCALE OF 7 BETWEEN 3D AND *HOLOCAVE*

From figure 5.9, it shows that the bar chart comparison of 3D visualization and *HoloCave*. Likert scale that is being used in the questionnaire is seven scale which is more suitable in psychological perspective because this research involved immersion, the feeling of being in the real situation. In Likert scale of 7 includes strongly disagree =1, disagree =2, more or less disagree = 3, undecided or neutral =4, more or less agree=5, agree=6, and strongly agree=7. From the above figure, the agree point is considered as a more positive view rather than focusing on the disagree. To conclude the agree point scales are consist of agree, between agree and strongly agree, between more or less agree and agree and obviously strongly agree. Between more or less agree and agree is belong to agree part because of it is toward to agree. Sum the percentage of agree point scale in *HoloCave* agree =47%, between agree and strongly agree =6%, and strongly agree and more or less agree= 12% both and the total is 77% vote for agree.

In 3D visualization part 6% vote for between more or less agree and agree, 35% for agree and 24% for strongly agree, more or less agree equal to 29% and sum of that gives 94%. To conclude, the comparison between these 2-bar chart, 3D visualization gets higher value than *HoloCave* for agree point. Thus, 3D visualization is more helpful than *HoloCave*.

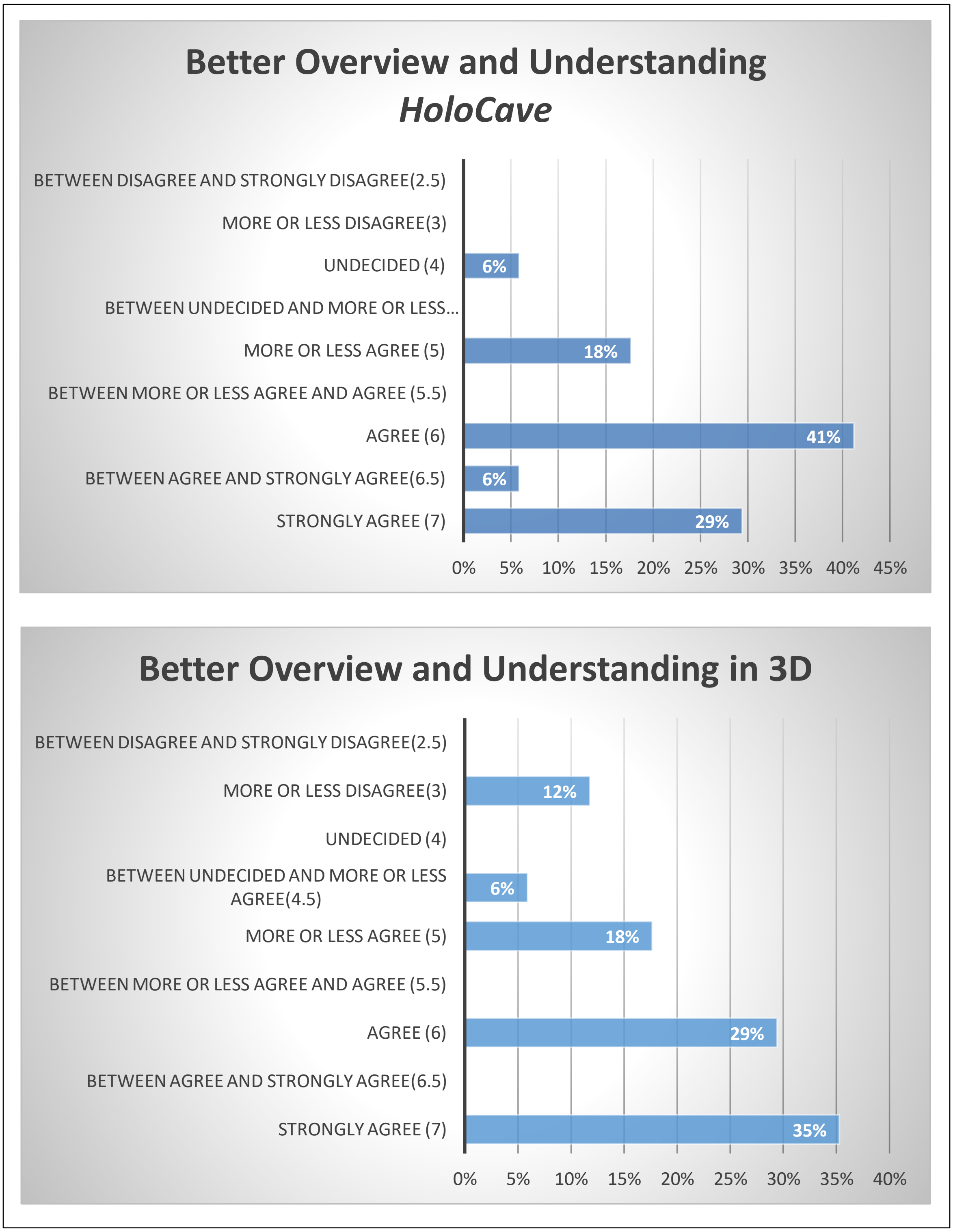


FIGURE 5-10:COMPARISON BETWEEN HOLOCAVE AND 3D IN BETTER OVERVIEW AND UNDERSTANDING

Figure 5.10 shows the bar chart of 2 visualization 3D and *HoloCave* in comparison for better overview and understanding of the wall structure. For this part, positive view will be considered. Agree point scales cover from scale 5 to 7. The percentage of agree part will be sum up for both visualizations. *HoloCave* received 94% agree part, while 3D get more lower value which is 88%. To conclude that, *HoloCave* get higher percentage of agree part in better overview and understanding the structure of the wall. Since the performance of each participant is significantly proven by alpha value (Table 3:two way anova without replication) so that further analysis of voting from expert level is being considered. Since they already have strong prior knowledge of climbing in outdoor 4 out of 5 do rock climbing multiple times a week, their voting is more significant in better overview and understanding compared to intermediate and beginner level.

Figure below show the comparisons of better overview and understanding and helpfulness scale between *HoloCave* and 3D visualization from expert level.

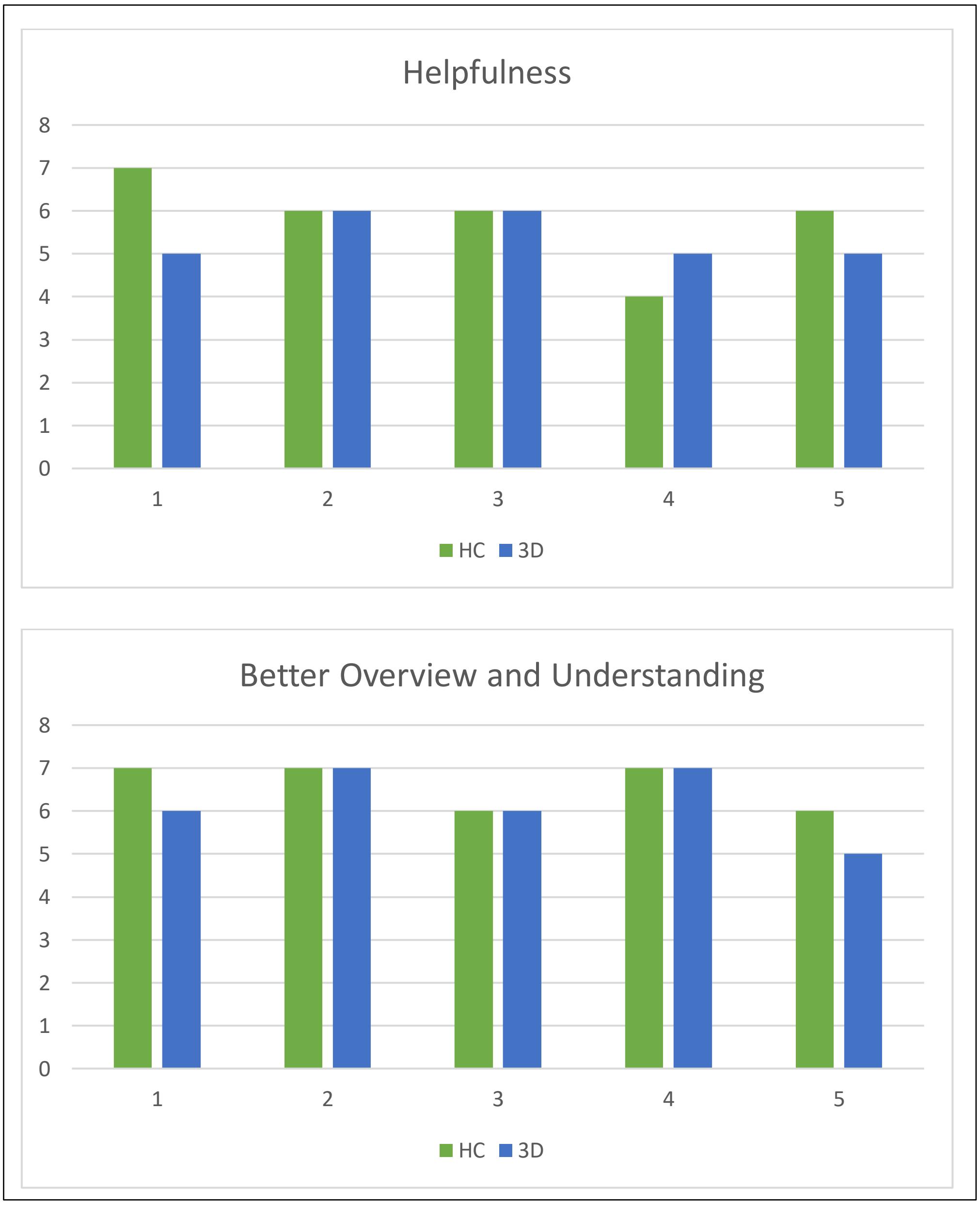


FIGURE 5-11: VOTE FROM EXPERT LEVEL

From figure 5.11, it clearly shows that two experts vote the same score for *HoloCave* and 3D in helpfulness level, while for better understanding and overview three of them give the equal score for both. Two experts give higher score for *HoloCave* rather than 3D visualization in helpfulness criteria and better overview and understanding. However only one expert gives lower rate for *HoloCave* in helpfulness criteria. When focusing on strongly agree part which represent by 7, one expert think *HoloCave* is strongly helpful. Three of them give the highest rate strongly agree for *HoloCave* as well in better overview and understanding structure criteria, and only two of them choose strongly agreed for 3D. To conclude this, *HoloCave* get more strongly agree vote compared to 3D visualization for both criteria. If the experts level claim it so, logically it will be more obvious to beginner level.

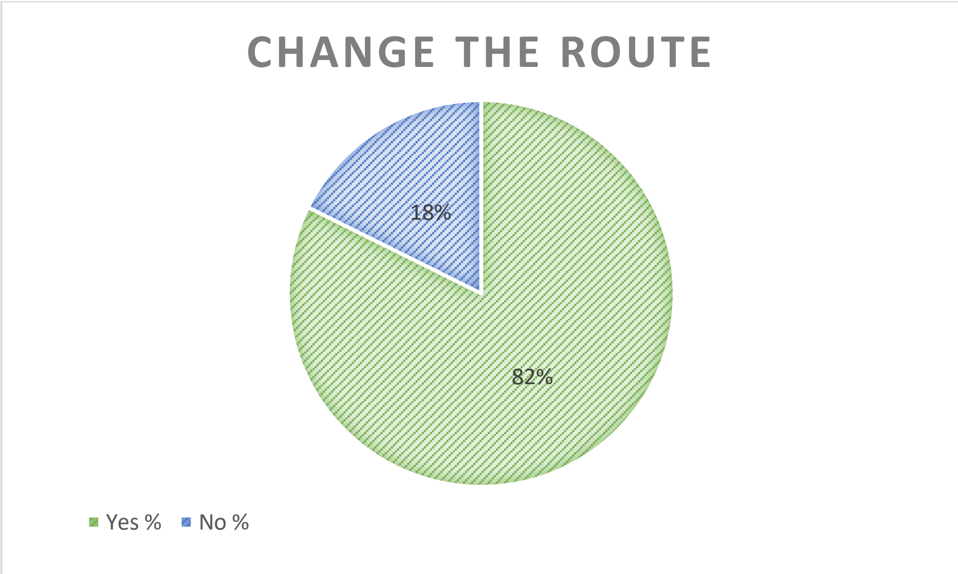


FIGURE 5-12:PERCENTAGE PARTICIPANT CHANGE THE ROUTE AFTER HAVE FIRST VISUALIZATION

Figure 5.12 above shows the percentage of the climbers who change the route after have first visualization. Only 18% did not change the route after having the first visualization and all of them use the *HoloCave* as the first visualization. During the experiment 9 respondents start with 3D visualization while the rest 8 climbers start with *HoloCave*. The reason why they change their mind as stated below:

TABLE 4: REASONS WHY CHANGE THE ROUTE

Change route during HoloCave	Change route during 3D
Interesting route	More time to decide
Nature controlling with eyes	Distinguish crack system clearer
Grove seen clearly	More confident route
Spot easier path – 3 participants	Spot difference rock structure while rotating
More confident route	In case don't make it
Able to see terrain better	Easier route

To analysis which visualization give benefit more to them question 13 and 14 are designed. It asks about which visualization they like the most and which one is better. All the stated reasons will be stated as a group in the graph. Figure 5.12 shows 53% respondents choose *HoloCave* as their most favourite, while 47% prefer 3D visualization.

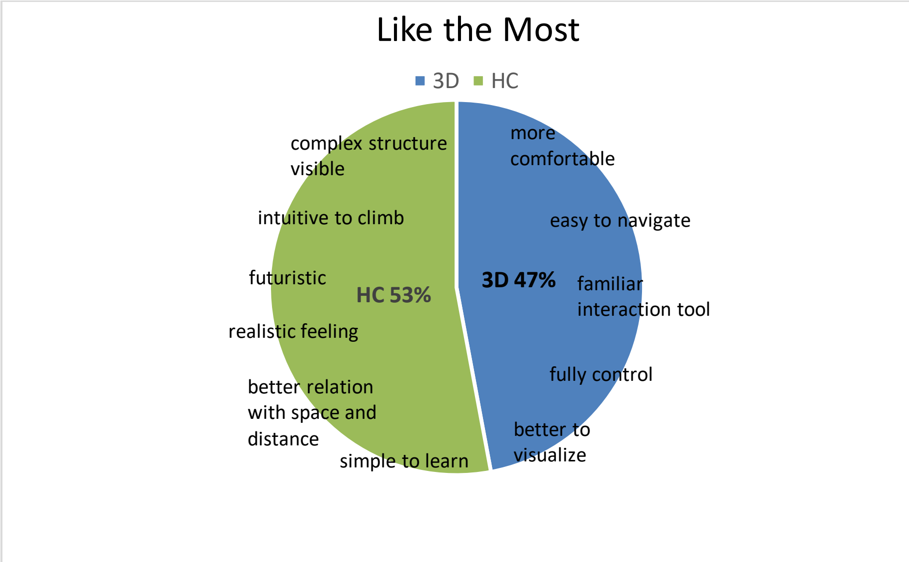


FIGURE 5-13: PIE CHART MOST LIKELY VISUALIZATION

Figure 5.13 shows the pie chart of which visualization they think is better. From the figure, 71% climbers vote for *HoloCave* while the rest 29% choose 3D visualization. Even when most of them complain that it is difficult to use the air tap gesture, they still choose *HoloCave* as a better visualization. Due to massive data of point cloud and low performance of first generation of HoloLens, *HoloCave* is not stable enough compared to 3D visualization. It lags and have to be controlled slowly.

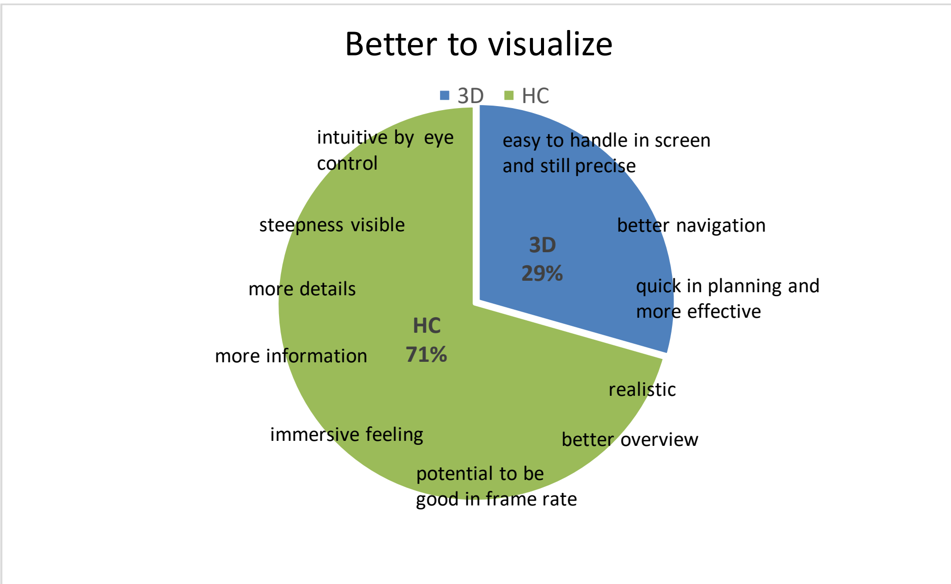


FIGURE 5-14:PIE CHART COMPARING BETTER VISUALIZATION

Figure below 5.14 and 5.15 shows the suggestions for 3D visualization and *HoloCave* for better improvement in the future. All the suggestions are analysed by grouping the same concept of suggestion and calculate as percentage. For each of the question, there is one respondent who do not understand the question well, thus her answers are excluded.

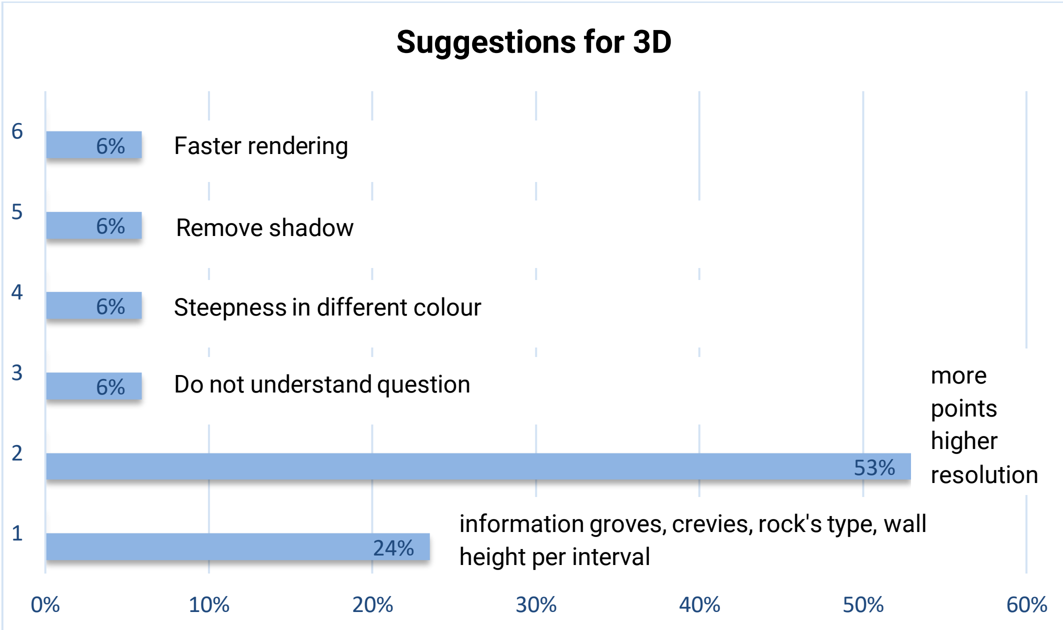


FIGURE 5-15:LIST SUGGESTIONS FOR 3D AS PERCENTAGE

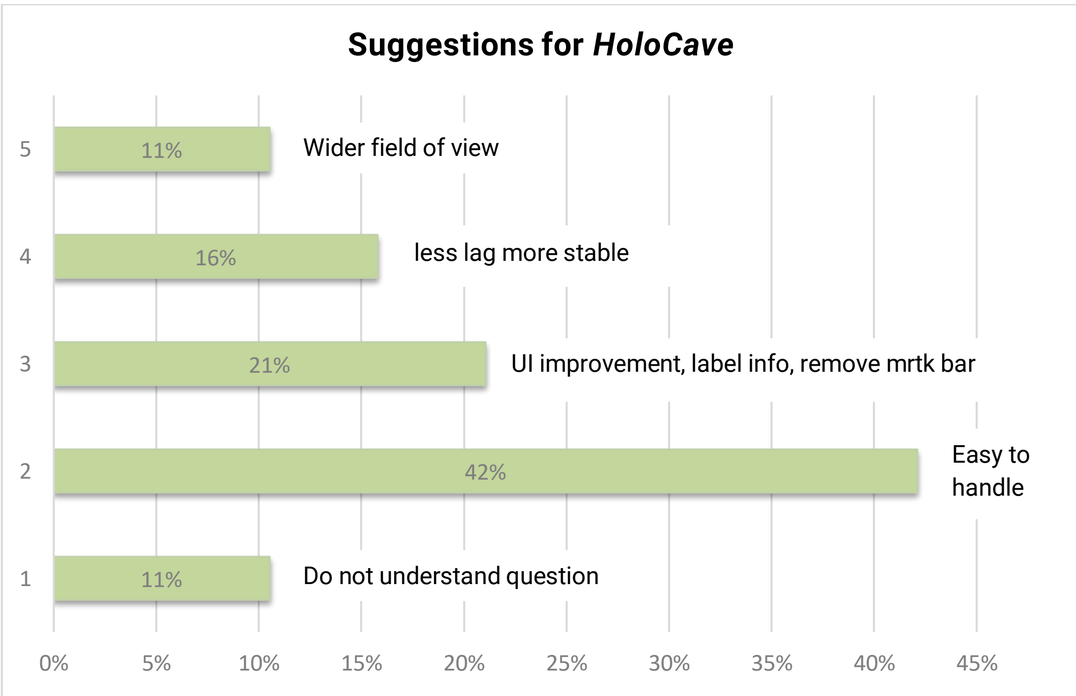


FIGURE 5-16:LIST SUGGESTIONS FOR *HOLOCAVE*

5.3 Unstructured interview

On 11th August 2017, during conducting the experiment in Eddy Crashpaddy Klettersteig in Osbahnhof Munich, 2 expert climbers, Lukas and Philipp are wiling to be interviewed.

Your opinion about 3D and *HoloCave*?

“It is much more better if 3D visualization can be applied in vertical life application in mobile. Vertical life apps is an application for climber to plan the route. In that apps also there are existing route that has been marked by previous climber who already climb there before.”

“In that apps the picture only 2D simple sketch most of the time and it is not helpful and it is really difficult to extract the information.

“Sometimes they do not mark the grass that existing because it is not frequently updated unless the rock wall is popular. They did not even have 3D model”

Do you think 3D and *HoloCave* are helpful for climber?

“Yes. Both 3D and *HoloCave* are really good in gaining in knowledge for planning a route for climber especially for beginner. “

From your opinion which one is more better and useful?

“In 3D we get the whole overview of the wall and easy to interact (easy interaction tool with mouse).But for better understanding of the structure of the rock *HoloCave* is better.”

“The only problem is it is really hard to interact using air tap gesture.”

Since both of them have their own limitation, what are your suggestions to improve both of the visualization for the future research in climbing sport?

“We proposed the joystick instead of moving and rotate the body and head for *HoloCave*.”

“For the orthophoto, 3D and also for *HoloCave* please include also the scale. It is much more helpful if there is a line with the measurement in meter for every 5 m interval for example. “

“We imagine we can bring the *HoloLens* at site and overlay with the realistic one. In hologram as well should has the measurement of the wall for every interval. Labelling the type of the rock also good for geoglogical study“

6 DISCUSSIONS

In this section, the result will be discussed in the context of referenced literature and challenge it to preliminary expectation. The result that has been interpreted and described will be further discuss concisely for each subtheme.

6.1 DIFFERENCE TIME TAKEN FOR EACH VISUALIZATION

One of the main findings of this study was there is no significant in time taken for knowledge construction between 3D visualization and immersive visualization *HoloCave*. It is proof by the T-test where the average difference of time taken for both visualizations is small than expected. It is totally rejects the first hypothesis of this research where 3D takes longer time compared to *HoloCave* during interpretation of the data visualization, and then transforming the information to the piece of orthophoto given. Finally, it becomes the knowledge construction. Lindholm and Sarjakoski, (1994) believe the prior knowledge may affect the knowledge construction through the task given. It is totally true. ANOVA two factors without replication is calculated which analyse the 2 factors coming together time taken and performance for each participant. Since the target group of respondents are climbers for each level beginner, intermediate and expert. There is a statistically significant performance for each participant based on their experience in climbing where can called as prior knowledge.

6.2 DIFFERENT VISUALIZATIONS IN KNOWLEDGE CONSTRUCTION

Second main part from the finding, is about interaction tool for every visualization and the relationship toward knowledge construction whether it is helpful enough or not. Helpfulness scale is measured using Likert scale of 7. From the regression model, there is a moderate relationship between familiarity of controlling 3D visualization interaction using mouse and get better and overview and understanding of the structure of the wall cave. Since no participants have use air tap gesture before so the interaction of *HoloCave* cannot be analysed. However, when the unstructured interview is conducted with expert climbers in rock climbing gym, both of them claim, they have better overview and understanding of the wall structure when they using *HoloCave* to plan and draft the route on 2D orthophoto given even though both of the visualization are helpful for planning the climbing route. Based on their statement, the regression model is used again to measure the relationship between helpfulness of 3D and *HoloCave* with better overview and understanding. Correlation coefficient, r value from 3D visualization is smaller than *HoloCave*'s r value. It is means *HoloCave* has more positive relationship between helpfulness and better overview and understanding the rock wall structure compared to 3D visualization. It answers hypothesis two where immersive visualization provide better overview and understanding of object reality. Hypothesis two is accepted where immersive visualization gives better overview and understanding of rock structure means that knowledge construction is more understandable.

Participants explained they finally seeing the rock structure clearer after checking the route in *HoloCave*. They feel like intuitive to climb once they first saw it. *HoloCave* represented in mixed reality environment help them gain more insight. Most common experience shared by participants was immersion feeling. Šašinka et al. (2018) describe immersion as a psychological state by perceiving environment around us and at the same time perceiving self as part of environment. Participants feel a stronger sense of being presence in front of the wall cave, feeling energized focus and enjoyment without having motion sickness because it is mixed reality environment. Because of that reason, 3 participants who do not make any changes of the route is, starts the task with *HoloCave*. They already felt confident and so sure to take the route. In Paiget's theory Piaget (2015) of cognitive development, participants underwent the process of accommodation when their pre-existing schemas were adjusted from 3D visualization to *HoloCave* or from *HoloCave* to 3D. Switching from first to second visualization creates new experience. The importance of the experience described by Dewey (1938) and his follower Kolb (2015) further elaborated learning as a circular process of creating knowledge via transformation of experience. Having *HoloCave* as second visualization for checking the route generates immersive environment making participants feel the experience being in front of the wall cave. It creates the cognitive conflict of decision making after first visualization 3D. Even if 3D visualization is already good enough, it can never create the feeling of immersion in front of the screen.

6.3 PRO AND CONS OF 3D AND *HOLOCAVE*

3D and *HoloCave* are both are helpful enough to plan the climbing route compared to existing climber application in smartphone or website which is only provide 2D images. Since the interaction help in knowledge construction, 3D interaction is already fully control and easy to navigate compared to air tap gesture via HoloLens. Since relationship of knowledge construction starts from data, some participants give the suggestions to increase the resolution for both visualizations. For 3D visualization if the workstation processor is powerful enough, they will not give any problem in term of data stability. However, for the *HoloCave* development using the HoloLens first generation creates the lag issue problem due to massive data of millions point. Using the mix reality toolkit (mrtk) to deploy the apps to the device HoloLens produce the red bar that distract the users during the visualization task in *HoloCave*. Both user interface (UI) of 3D and *HoloCave* would be more useful if it has the information of the wall's height for every interval, types of the rocks, groves and crevices information and display the wall cave in different colour represented by steepness. *HoloCave* already creates immersion feeling to climb but with addition of information of the wall it would be more fantastic.

7 CONCLUSIONS

Humans are spatial thinker. Therefore, they could not run from reading or visualize any kind of map either hardcopy or digital. Digital can be either 2D, 2.5D, 3D, or 4D. From the eye to brain based on Marr's vision it only stops until 3D. But nowadays with the globalization, new formalization and computerize techniques become more in advanced. From visualization it processes the information through the extraction and interaction tool as a platform to communicate to the object. After the information is extracted, it becomes to the knowledge construction.

Since evolution of technology is rapidly growing, new approach of visualization should be fitted well in modern cartography. The transition from 2D to 3D and now with AR, VR and MR, makes human brain can work less to extract the information and gain insight much easier, without missing any important information.

Thus, this research findings by comparing visualization of 3D and immersive 3D with the same interaction tool is recommended for further research in knowledge construction. From this study, the main major finding is about time difference for each visualization while constructing the knowledge. There is no significant time difference between 3D visualization and 3D immersive visualization which specifically named in the case study as "*HoloCave*". Second major result of this research is, using the *HoloCave* where the visualization creates the immersive feeling gives better overview and understanding which is good for constructing knowledge. Even when the data from both visualizations are the same and the interaction tool is also constant, but in different method and device, the feeling of immersion plays around with psychology of human being wins.

Since the interaction of 3D visualization is quiet familiar compared to air tap gesture, implementation of user interface and smoothing in controlling the interaction of 3D immersive visualization should be considered. Even the *HoloCave* wins climbers vote for both most like and better visualization but the data is still unstable as 3D visualization. Enhancing the user interface design for both visualizations would be good to gain insight not only for climbing activities but also for geological study purpose by including the information of type of the rocks, crevices and groves. Displaying the steepness level in different colour might be helpful too.

For the future research in knowledge construction in visualization, a few recommendations will be highlighted here:

- Use the VR approach to get the complete immersion in knowledge construction and comparing the result.
- Extend Marr stages of vision to 3D immersion and explore how the user interpret the data, extract the information and later gaining the knowledge.
- Simple task is already good enough for study the behavior how human's brain works from two different visualizations. However, put the timing and design the simulation such as emergency response through different visualization might be more interesting. Including the real situation phenomena will make the brains works more and feeling being in the situation, can create different spatial decision from psychological perspective.
- Measuring the height of the climber, the length of the step and one fathom of each climber should be taking into consideration.
- Enhance the user interface design to make the visualization much more interesting for user and include the important information such as rock's types.
- Make 3D visualization accessible in the webpage or mobile cartography apps and challenge the famous existing apps for climber such as vertical life apps, in order to get many respondents from different countries with different perspective based on their prior knowledge.
- Geo-collaboration for each visualization either sharing the same place or in different place and analyse the difference in knowledge construction when they are having the role of the collaborator. But it requires high level in computer background because it needs to set up the same network if the user and the collaborator are not in the same place.

This thesis represents one step forward in modern visualization in term of knowledge construction for climbing activities in planning a route in effective ways. Climbing is an extreme sport and in 2020 it become first sport that will be introduced in Olympic in Tokyo, Japan. As a future modern cartographer, the role to give better service to others and focus on the climber is the main objective. That is why this research should be further extend.

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9 APPENDICES

Consent in participation (English)

Consent to participate in a user study

Thank you for finding time for the user test, which is conducted by Irhamillah Khamsim, Master student of the Technical University of Munich. It is organized within my work on the master thesis with the topic "*A Comparative Study of 3D Visualization versus Immersive Visualization (HoloCave) – in Knowledge Discovery*"

The task is about planning a rock-climbing route in the orthophoto image of wall cave by using 3D visualization and hologram (HoloCave). Participants will be given a questionnaire after the task is completed.

Confidentiality and rights

This study is anonymous and is not aimed to collect or retain any personal information. All the records and data gained from the test will be anonymized and used only within the work on my master thesis research.

The decision to participate in this study is entirely up to you. You may refuse to take part in the study at any time. You have the right to ask questions about this research study and to have those questions answered by me before, during or after the research.

Consent

- I have been informed on the procedure and purpose of the study and my questions have been answered to my satisfaction.
- I have volunteered to take part in this study and agree that during the study information is recorded (time during my interaction with the system). This information may only be used for research purpose. I understand that my participation in this study is confidential. All personal information and individual results will not be released to third parties without my written consent.
- I understand that I can withdraw from participation in the study at any time.

Subject's Name: ____

Subject's Signature: ________________________ Date: __________________

Consent in participation (Deutsche)

Zustimmung zur Teilnahme an einer Nutzerstudie

Vielen Dank, dass Sie sich Zeit für den Nutzertest genommen haben, der von mir Irhamillah Khamsim, Masterstudentin an der Technischen Universität München, durchgeführt wird. Er ist Teil meiner Masterarbeit mit dem Titel: „…“ (german translation)

Die Aufgabe besteht darin, mithilfe von 3D-Visualisierung und Hologramm (HoloCave) eine Kletterroute im Orthofoto, welches die Wand der Höhle darstellt, zu planen. Nach Abschluss der Aufgabe erhalten die Teilnehmer einen Fragebogen.

Vertraulichkeit und Rechte

Diese Studie ist anonym und zielt nicht darauf ab, persönliche Informationen zu sammeln oder zu speichern. Alle Aufzeichnungen und Daten aus dem Test werden anonymisiert und nur im Zuge meiner Masterarbeit verwendet.

Die Entscheidung, an dieser Studie teilzunehmen, liegt ganz bei Ihnen. Sie können die Teilnahme an der Studie jederzeit abbrechen. Sie haben das Recht, Fragen zu dieser Studie zu stellen und diese Fragen vor, während oder nach der Forschung von mir beantworten zu lassen.

Zustimmung

- Ich wurde über den Ablauf und den Zweck der Studie informiert und meine Fragen wurden zu meiner Zufriedenheit beantwortet.
- Ich habe mich freiwillig zur Teilnahme an dieser Studie bereit erklärt und bin damit einverstanden, dass während der Studie Informationen aufgezeichnet werden (Zeit während meiner Interaktion mit dem System). Diese Informationen dürfen nur zu Forschungszwecken verwendet werden. Ich verstehe, dass meine Teilnahme an dieser Studie vertraulich ist. Alle persönlichen Daten und individuellen Ergebnisse werden ohne meine schriftliche Zustimmung nicht an Dritte weitergegeben.
- Ich bin mir bewusst, dass ich die Teilnahme an der Studie jederzeit beenden kann.

Name des Probanden: ____

Unterschrift des Probanden: _________________________ Datum: ___________________

Instruction (English)

The task is about to plan rock climbing route based on the two different type of visualizations; (i) 3D visualization and (ii) HoloCave.

Participants will have short briefing about how to use the interaction tool in 3D visualization and air tap gesture using HoloLens.

1. Participants are given printed orthophoto image of the wall of the cave, Gua Damai which is in West Malaysia.
2. Participants need to draft the route planning on the orthophoto after they are having or while have first visualization.
3. Then, participants need to recheck their route planning with the second visualization.
4. If there are any changes, please remark on the existing route with different colour marker on the same orthophoto.
5. Make another one possible route planning with second visualization.
6. Time is recorded for every task.
7. Answer the questionnaire.

(Deutsche)

Die Aufgabe besteht darin, eine Kletterroute basierend auf zwei verschiedenen Arten von Visualisierungen zu planen. (i) 3D-Visualisierung und (ii) HoloCave. Die Teilnehmer erhalten eine kurze Einführung in die Verwendung des Interaktionswerkzeugs für die 3D-Visualisierung und die HoloLens.

1. Die Teilnehmer erhalten ein gedrucktes Orthophoto der Wand der Höhle, Gua Damai in West-Malaysia.
2. Die Teilnehmer müssen die Routenplanung auf dem Orthophoto entwerfen, nachdem sie eine der beiden Visualisierungen zur Routenplanung verwendet haben..
3. Nach der ersten Visualisierung müssen die Teilnehmer ihre Routenplanung mit der zweiten Visualisierung überprüfen.
4. Falls sich Änderungen ergeben, vermerken Sie diese bitte mit einem anders farbigen Stift.
5. Führen Sie eine alternative Routenplanung mit der zweiten Visualisierung durch. Vermerken Sie ihre alternative Route bitte mit einem andersfarbigen Stift. .
6. Die Zeit wird für jede Aufgabe gemessen.
7. Beantworten Sie bitte den Fragebogen.

Questionnaires

1. Gender: F / M

2. Age:

☐ 12 – 17 years old

☐ 18 – 24 years old

☐ 25 – 34 years old

☐ 35 – 44 years old

☐ 45 – 54 years old

3. Did you ever visualize 3D point cloud from any kind of data sources before?

☐ Yes

☐ No

4. Did you ever have an experience in HoloLens before?

☐ No

If yes, how familiar you are in controlling air tap gesture interaction?

Not Familiar	Neutral	Very Familiar

5. Did you ever have experience in controlling mouse to visualize 3D object?

☐ No

If yes, how familiar you are in handling the interaction?

Not Familiar	Neutral	Very Familiar

6. How often do you do rock climbing?

- [ ] Less than once a month
- [ ] Once a month
- [ ] Multiple times a month
- [ ] Once a week
- [ ] Multiple times a wee

7. Which level did you considering yourself as a rock climber?

- [ ] Beginner
- [ ] Intermediate
- [ ] Expert

8. Do you think "**HoloCave**" visualization is **very helpful** in planning rock climbing route?

Strongly Disagree	Neutral	Strongly Agree

9. Do you think **3D visualization** is **very helpful** in planning rock climbing route?

Strongly Disagree	Neutral	Strongly Agree

10. Do you think you get **better overview** and **understanding** of the **structure of the wall** after having "**HoloCave**" visualization?

Strongly Disagree	Neutral	Strongly Agree

11. Do you think you get **better overview** and **understanding** of the **structure of the wall** after having **3D visualization**?

Strongly Disagree			Neutral			Strongly Agree

12. Are there any **changes** in route planning after having two different types of visualizations?

☐ Yes

☐ No

If **yes**, please state **why you change your decision**?

____

13. Which visualization do you **like the most**?

☐ 3D Visualization

Why?

____

____

☐ HoloCave

Why?

____

____

14. Which visualization do you think is **better**?

☐ 3D Visualization

Why?

____

____

☐ HoloCave

Why?

____

____

15. From your opinion, please give any suggestion **how to improve each visualization to get better understanding in rock climbing activity.**

3D Visualization

____

____

HoloCave

____

____

HC ☐ 3D☐

Questionnaire (Deutsche)

1. Geschlecht: W / M

2. Alter:

☐ 12 – 17 Jahre alt

☐ 18 – 24 Jahre alt

☐ 25 – 34 Jahre alt

☐ 35 – 44 Jahre alt

☐ 45 – 54 Jahre alt

3. Haben Sie vorher von irgendeine Datenquellen mit ‚3D point cloud' visualisieren?

☐ Ja

☐ Nein

4. Haben Sie vorher Erfahrungen mit Hololens?

☐ Nein

Wenn ja, wie gewohnt sind Sie mit der Luftklickgesten?

Nicht gewohnt   Neutral   Sehr gewohnt

5. Haben Sie vorher Erfahrungen mit einem Maus, um ein 3D Objekt zu visualisieren?

☐ Nein

Wenn ja, wie gewohnt sind Sie mit der Interaktion zu bearbeiten?

Nicht gewohnt   Neutral   Sehr gewohnt

6. Wie oft gehen Sie Felsklettern?

- ☐ Weniger als einmal pro Monat
- ☐ Einmal pro Monat
- ☐ Mehrere Male pro Monat
- ☐ Einmal pro Woche
- ☐ Mehrere Male pro Woche

7. An welcher Niveau sind Sie als Felskletter?

- ☐ Anfänger
- ☐ Normal
- ☐ Expert

8. Glauben Sie, **dass mithilfe der ‚Holocave' Visualisierung**, die **Routenplannung** für Felsklettern **leichter** sein wird?

Absolutely nicht — Neutral — Definitiv

9. Glauben Sie, **dass mithilfe der 3D Visualisierung**, die wird **Routenplannung** für Felsklettern **leichter** sein wird?

Absolutely nicht — Neutral — Definitiv

10. Glauben Sie, dass Sie, **nach der ‚Holocave' Visualisierung**, einen **besseren Überblick und Einsicht** über die **Wandstruktur** haben?

Absolutely nicht — Neutral — Definitiv

11. Glauben Sie, dass Sie**, nach der 3D Visualisierung**, einen **besseren Überblick und Einsicht** über der Wandstruktur haben?

Absolutely nicht — Neutral — Definitiv

12. Gibt es **Änderungen** an der **Routenplannung nachdem** Sie **die zwei unterschiedlieche Visualisierungen genutzt** haben?

☐ Ja

☐ Nein

Wenn **ja**, warum, haben **Sie Ihre Route geändert?**

____

13.Welche **Visualisierungen** gefält am **Besten**?

☐ 3D Visualization

Warum?

____

____

☐ HoloCave

Warum?

____

____

14. Welche **Visualisierungen** glauben Sie ist **besser**?

☐ 3D Visualization

Warum?

____

____

☐ HoloCave

Warum?

____

____

15. Bitte teilen Sie**, uns mit sowohl die 3D Visualization als auch die HoloCave Visualisierung verbessert werden können um eine bessere Routenplanung für das Felsklettern zu ermöglichen.**

3D Visualization

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____

HoloCave

____

____

☐ 3D ☐ HC