Cartography M.Sc.

Master thesis

Communicating Disaster Risk Information – Cartographic Dashboards and Mixed Reality

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ITC UNIVERSITY OF TWENTE.

2021

Communicating Disaster Risk Information – Cartographic Dashboards and Mixed Reality

submitted for the academic degree of Master of Science (M.Sc.)
conducted at the Department of Aerospace and Geodesy
Technical University of Munich

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Date of submission: 10.09.2021

Statement of Authorship

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

"Communicating Disaster Risk Information – Cartographic Dashboards and Mixed Reality"

I have fully referenced the ideas and work of others, whether published or unpublished.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

Berlin, September 10th, 2021 McCall, John

Acknowledgements

I’d like to thank everyone who was involved in my thesis including the survey respondents and my supervisor Professor Jahnke. Big thank you to the experts for their time.

Last, a special thank you to everyone in my life who helped stay positive and encourage me through this difficult process.

Abstract

With disasters as an ever-increasing threat to humanity, the field of disaster risk management is growing and using new technologies to address both natural and anthropogenic hazards. In this context, this master's thesis aims to evaluate a proof-of-concept cartographic dashboard with an augmented reality (AR) element to help improve the communication of disaster risk information.

The proof-of-concept cartographic AR dashboard prototype was designed using input from a user requirement survey of experts in the field. In order to test the concept, expert interviews were conducted to learn how this prototype could be used in their line of work and what benefits the dashboard and AR add to their current processes. Ultimately, an AR dashboard was found to improve the communication of disaster risk by providing both a more in-depth geographic overview and a more detailed on-the-ground view due to its ability to rotate and zoom. From there, it is possible to extrapolate how AR dashboards can further be used in the disaster risk management cycle and what specific applications they have throughout the industry.

Keywords: Disaster risk management, Mixed reality, Augmented reality, Dashboards, Cartographic dashboards, proof-of-concept

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1 Introduction

Background and Motivation

Though disasters, both natural and anthropogenic, are not new to humanity, modern technology, specifically the ability to collect and visualize large quantities of data, can allow us to be aware of, prepare for, and hopefully mitigate the effects of disasters. However, in order for this technology to be helpful, it must successfully communicate disaster information to humans.

Since many disasters are spatial in nature, cartography is and has been a useful tool for communicating disaster risk information. Dating back to the 19th century, maps, such as John Snow's 1854 cholera map (Figure 2)[1] or the maps created to show the damage of the great Chicago fire of 1870-71 (Figure 1)[2], have a long-standing tradition of communicating disaster information.

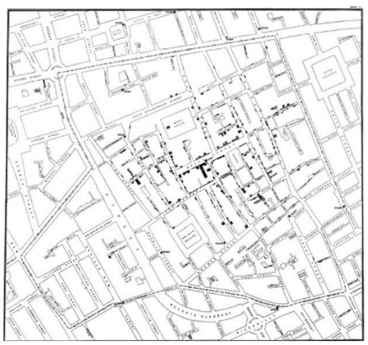

Figure 2: John Snow's cholera map addressing a public health crisis

Map Showing the Burnt District in Chicago, 3rd Edition; R. P. Studley Company, 1871 (ichi-02870)

Figure 1: An R.P. Studley Company map showing the burn damage in the Chicago fire of 1870-71

With the development of computer technologies in the late 20th century, disaster mapping is now able to be done digitally, both in data processing and visualization. While many digital maps are simply 2D reproductions on the web, technology is progressing even further, including dashboards and augmented reality (AR). With the ever-increasing amount of data available, dashboards have become a popular visualization tool to show both maps and graphs/charts at the same time. So much so that ESRI, a leading supplier of GIS software, offers a dashboard tool. An example is John's Hopkins University's popular COVID-19 (the global corona virus pandemic during which this thesis was written) dashboard (Figure 3)[3], showing both a map and additional data visualizations.

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[1] https://www.loc.gov/item/2010592712/ (Accessed September 2021)

[2] https://commons.wikimedia.org/wiki/File:Snow-cholera-map-1.jpg (Accessed September 2021)

[3] https://coronavirus.jhu.edu/map.html (Accessed September 2021)

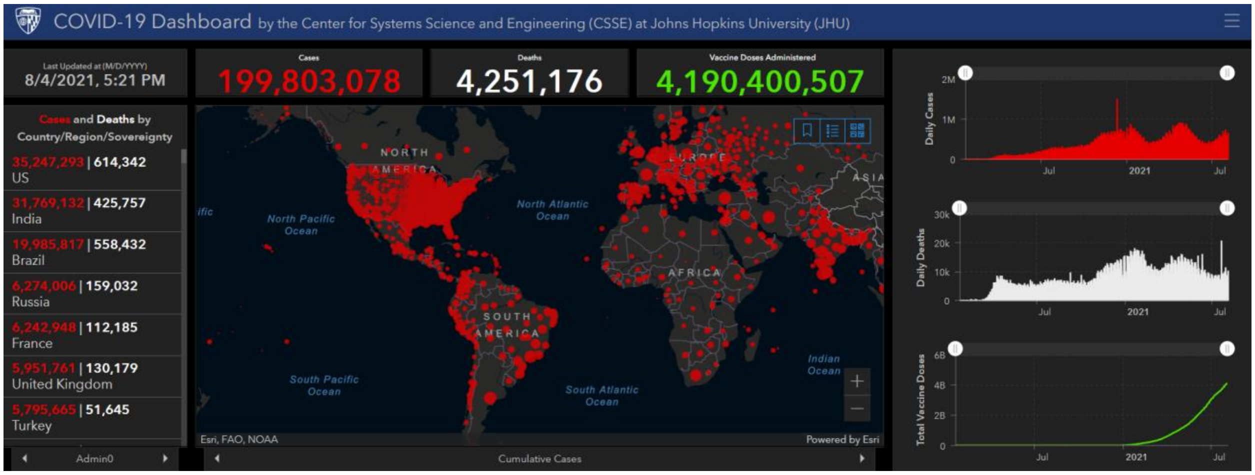


Figure 3: John's Hopkins University COVID-19 cartographic dashboard proving its use during the pandemic.

Dashboards can improve a visualization using only a map by providing supporting numbers, graphs, and charts that complement what is seen on the map. While maps are often limited to generalizations and by geography itself, dashboards can offer exact numbers or a non-spatial way to understand the same data seen on the map via a graph.

One of the most recent technologies being pioneered for geospatial purposes is augmented reality. Big tech companies such as Apple and Google now offer AR software development kits (SDKs), ARKit[4] in 2017 and ARCore[5] in 2018, respectively, so developers can make AR-enabled applications. While there are widescale applications of the technology used in fields such as civil engineering, there are few instances of it currently being employed in the field of disaster risk management. The few examples include ESRI's AuGeo[6] app, which allows you to view GIS data in AR and Edgybees[7], which uses drones to provide aerial video streams with AR overlays allowing disaster risk professionals to have more precise intelligence from the scene of the disaster.

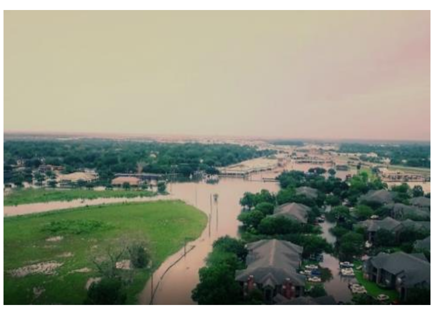


Figure 4: Normal aerial drone image from Edgybees.

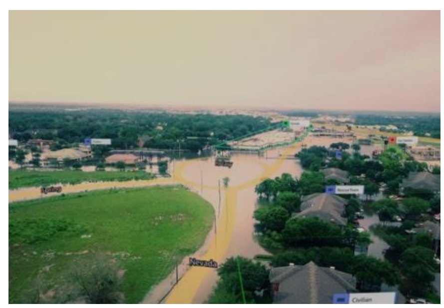


Figure 5: Same image with yellow AR stripe overlay to show where roads are located

[4] https://developer.apple.com/augmented-reality/ (Accessed September 2021)
[5] https://developers.google.com/ar (Accessed September 2021)
[6] https://www.esri.com/arcgis-blog/products/3d-gis/3d-gis/ar-for-your-gis/ (Accessed September 2021)
[7] https://edgybees.com/ (Accessed September 2021)

The left image (Figure 4) above depicts a flood scene in which the excess water makes it impossible to know the exact location of the submerged roadways. The image on the right (Figure 5) contains superimposed AR elements – thick yellow lines and labels – which allows one to see the submerged road network. In addition to the commercial applications, there is a wealth of research into potential uses of AR in disaster management.

While dashboards and AR technology have mostly been researched separately, this thesis will aim to understand AR within the context of cartographic dashboards, all of which is supporting the communication of disaster risk information. Using augmented reality cartographic dashboards could be the beginning of the future of the way humans manage disasters.

Research Identification

The overall research focus of this thesis is to understand how it is possible to integrate augmented reality technology into a cartographic dashboard and if it is useful in communicating disaster risk information. Within the scope of this investigation there are three main research objectives and two sub-research objectives with corresponding research questions. The aim is to develop a prototype for experts in the field of disaster management to evaluate what value or added benefit they see using these technologies.

Research Objectives

1) Discover needs of a disaster risk management professional for cartographic technologies.
    a. Identify how an AR cartographic element can support disaster management
2) Identify how to integrate AR technologies into a cartographic dashboard.
3) Understand if a dashboard with an AR element can improve the communication of information to a user about disaster risk and how
    a. Analyze how dashboard layout impacts user

Research Questions

1) What is important to disaster risk professionals when designing a cartographic product?
    a. What part of disaster risk management can AR support?
2) Within the context of a dashboard, how can an AR element be integrated?
3) Does an AR element within a dashboard improve the communication of information to a user about a disaster, and if yes, how?
    a. How does the dashboard layout impact the user?

Hypothesis

In order to conduct this scientific work, the research questions have been synthesized into 3 main hypotheses to be tested:

- There are multiple ways to integrate AR into a cartographic dashboard.
- An AR cartographic dashboard can improve the communication of information to a user within the context of disaster risk management.
- A well-designed and intuitive dashboard layout is necessary for user comprehension.

Innovation

The innovation intended in this thesis is to continuing building the knowledge of cartography's impact in disaster risk management using contemporary technologies. The aim is to understand how, in a novel way, augmented reality can be integrated into a cartographic dashboard to support disaster management professionals. It will additionally analyze dashboard layout design. Using previous research of dashboards and AR, this thesis will prototype a cartographic AR dashboard and assess its contribution to communicating disaster information. There is very limited scholarship on this topic where other prototypes were developed. This thesis will provide additional ways to use cartographic AR dashboards in disaster management.

Thesis Structure

This thesis is divided into 6 chapters. First the background and motivation were explained, and the research objectives and questions defined. The second chapter will go over the existing literature of the different themes involved: disaster management, cartographic dashboards, and augmented reality. The methodology will be explained in the third chapter, followed by the results, analysis and discussion, and finally the conclusion and outlook.

2 Literature Review

Disasters Risk Management

Disaster risk management is a thoroughly analyzed and well-document field. The field begins with the understanding of what actually defines a disaster, which according the UN is, “a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts” (UN, 2016). In order to understand this definition, a few further are required:

Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.
Exposure	The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard prone areas.
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.
Capacity	The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience.

(UN, 2016)

Using the above definitions, disaster risk can be expressed as an equation in Figure x.x.

Hazard + Exposure + Vulnerability – Capacity = Disaster Risk

By understanding the strength of the hazard plus how exposed and vulnerable a community is, all reduced by the community’s capacity to deal with the hazard, gives you disaster risk.

Hazards can be anthropogenic (man-made) or natural. Examples of anthropogenic hazards include nuclear radiation, dam failures, traffic accidents, factory explosions, building fires, or oil spills. Man-made disasters are technological in origin, derived entirely from structures created by man. Natural disasters, derived entirely from nature and natural cycles, can be further broken down into different categories including: hydro-meteorological (hurricanes, floods, tornadoes, heat waves), geophysical (earthquakes, landslides, volcanic eruptions), and biological (pandemics, insect swarms). There is also a subset called socio-natural disasters, which are natural in character, but caused or exacerbated by human activity. Examples of socio-natural hazards would be a forest fire caused by agriculture or camping and earthquakes caused by fracking. As humanity's impact on the earth and climate is further understood, it is necessary that many hazards be understood within the context of human activity (UN, 2015).

Once one understands the nature of the hazard, one then has to look at how exposed the community is. Exposure shows how likely a community is to be affected by a hazard. For example, cities built along fault lines are highly exposed to earthquakes, and cities situated along coastlines (in a known hurricane path) have high exposure to hurricanes and flooding. Highly exposed communities have a higher disaster risk, whereas less exposed communities' risk is lower.

The terms vulnerability and capacity can be understood as inverses of each other. A highly vulnerable community will have less of a capacity to cope with a hazard, whereas a community with a greater capacity to deal with a hazard is less vulnerable. A good example of the intersection of these concepts is Hurricane Katrina. Despite the whole New Orleans region being exposed to the threat of hurricanes, certain neighborhoods were more vulnerable/had less capacity to cope than others and therefore suffered more during the hazardous event.

The combination of these three concepts shows you what risk a community faces. The United Nations Office for Disaster Risk Reduction (UNDRR) defines risk as, "The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity" (UNDRR, 2021). It is from this concept that the field of disaster risk management gets its name.

Disaster Risk Management Cycle

Understanding the nature of disaster risk is obviously not enough. In order to do something about it, the UN developed the disaster risk management cycle as seen in Figure 6.

The first step is planning and preparedness. Humans know that disasters are inevitable, for example, earthquakes in California or hurricanes in the US southeast. Being prepared for a disaster is an important step in preventing damages. The next step is the response. The response occurs after the disaster has taken place. It includes how the community, government, NGOs, and the private sector react to the disaster. The third step is recovery and rehabilitation. After the disaster occurs, the community must rebuild or recover from the damages incurred. If buildings were damaged, they need to be repaired. If human lives were taken, families need to be cared for. The last step in the cycle is prevention and mitigation. This step asks the question: how can we prevent loss from another similar disaster? (UNOOSA, 2021)

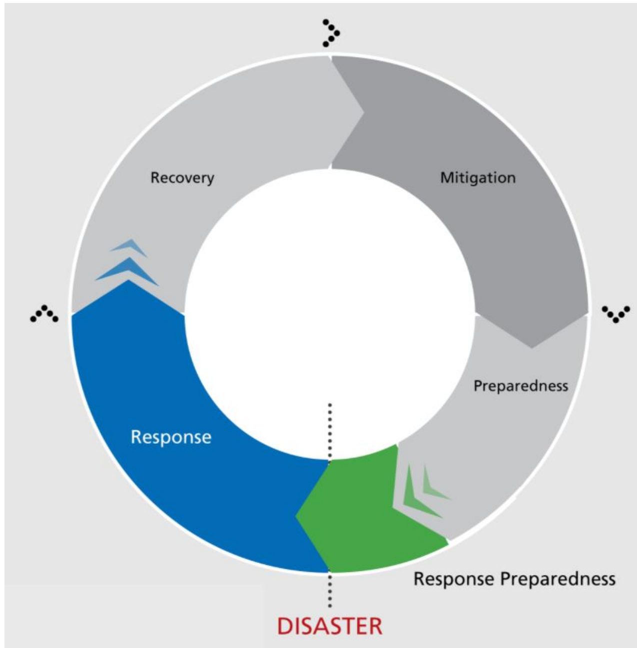


Figure 6: The Disaster Management Cycle forms the basis for understanding how we approach disasters.

While the disaster risk management cycle provides a framework for action, it is somewhat limited in its theoretical approach to the highly complex and synergistic activities that occur within the cycle. In order to tie the cycle to more concrete actions, a decision framework (Figure 7) will be employed to understand which maps are used within the cycle.

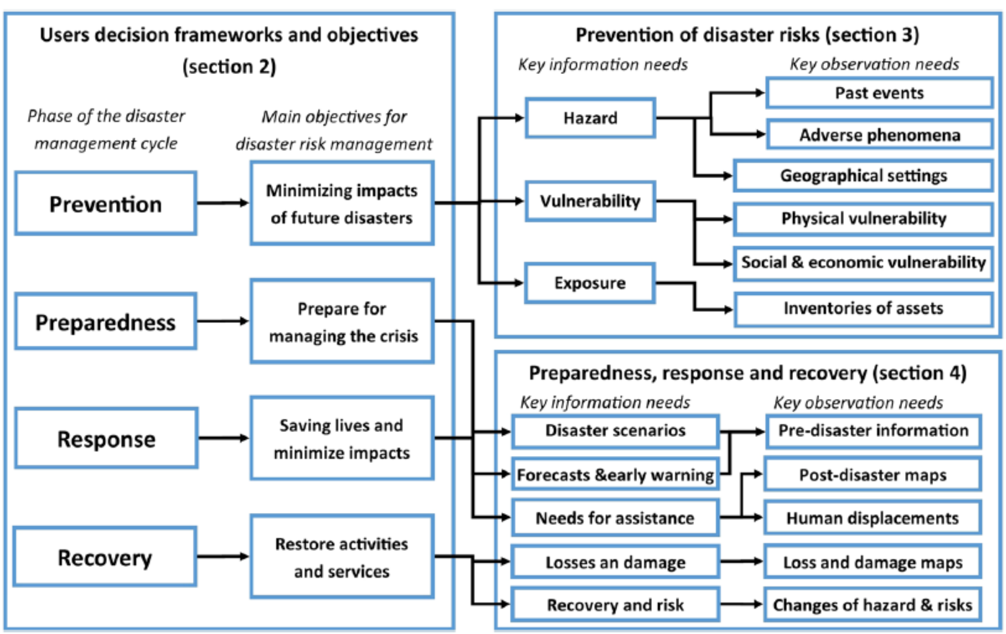


Figure 7: Tying to the disaster management phases to specific actions makes it easier understand the process of communication and decision-making within the cycle (Cozannet, 2020).

As seen in Figure 7, phases of the disaster management cycle are tied to objectives and those objectives are further tied to key information and observation needs (Cozannet, 2020). This decision framework will be broken out by each of the elements of a disaster and which maps are used in each part of the cycle.

Hazard Mapping

Hazard maps provide disaster risk professionals with information about the extent and impact of the hazard. In the prevention phase, a hazard map containing past information shows the likelihood of a hazard occurring in a certain area. For example, the United States Geological Survey (USGS) provides a publicly available earthquake hazard map[8] seen in Figure 8 so that people may understand where there is the greatest threat of an earthquake.

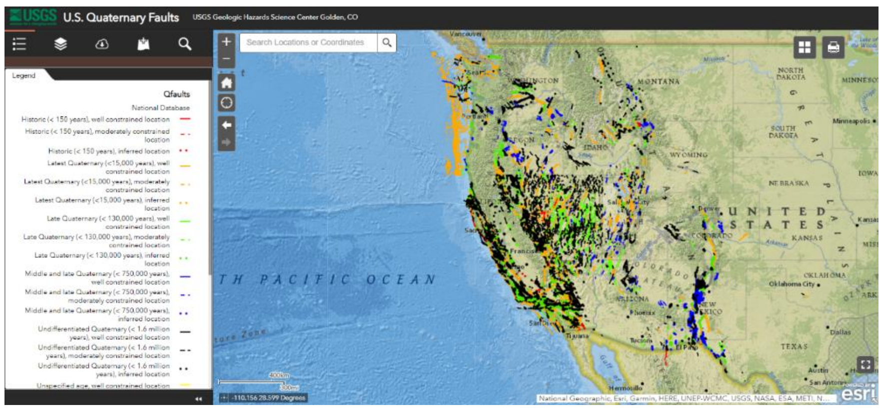


Figure 8: USGS earthquake preparation hazard map

In the preparation phase, early warning/forecast maps and disaster scenario maps provide information on the expected extent of a hazard. An example of this is hurricane forecast mapping. This shows where a hazard is likely to happen and what one can expect in that area. In the response phase, real-time maps of the hazard are invaluable. As a disaster is actually occurring, knowing where and how impactful the hazard is gives disaster risk professionals the information they need to make decisions about how to approach the hazardous area. An example would be having a real-time flood level map, which would be used by disaster professionals in their decision on how to ingress or egress a hazardous area in order to save lives. And last, in the recovery phase, post-hazard analysis maps can be used to assess the extent and impact of the hazard.

Exposure Mapping

Outside the context of disaster management, “exposure” maps, are actually made all the time, known namely as land-use and land cover maps and population distribution maps. Land-use and land cover maps provide an inventory of assets to disaster professionals. During the prevention and preparation phase, a land-use map shows what exactly can be affected in certain areas. For example, if an area is more residential or industrial affects how many people will be affected and what kind of damage to expect. Similarly, population maps, whether density or real values, are extremely useful in preparing a

[8] https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5a6038b3a1684561a9b0aadf88412fcf (Accessed September, 2021).

location to mitigate fatalities. In Figure 9, the combination of land-use and population density is used to create an exposure risk map in Figure 10. (Wu, 2019).

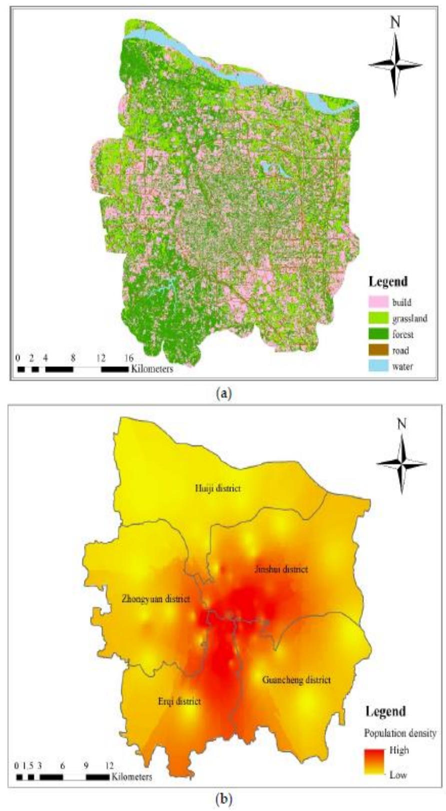


Figure 9: Map a shows land use and Map b shows population density (Wu, 2019).

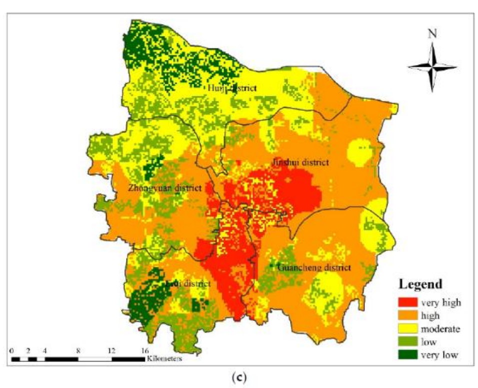


Figure 10: By combining land use and population, an exposure map can be made (Wu, 2019)

In the response phase, these maps can be overlayed with hazard data in order to show what types of building and how many people are being affected. They are however less useful for on-the-ground action. Exposure mapping in the recovery phase is a very useful to way to see what has changed from the disaster, allowing a community to reassess its exposure in preparation for the future (Sheykhmousa, 2019).

Vulnerability/Capacity Mapping

Vulnerability maps are also commonly created maps that can be applied to disaster management. They often take the form of a thematic map with data relevant to disaster management (Bankoff, 2013). In the prevention phase, building and city maps are used to understand the physical vulnerability of city. For example, a map showing building age or earthquake preparedness shows what sections of a city may be most vulnerable to a hazard. In addition to physical vulnerability, there is also social and economic vulnerability. Thematic maps showing the distribution of economic or social factors of a community or society gives insight into what areas may be more vulnerable. Using the example of Hurricane Katrina again, it was the economically vulnerable communities that suffered the most as they didn't have the capacity to deal with the devastation of the hurricane.

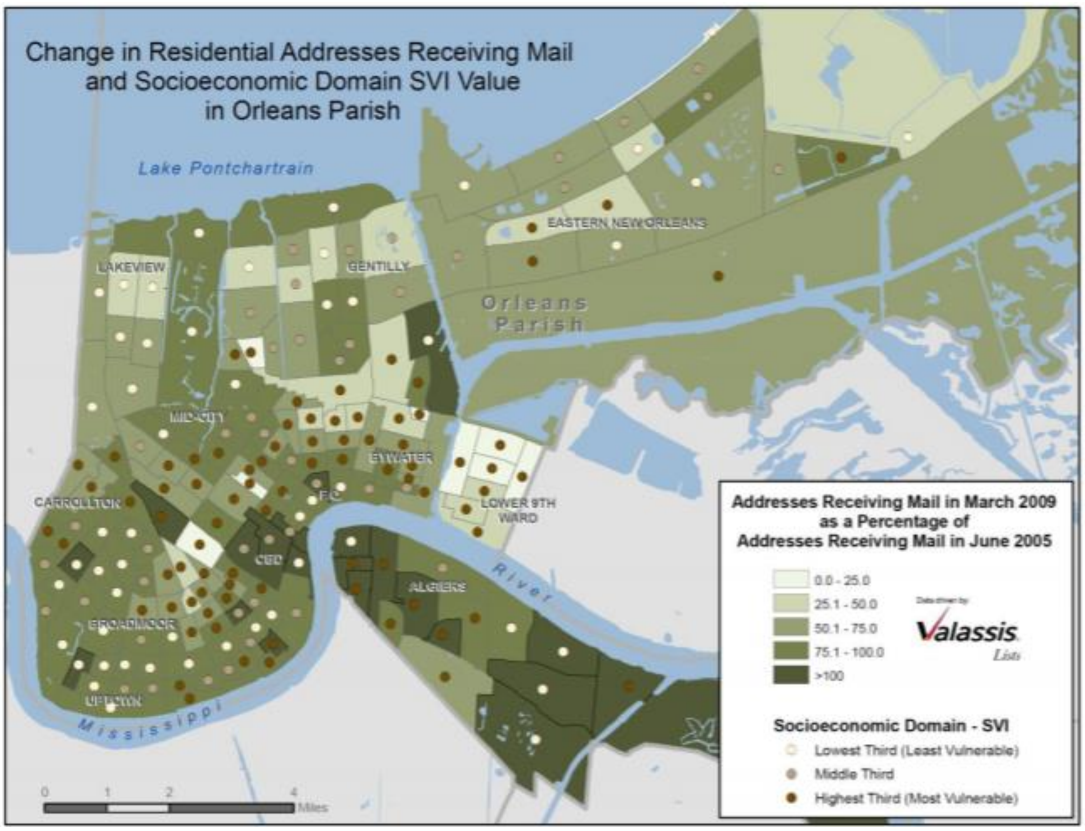


Figure 11: New Orleans vulnerability map showing addresses receiving mail before and after the hurricane (Flanagan, 2011).

In Figure 11, socioeconomic data is overlayed with addresses receiving mail before and after the hurricane in order to show how effective the recovery process was throughout the city. It highlights that lower income areas are receiving less mail four years later meaning the recovery was weaker in those areas (Flanagan, 2011). In the response phase, vulnerability maps can be used to assess what area requires the most immediate or severe attention. Then in the recovery phase, similar to exposure, after the occurrence of a disaster, it is important to reassess the vulnerability of an area in preparation for the future.

As seen in the examples in this chapter, maps are used consistently throughout the disaster management cycle in a myriad of different capacities.

Cartographic Dashboards

While dashboards have become common in different industries, its academic definition has found some scrutiny over the years. Stephen Few, a well-known visual intelligence researcher, states that, "a dashboard is a predominantly visual information display that people use to rapidly monitor current conditions that require a timely response to fulfill a specific role" (Few, 2017). He purposefully leaves the definition quite broad since the term dashboard has different uses. Ultimately, a dashboard is meant to provide a visual aid for making decisions. Research over the past years has sought to further understand and expand on that. For example, it is understood that there are different types of dashboards depending on use such as strategic, tactical, and operational (Sarikaya, 2019).

In addition to types of dashboards, dashboard design is a major factor in how it is perceived and used. Ogan M. Yigitbasioglu conducted a comprehensive study of existing literature of dashboard design. The study broke out design into functional features and visual features and comes to the conclusion, as seen in Figure 12, that functional features must be specifically curated depending on the task at hand, the user's knowledge and cognitive style, whereas there are universal visual features such as using a single page, frugal use of colors, high data ink ratio, and use of grid lines for graphs (Yigitbasioglu, 2012).

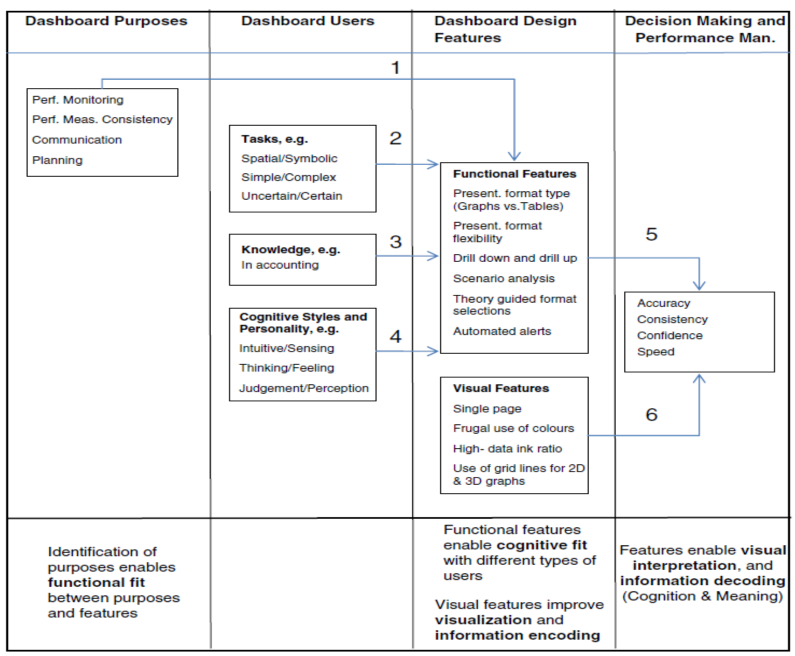


Figure 12: Dashboard design discoveries (Yigitbasioglu, 2012).

Maps, being visual in nature, have found a natural synergy with dashboards. In 2014, FEMA initiated the Disaster Assessment and Assistance Dashboard (DAAD), an earthquake detection dashboard, for San

Francisco.[9] More currently, ESRI has developed a product called ArcGIS Dashboards due to their popularity.

Figure 13: City of Raleigh's ESRI dashboard

The dashboard in Figure 13 is operational in nature, used by The Emergency Management Office of the City of Raleigh[10], and allows the user to view multiple pieces of information at once while also doing minor analysis on the fly.

Recently, Zuo, Deng, and Meng assessed that map-based dashboards are feasible for spatial knowledge acquisition and analysis (Zuo, Deng, and Meng, 2020). While we therefore know that cartographic dashboards have been used for transferring spatiotemporal knowledge and are already being applied to disaster risk management, more formal research has recently been done by Rosalie Kremser into the actual need and effectiveness of them, which identified that a dashboard is, in fact, better at communicating risk information than a static map (Kremser, 2020). In addition, Hääg, Rönnberg, and Weil discussed the usefulness of map-based dashboards for decision-making offering scientific ways to evaluate such dashboards and discovering the customized dashboards with specific goals are always more useful (Hääg, Rönnberg, and Weil. 2020).

Cartographic Dashboards and the Disaster Risk Management Cycle

Cartographic dashboards have a strong presence in disaster risk due to their ability to show multiple important pieces of information simultaneously while correlating to the disaster information shown on a map.

In prevention and preparedness, dashboards are a good way to analyze past events in preparation for the future. Combining maps and graphs to show physical socioeconomic vulnerability and providing an

[9] https://appallicious.com/products/daad/ (Accessed September 2021)
[10] file:///C:/Users/John/Zotero/storage/LWKIRHQZ/raleigh-nc-case-study.html (Accessed September 2021)

inventory of assets gives an overview of pre-disaster circumstances. Planning evacuation routes and emergency response routes can also be supported by surrounding assets.

In the response phase, disaster management professionals in command centers can track and instruct field crews. Showing live locations of crews gives the ability to send the closest crew to the scene. Ingress and egress routes must be planned to approach the scene, while monitoring any disturbances on the way. Any mass-casualty event is being monitored from a command center in order to have all the real-time information available to make decisions.

The recovery phase is similar to the prevention phase in that post-disaster maps can be supported by surrounding information to get an overview picture.

Mixed Reality

Mixed reality is the spectrum of real, augmented, and virtual reality. Augmented reality is placing virtual elements on top of our reality, while virtual reality is an entirely artificial environment. Mixed reality is therefore on a spectrum, using elements of both augmented and virtual reality as needed. (Milgram, 1994). Milgram's infographic (Figure 14) is commonly used to understand this spectrum.

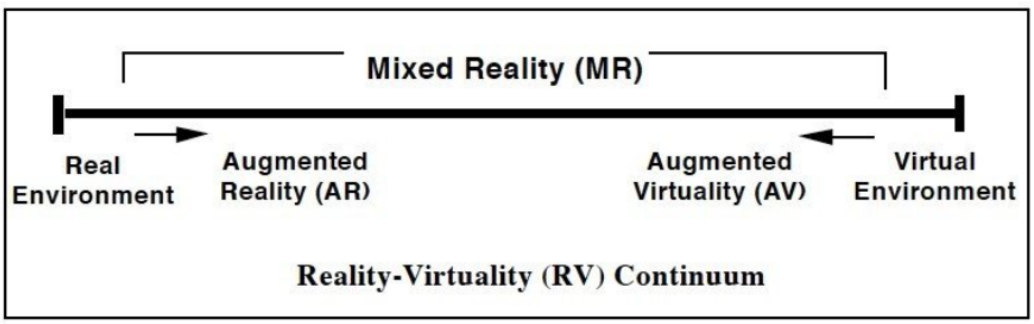


Figure 14: Milgram's mixed reality spectrum (Milgram, 1994).

For the purpose of this thesis, augmented and mixed reality will be the focus since there is no exploration into an entirely virtual reality. In order for mixed reality to work, it needs four elements: a display, a pointing device, a tracker, and a computer. The display is where the user sees the mixed reality experience and is either a headset, mobile device, or spatial display (such as a projector or hologram). The pointing device, also known as an input device, is used to point to the augmented object or space, most often a mobile device, but can also be a laptop or desktop. The tracker or tracking device aligns the digital information with what the user is seeing; the tracker can be a digital camera or other optical sensor or GPS, for example. And the last component is a computer, which is used to process all of the information from the previous components (Carmigniani, 2010).

Different Types of Augmented Reality

While there have been different classifications of AR over time, the following categories are one of the most commonly seen in literature.

Marker-based/Recognition

Marker-based augmented reality requires a device to scan a code, usually QR-code or another unique graphic to trigger an augmented experience. When the device registers the marker, it will place the augmented object on it. This requires a mobile device or table in order to scan the code. (Edwards-Stewart, 2016).

Markerless

Markerless augmented reality is similar to marker-based except it doesn't need a mark. It simply needs a flat surface for the augmented experience to appear. It uses the phone's GPS, compass, a gyrator in order to give the device enough information to form the augmented object (Poetker, 2019).

Projection

Projection augmented reality projects digital images onto objects in physical space. It has the possibility to be interactive or non-interactive. In some cases, it is required to wear a headset or 3D glasses to properly see the hologram (Poetker, 2019)..

Location

Location or GPS-based augmented reality functions by using the GPS on a mobile device. This means the augmented reality is specific to a certain location, and when a mobile device is in that location, it has the ability to view the augmented reality objects (Poetker, 2019)..

Outlining

Outlining is similar to projection, but instead uses line and edge detection to add augmented reality elements on top of the real world. An example of this is the rear-view camera on a car (Poetker, 2019)..

Superimposed

Superimposition uses object recognition and shows an alternate object to the one in reality. It effectively superimposes an image over an existing object to add information. An example within disaster management could be to superimpose disaster relevant information such as humans hidden in debris or a damage simulation (Leebman, 2003).

Cartographic AR in Disaster Management

As technology continues to improve, cartographers are currently exploring applications of mixed reality in disaster management. In Figure 15, Zhu and Li connected AR and VR to the disaster management cycle (Zhu and Li, 2021).

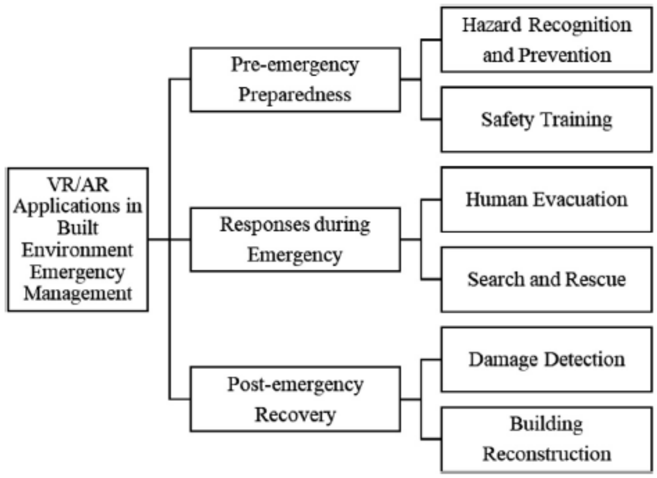


Figure 15: AR/VR applications in the disaster management cycle (Zhu and Li, 2021).

Similar to the general taxonomy of decision-making in disaster management, this figure shows what AR can be specifically applied to. For example, in 2017, Lochhead and Hedley analyzed the use of MR for evacuation simulations, an important part of the disaster preparation phase, discovering that there is a use for MR in this context with associated limitations. (Lochhead, Hedley 2017). For an example of search and rescue and/or damage detection, Tomkins and Lange created and tested a table-top AR flood visualization using the Unity Game Engine (Tomkins and Lange, 2019) seen in Figure 16.

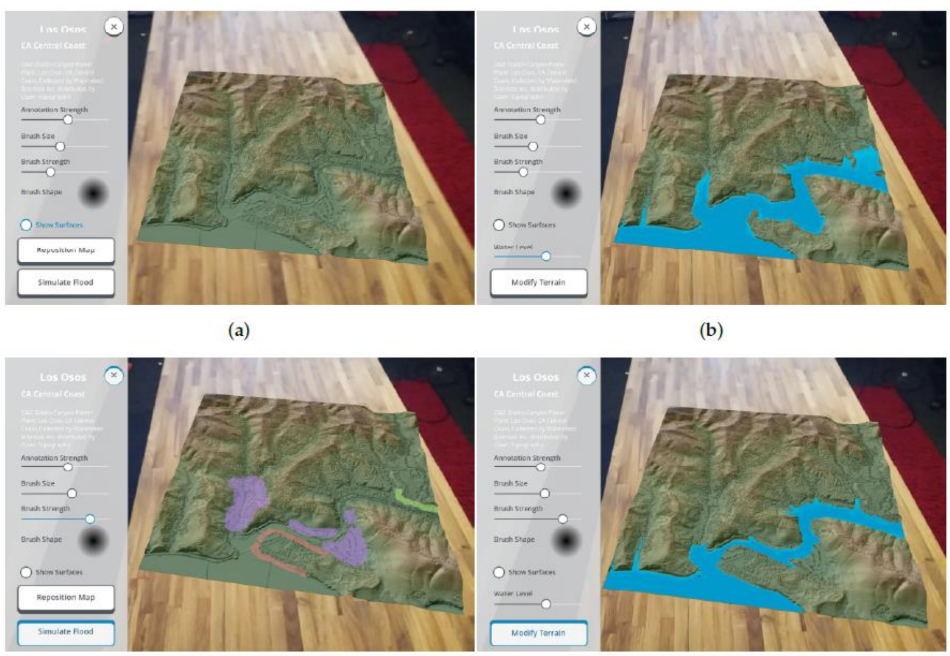


Figure 16: Tabletop AR flood simulation (Tomkins and Lange, 2019)

Kevin Helzel addressed the specific application of MR to disaster risk information discussing that they do have a use in the field (Helzel, 2019). While there is promise, technology such as AR is still limited to spatially confined environments (Keil, Edler, Dickmann, 2019).

Cartographic Dashboards & Mixed Reality in Disaster Management

So far, there has been minimal scholarship on the specific topic of cartographic dashboards using AR in the field of disaster management. However, there are two examples. The first example is Whistland, an AR app and dashboard used for river basin maintenance and monitoring.

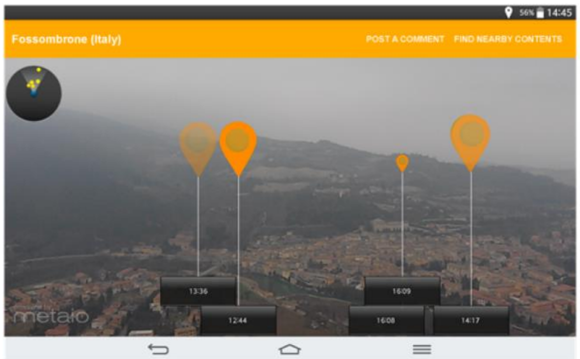


Figure 18: AR pins using the GPS method of AR ((Luchetti, 2017).

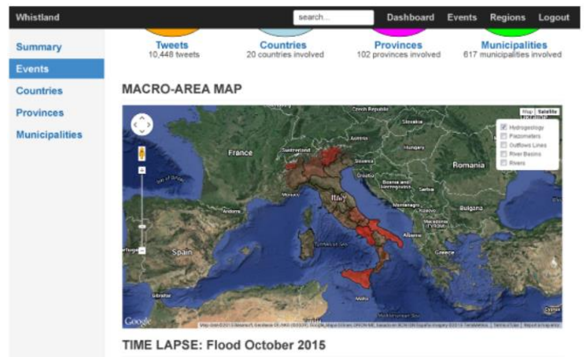


Figure 17: Dashboard developed for flood management (Luchetti, 2017).

On the right (Figure 17), a dashboard displays a map with collected Twitter data about flood-related disasters. The dashboard provides information regarding the number of tweets, the number of provinces and municipalities affected, and a summary. The image on the left (**Error! Not a valid bookmark self-reference.**) is an AR overlay of the geographic locations of where the tweets came from. The idea is to provide a complete spatiotemporal system for quick, geo-localized reactions to disasters (Luchetti, 2017). In this example, the AR type being used is location-based because it requires the mobile device to be at the specific location of the disaster.

The second example, called Panacea Cloud, was designed as “a novel Intelligent Dashboard that provides augmented reality benefits with minimal human communication” (Ahmad and Calyam, 2017). In Figure 19, one can see how the dashboard is designed.

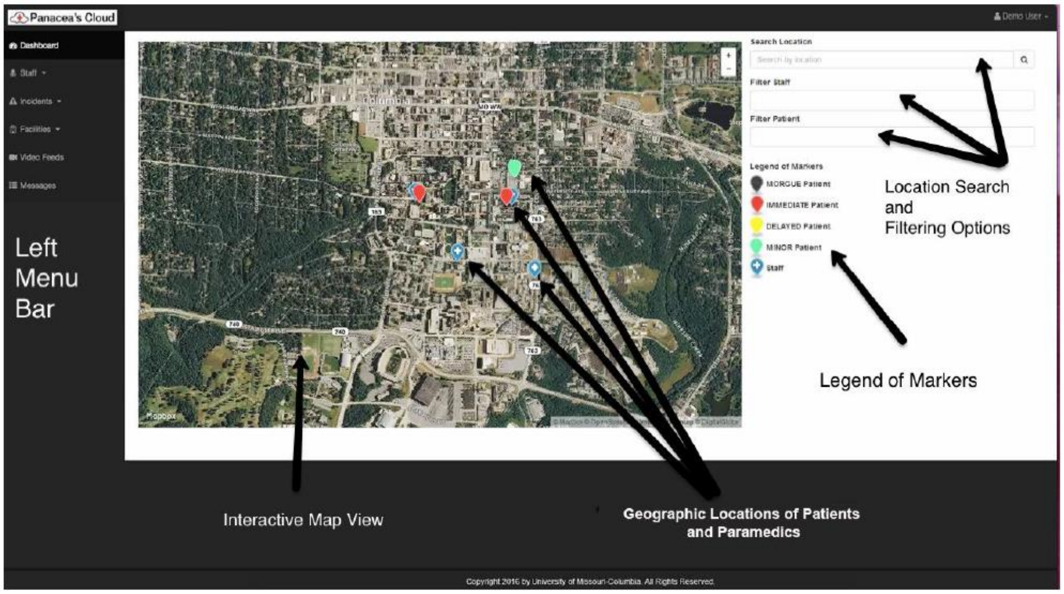


Figure 19: Panacea Cloud's dashboard layout (Ahmad and Calyam, 2017).

In this example, the dashboard design is relatively straight-forward with a menu bar on the left, interactive map in the middle, and on the right, there is a legend and search and filtering options. The AR element is added with first responders in the field wearing AR-enabled eyewear, in this case Google glass. The glasses transmit what the first responder sees back to the command center to increase situational awareness of those not at the scene. In this example, the AR element is not cartographic in nature. The takeaways about AR design include: real-time map view, the ability to write digital notes, and proprietary WiFi.

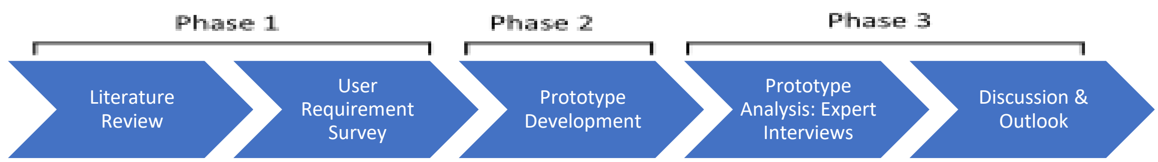
From these examples, it is evident that inroads have been made into cartographic AR dashboards, but the actual applications have been limited.

3 Methodology

The third chapter will discuss the research methodology chosen to address the thesis objectives and questions as stated in chapter 1. The main goal is to discover the needs of disaster risk professionals a develop a prototype using augmented reality in a cartographic dashboard to improve decision-making in the disaster management cycle.

Research Approach

The research approach is broken down into three stages as shown in figure x.x. Phase 1 is the theoretical background and user research in which a literature review of the state-of-the-art technology and a user requirement survey are conducted. In phase 2, the concept for the prototype is formulated and then put into action. In phase 3, the prototype is analyzed with experts to evaluate its potential use in disaster management.



Phase 1: Theoretical background and User Research

Research Objective 1

- Discover needs of a disaster risk management professional for cartographic technologies
    - Identify how an AR cartographic element can support disaster management

In order to address Research Objective 1, a literature review and user-requirement survey were conducted.

The literature review of state-of-the-art technologies was an important part of the process for understanding how to develop a prototype that may be useful to disaster risk professionals. The first step was to fully understand disaster risk management and its associated tasks and needs. By breaking down the definition of disaster into hazard, exposure, and vulnerability/capacity and placing it within the disaster management cycle, it becomes evident what tasks are done at each step of the cycle. From there, it can be understood what types of maps are used in each step. In addition to reviewing literature for disaster risk management, it was also necessary to do a literature review of cartographic dashboards and mixed reality technologies, both generally and specific to disaster management.

The next step was to conduct a user-requirement survey of disaster risk professionals. In order to design and introduce a new technology, it is important to have both quantitative and qualitative input from those who would actually use the product. The survey was designed to figure out what types of maps and what devices disaster risk professionals are already using, how important maps are for them and what type of information is on them, if they have already worked with AR products, what their biggest problems and needs currently are, and what they see for the future of the technology they use to address disasters. The survey is crucial in understanding the motivations and needs when it comes to designing a map and dashboard.

Phase 2: Proof-of-Concept

Research Objective 2

- Identify how to integrate AR technologies into a cartographic dashboard

Using what was learned from addressing research objective 1, it was then possible to decide how to design and build the prototype. The proof-of-concept methodology was used when designing the prototype. The proof-of-concept is the first state of prototype development and is used to help better understand what direction to take when designing a product (Yang, 2005).

For the dashboard layout, a comparative proof-of-concept methodology is employed. Several different dashboard layouts are designed and presented to experts in order to learn which layouts work best for the given user.

For the AR component, an individual proof-of-concept is employed. The type of AR was selected based off the literature review and user requirement survey. The idea is to test this prototype with experts in order to further understand and elucidate how this could be used in the field of disaster management and if it generates further requirements or possibilities for future designs. If experts were to find the proof of concept useful, then it would be possible to move forward with an actual product (which is outside the scope of this thesis).

Phase 3: Prototype Evaluation and Analysis

Research Objective 3

- Understand if a dashboard with an AR element can improve the communication of information to a user about disaster risk and how
    - Analyze how dashboard layout impacts user

In order to address the third research objective, two expert interviews were conducted to analyze if and how an AR cartographic dashboard could be used in disaster risk management. Expert interviews were chosen as the best method to analyze a proof-of-concept prototype. Since a proof-of-concept prototype is not fully functional, testing behavior is not possible. Instead, having a deeper conversation about the pros and cons and possible uses is important and provides attitudinal feedback (Rohr, 2014). Interview questions were developed beforehand, but the ability to dig deeper on any topic is possible.

4 Proof-of-Concept & Results

This chapter will present the results of the methodology's execution. It will show the discoveries of each phase, them being the user requirement survey, proof-of-concept prototype development, and the expert interviews.

User Requirement Survey

The user requirement survey was done using SoSCi[11] Survey. It offers a free version for students, while also offering robust functionality in terms of question- and answer types. It outputs the results in a tabular format in order to successfully display quantitative and qualitative data.

Description and Overview

As described in chapter 3, the purpose of the survey was to gather information about what disaster risk professionals are currently using for their role, what problems they face, and what their needs are for a cartographic dashboard AR tool to help them in their job. The survey was split into 4 sections as seen in figure x.x.

The first step was to limit the survey to at least mid-level experienced to highly experienced disaster risk professionals. Next was to get an idea of what products they are currently using and for what purpose. It was important to know, for example, if they are already using dashboards. The third step was to ask directly what their issues are with their current technology and if they have specific needs. And the last step was to see if they believe that there is a future of using technologies such as mixed reality in their work.

Survey Population

Profession and Experience

While the survey was sent out to multiple organizations, it received very little attention. Ultimately, the survey was only successfully filled out by six people. Four were from the German Federal Office of Civil Protection and Disaster Assistance, known as the BBK in German, one was from the Munich Fire Department, and one from the Berlin Fire Department. The average experience level of the respondents was four on a five scale. So, while the answers were few, they were from experienced professionals, and provided a lot of good feedback. The age section was not filled out correctly, so there is no age data available. The BBK deals with all manners of disasters and so has experience dealing with everything

[11] https://www.soscisurvey.de/ (Accessed September 2021)

from floods to fires, whereas those from the fire departments experience is limited more to fire disasters. Professions included geoinformation expert, geoinformation consultant, and administrator.

Results Overview

Current State

The goal of the *Current State* section of the survey was to understand what tools and technologies people are already using as disaster risk professionals. As seen in Figure 20, 100% of respondents are already working with 2D digital interactive maps, 83% are working with 2D digital static maps, information dashboards, and 3D digital maps, 66% are using 2D printed maps, one respondent (20%) admitted to already using AR/VR and none are using a form of 3D physical maps/city models.

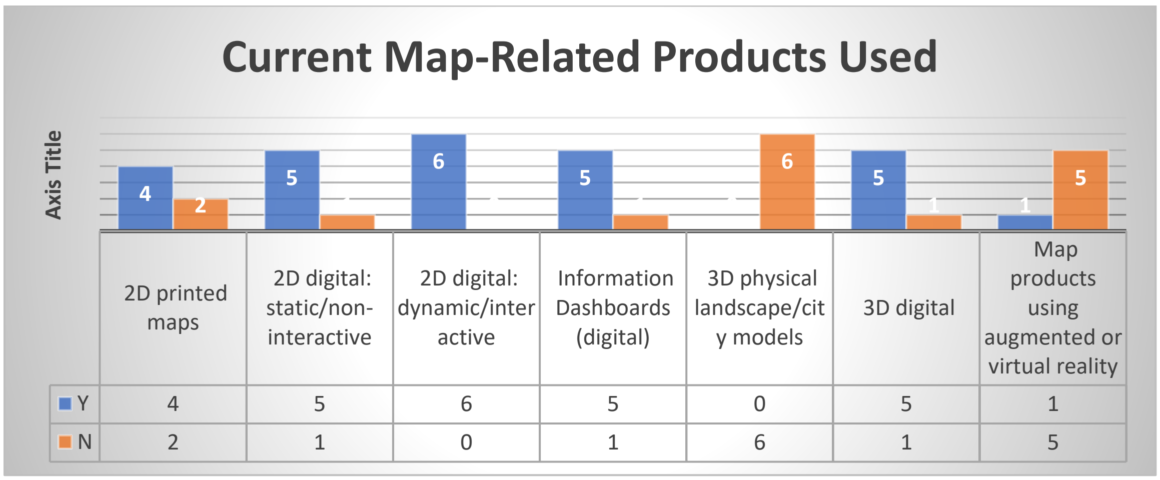


Figure 20: User requirement results of current map-related products

In addition to map products being used, it was also important to know what devices they are using. As seen in Figure 21, 100% are using analogue maps, 83% are using digital desktop/laptops, 33% are using mobile devices, and 20% are using AR/VR devices. The discrepancy between numbers regarding 2D printed maps for product use and analogue/print maps for device use is unclear.

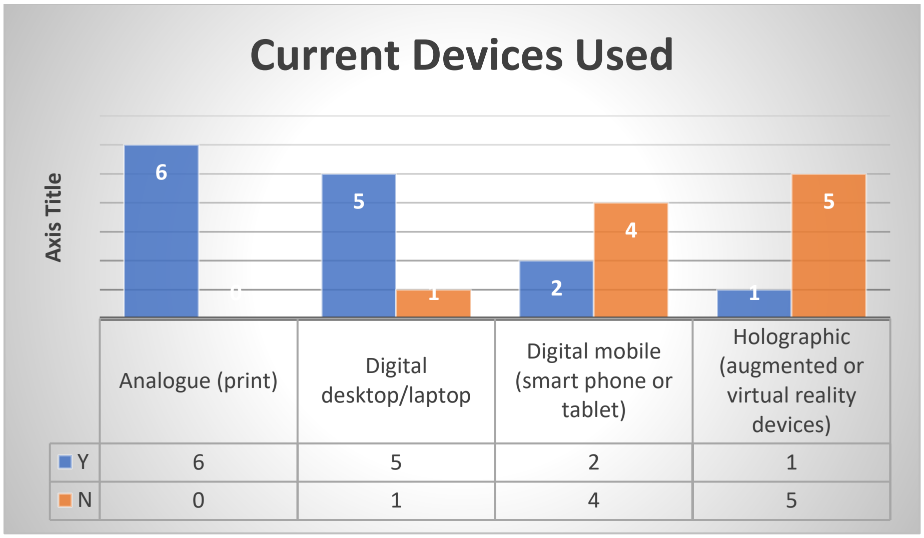


Figure 21: User requirement survey results of current devices used

In addition to the devices being used and types of maps, respondents were also asked about how often they use maps and how important maps are to their work. 100% of respondents said they use maps every day at work, and the average rating of importance of maps to their job was a 4.7 out of 5, 5 being critically important.

The last two questions asked were open-ended. The first question asked what type of information is displayed on map products. A word-cloud is provided in Figure 22 to show the most popular answers (after removing the word “information”).

Figure 22: Word-cloud generated from qualitative answers from the user requirement survey

Infrastructure was the most commonly used word when answering this question, followed by location, points, maps, deployment, and data. Other words with multiple appearances include COVID-19, extent, structure, and tactical.

Many of the responses specifically mentioned "critical infrastructure" such as hospitals or power plants, the location and extent of the disaster, deployment and tactical (ingress/egress) information for disaster sites, and statistical thematic maps showing, for example, case numbers.

The second open-ended question asked if they are already using AR/VR products and/or dashboards. Five out six respondents mention using ESRI's dashboards. Only one respondent answers that they use AR/VR but that it is "implemented in a rather rudimentary way." Two others respond by saying that they are experimenting with AR/VR, but it is not being used professionally yet.

Problems, Need, and Future Products

The last four questions were also open-ended. The first question asked what problems they face using their current technology. The main answers were:

- Data availability
    - Specifically getting real-time data
- Modifiable are unit problem
- Data quality
- Complicated operation

- Not developed for mobile

The next question asked what their needs are from a cartographic product. The main answers were:

- Ease of use/user-friendly
- Convey the information without room for misinterpretation/simple, meaningful representations
- Data quality/official information
- Real-time data

The third question asked what their information needs are. The main answers were:

- Understanding spatial context and relationships
- Data exploration
- Geo-referenced information
- A broad overview
- Quickly identify trends
- Comprehensive information on urban development data
    - Populations figures
    - Infrastructure and settlement structures
    - 3D overview of deployment site

The last question asked if they see the benefit of new technology helping with their job. While two of the respondents said they do not see the benefit of new technologies, others saw the potential for the future. Their responses are as follows:

- "…the benefits can be very great. However, it must also be guaranteed that these technologies can also be operated by absolute laymen and, if necessary, still function after a power failure."
- "In the context of disaster risk management cycle, the most direct potential would be in the response or recovery phase. However, scenario-based preparation tasks might also be supported."
- "Allows a better understanding of the situation, possibly integration of real-time information (task forces, situation picture)."
- "A challenge might be the complexity of such an application, e.g., user-friendliness, design, and experience."

Cartographic AR Dashboard prototype

The development of a prototype to meet the needs of disaster risk professionals is generally a difficult task due to the expansive nature of the field and varied needs of different roles. As learned in the literature review, functional features should be highly-customized the specific need of the office or even person. There are, however, consistent visual rules that can be applied. A proof-of-concept methodology was chosen to test the prototype.

Approach

Using what was learned from the literature review and user requirement survey, a prototype was designed that integrated both a dashboard and AR element. The design was meant to integrate with a disaster risk professional's existing workflow and further enhance it. Certain AR methods do not fit with current workflows or the technology is not advanced enough to provide the detailed information required to address a disaster; this will be discussed later in the chapter. For example, it is technically possible to create a small dashboard on a mobile device with AR capabilities, but using what was learned from the user requirement survey, an application like that would not be useful to those in an office. The decision to make a general prototype instead of a case study was based on previous research that suggests that tasks tested should be derived from real situations at the time of disaster (Ahmad and Calyam, 2017).

Dashboard layout

For the dashboard element, dashboard *layout* was the main goal of analysis for the purpose of this thesis. As stated in chapter 2, functional features are specific to the office and role of the person using it. Providing a random disaster scenario does not make sense in this context since the interviewees are not familiar with the functional requirements of that specific disaster. Instead, the dashboard was designed using visual feature guidelines and different layouts were created and later tested. For example, a single page and frugal use of colors were employed (Yigitbasioglu, 2012). The main elements of a dashboard from a functional understanding are:

- Menu/toolbar
- Map pane
- Data visualization panes

Several options were created and then tested with the experts. Affinity Designer[12], a vector-editing software, was created to make the layouts.

Map and data visualization location

Several dashboards were created for testing with the experts to understand if the placement and number of panes were important to their comprehension. Each layout has a space for the *map element* and anywhere between one to four spaces, called panes, for *relevant data visualization*s. Actual data visualizations were not created because they are too specific, and the goal is not to test the data visualizations themselves. The base map is from WRLD3D.[13] Below the layouts are presented:

Three layouts were created with two panes:

Figure 23: One data visualization pane on the left and map pane on the right

[12] https://affinity.serif.com/en-us/designer/
[13] https://www.wrld3d.com/ (Accessed September 2021)

Figure 24: Map pane on the left and one data visualization pane on the right

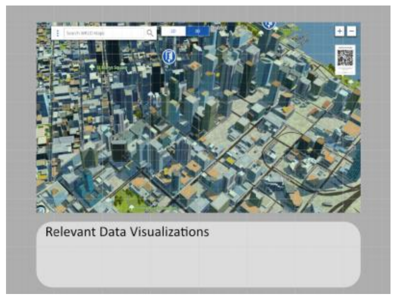


Figure 25: Map pane on the top and data visualization pane on the bottom

The first set of layouts uses only two panes, one for the map and one for data visualizations. In Figure 38, one can see the expert currently uses a dashboard similar to Figure 23.

Two layouts were created with three panes:

Figure 26: One data visualization pane on the left and one on the bottom and the map pane on the right

Figure 27: Map pane on the left and one data visualization pane on the right and one on the bottom

Here the layout has added complexity by having a data visualization pane on both the bottom and left or right.

One layout was created with 4 panes:

Figure 28: Map pane in the middle surrounded by data visualization panes on the left, right, and bottom

The layout in Figure 28, has three panes for data visualizations and one for the map element. Here, the map pane is surrounded on 3 sides by data visualization panes.

Last, one layout was created with 5 panes:

Figure 29: Map pane in the middle surrounded by data visualization panes on all sides

The final dashboard layout has the maximum number of panes at four data visualization panes and one pane for the map element. In this design, data visualizations completely surround the map.

Menu/Toolbar location

The next element test is if the menu/toolbar location affects the users' comprehension. Four locations for the menu/toolbar location were selected: bottom, top, left, and right. These are essentially the only locations for a menu/toolbar.

Figure 30: Menu/toolbar situated at the bottom

Figure 31: Menu/toolbar situated at the top

Figure 32: Menu/toolbar situated at the left

Figure 33: Menu/toolbar situated at the right

MR Scene

After the dashboard design, the next step was choosing how to integrate an AR element. This was a difficult process as there are many different types and applications of AR. Based on the user requirement survey, many professionals are still using desktop/laptops for their work, especially when in command centers as opposed to those in the field. With this in mind, it was important to design something that was not limited to solely a mobile device, but rather has a desktop and mobile part. The idea was for both those at the command center and in the field to be able to utilize AR.

Since many of the responses also included the need for information regarding infrastructure and deployment, the decision was made to visualize a city-section in which there could be a disaster. The intention was to make the actual cartographic element the main AR focus. The area is local, i.e., it is not an extended geographic area. The idea is that the person in the command center can get an in-depth, 3D, zoomable view of a city section in order to make decisions about deployment, ingress/egress, and critical infrastructure locations. This narrowed down the AR types to markerless and projection. While a projection technology was tried (HoloSDK[14]), the image that appeared was not sharp enough for disaster management. This left a markerless approach. Using the markerless approach, the user can simply scan a QR from their desk with a mobile device or vision system (such as Google glass). Once the device has registered the code, one simply has to point the device at a flat surface in which the image can be projected as seen in Figure 34.

Vectary[15] was ultimately chosen as the AR development platform for the prototype. One of the main reasons for its selection was that fact that it is a web AR based too and therefore a user can view a 3D composition in a desktop browser, then seamlessly transition to a mobile AR experience.

Figure 34: QR code located on the map that would allow the user to open an AR scene on whichever display device is being used

[14] https://www.holo-sdk.com/ (Accessed September 2021)
[15] https://www.vectary.com/ (Accessed September 2021)

Figure 35: Zoomed out view on the floor

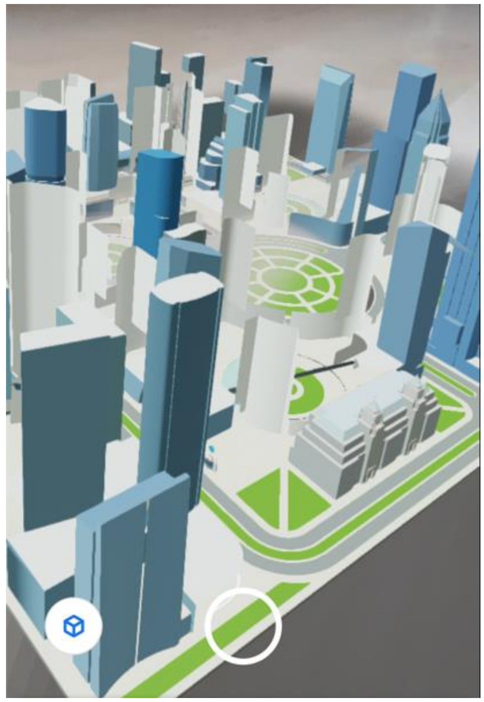


Figure 36: Zoomed in view in white space

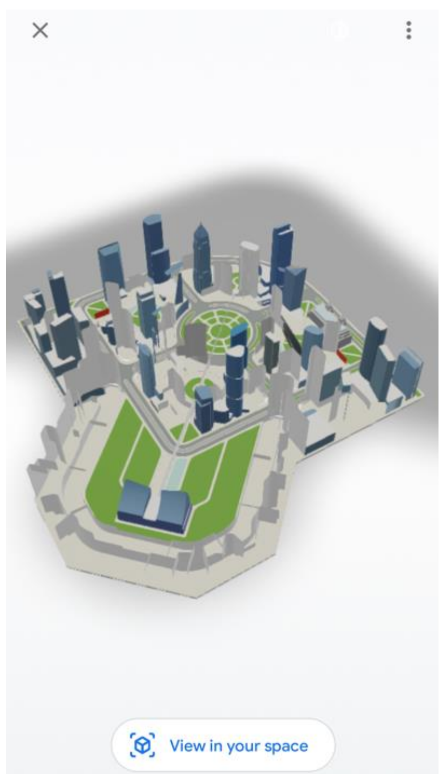


Figure 37: Zoomed out view in white space

Figure 35, Figure 36, and Figure 37 show what the AR experience looks live when you scan the QR code and generate the AR image. The AR scene can be viewed on a surface near you or in an empty white space offered by Vectary. The markerless AR makes it easy to create the AR experience at your desk or wherever you are. Both offer zoom, pan, and rotate functionality, allowing the use to get closer to a building if needed. A 3D object was chosen that offered different building types, road types, and green areas to portray different possibilities within a city (Yoshi Productions, 2017). The object specifications include:

- 12,994 polygons
- 24MB
- 137 materials
- Bounds: 101K x 101K x 14K

The AR model can be used to simulate a mass casualty incident (MCI) or a building fire.

Expert Interviews

In order to assess the prototype qualitatively, two experts were chosen for an interview. It was important to select both someone from a command center and someone who works in the field to get different perspectives. First, they were asked about the current tools they use and why they do or do not work. Then the prototype was shown to them (i.e., they scanned the QR code and projected the AR model in their own space). After that, they were showed the different dashboard layouts and asked which they found to be the easiest to understand and if they had a preference. The main goal was to learn from them if they believed an AR dashboard like this would be useful to them in their line of work.

Office Expert: State of California – Deputy Director of COVID-19 Response & Paramedic Supervisor for San Mateo County EMS 911 System

The first interview was with a highly experienced disaster risk professional. With roles as a paramedic supervisor and the deputy director for California's COVID-19 response, he has worked in all phases of the disaster management cycle and has managed everything from small to large scale responses. The interview was conducted virtually.

The following section contains the main takeaways from the interview.

The interviewee was able to send photos of the current technology used in his role as seen in Figure 38, Figure 39, and Figure 40.

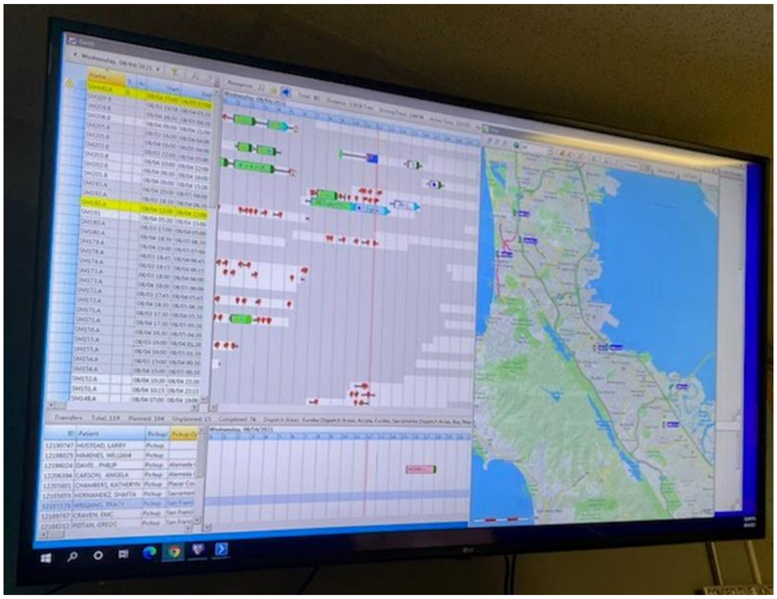


Figure 38: Dashboard with four panes for data visualizations on the left and a map pane on the right

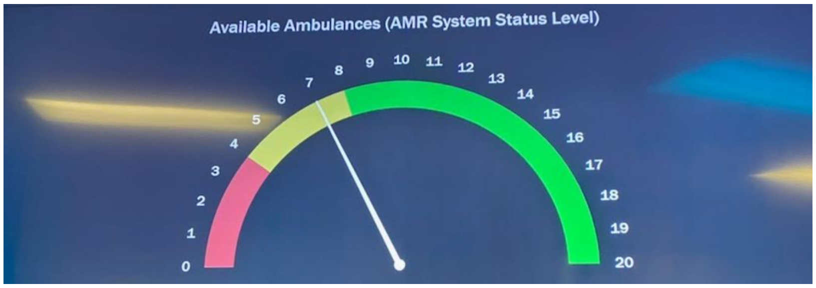


Figure 39: Data visualization showing number of available ambulances

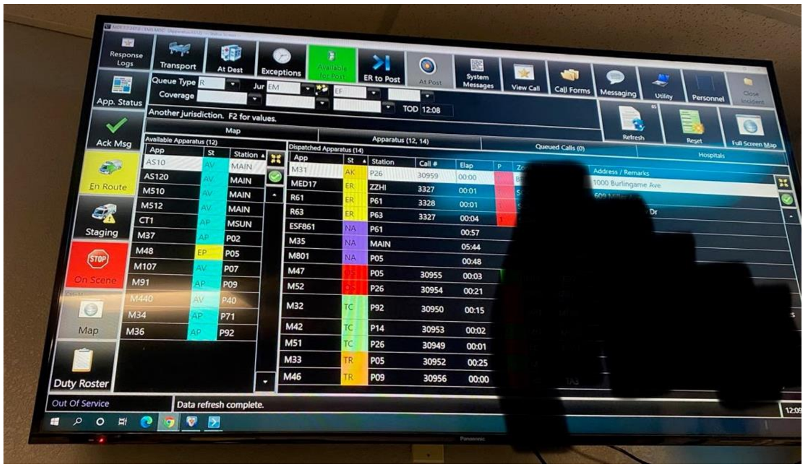


Figure 40: Dashboard of emergency vehicles' status

Current products:

- Pros:

    - Software automatically identifies which ambulance is closest and sends info for recommended travel directions
    - Country-wide 911 coverage map shows likelihood of an ambulance making it to the site on time
- Cons:
    - Uses 4 different tools/softwares that don't "talk" to each other
    - Sometimes software doesn't work and has to use radio to inform driver
    - Lack of legend and key means a lot of trial and error
    - Bad delay when updating real time (around 2 minutes)
    - Too many layers

Prototype:

- First impression:
    - 3D looks good
    - Zoom function was useful
    - "This would be extremely useful for a tactical EMS (TEMS) operator or a SWAT medic."
- For law and fire services, the benefits are:
    - Indoor navigation
    - Ingress/egress points
- For EMS, the benefits are:
    - Ability to establish a triage treatment and transport zone for a large-scale event.
    - Ingress/egress information on mobile devices for those at the scene
- Concluding thoughts:
    - With 3D and the ability to spin/turn it around, it would help understand how big a space or building is, which is difficult to do with the technology available
    - If this data could be gathered by private locations such as an airport and offered to emergency services, it would extremely beneficial because they currently use publicly available information such as Google maps, which doesn't have detailed information about gates and entrances, for example.
- Dashboard layout:
    - Map and data visualizations:
        - Found anything up to four panes to be fine
        - Location of panes didn't bother him
        - Five panes is too many
        - Showed some hesitancy with 4 panes, but said if it's designed clearly, then it would be okay
    - Menu/Toolbar
        - Said again, the location of the menu/toolbar doesn't affect his understanding
        - Make sure the menu/toolbar is prominent enough to know where it is

Field Expert: American Medical Response

The second interview was with a field EMS responder with 7 years' experience and now analyzes self-driving cars. Since he is a responder, he mostly works in the response phase of the disaster management cycle. The interview was conducted virtually.

Current products:

In his role, navigation and approach to a casualty incident are the most important needs. For navigation, they use GPS and for ingress/egress planning they use a map book with print maps.

Pros:

- GPS is reliable
- Print maps work with or without electricity, WiFi, etc

Cons:

- Neither of what he uses is adequate for facilitating effective disaster management response

Prototype:

- First impression:
    - Looks a map of a baseball field
    - Seems glitchy
    - Nothing too shocking
- For his role:
    - Useful for zooming in on
    - Doesn't think it would be useful for navigation
    - "Would be great for buildings to have QR codes so you could scan it and get an AR model."
- Concluding thoughts:
    - Considers AR technologies to have possible use if implemented correctly
    - Saving any number of seconds is valuable in emergency services, so if it can take time off of decision making then it's important.
- Dashboard layout:
    - Map and data visualizations:
        - "Simpler the better."
        - Like the 2 pane layouts the most
        - Said increasing number of panes adds increasing complexity
    - Menu/Toolbar
        - Having the menu bar at the bottom or right seems unintuitive
        - Prefers left or top orientation
        - Also said if it's clear enough, then it shouldn't matter

5 Analysis and Discussion

This chapter will discuss the results from the previous chapter. The main concept is to assess how well the prototype can be used in disaster risk management. It will also discuss the drawbacks and limitations of the proof-of-concept.

User Requirement Survey

The results from the user requirement survey provided many insights that were used in the proof-of-concept design. From the survey, it was learned that disaster risk professionals are largely using printed maps and all forms of digital maps, including 2D static or interactive, 3D maps, and digital dashboards, while excluding mixed reality technologies. They are expressly not using physical 3D models. In addition, using mobile devices is not as common.

Many of the issues and needs brought up be respondents are related to data and design. From the data perspective, respondents want the data to accurate, real-time, and complete. The data should be able to provide a broad overview, emerging trends, and details as needed (for buildings for example). Because disaster management involves saving lives, good data is crucial to do the job well. From the design perspective, respondents commented that a product needs to be easy to understand, and easy to use. Another main takeaway is that the product should provide the ability to communicate an overview, trends, and details. All levels of information are relevant in disaster management.

The ultimate takeaway from the user requirement survey is that, while AR may increase their ability to do their job better, the way it is integrated into a piece of software is more important. Overall, the correctness of the data and the simplicity of the design, which allows someone to do their job faster, is the most important factor.

Some respondents saw that there could be a benefit to using AR, but feel that the technology is not quite ready yet and needs to be at a level in which it seamlessly integrates into their workflow.

Cartographic AR Dashboard Prototype Proof-of-Concept

When designing a cartographic AR dashboard, several considerations should be taken into account.

For the dashboard design, the panel layout needs to be clear and not overwhelming. Too many panes can be confusing to a user and draw the attention in too many places. The orientation of the menu/toolbar does need to be any specific place as long as it is clearly labeled. The map can be left, center, or right aligned. The number of data visualization panes should be limited to 1-3. Completely surrounding the map with data visualization panes will overwhelm a user and should be avoided. As per the literature review, visual features should have limited colors and be one page only. When adding functional features, they should be customized to the specific organization or even a specific user. The location of the AR toggle (usually in the form of a QR code) should also be apparent.

Implementing AR into a cartographic dashboard at the current time has many limitations. Because dashboards are still most commonly used on a desktop or laptop, an AR solution ideally integrates with it in that way. While there is a future of interactive AR dashboards, that technology is still not advanced enough for disaster management. Having an AR toggle in the form of a QR code for the geographic section you are looking at is the simplest way to integrate AR functionality into typical dashboards. This allows the user to perform their normal workflow, while having the option to use AR to enhance their decision-making. A markerless approach allows the user to stay at their desk and still have the AR experience.

Expert Interviews

The expert interviews provided insight into how AR could be used in disaster risk management. The main drivers of interest were the overview that it gave of a city-section and the ability to zoom in and see details. Both having an overview and details were mentioned in the user requirement survey and proven to be necessary in the expert interview as well.

The expert from the command center immediately saw the value in an AR map. His mind jumped to tactical and operational uses of an AR model. He mentioned establishing a triage treatment and transport zone, ingress and egress points, and the potential for indoor navigation. Since it is possible to zoom in and out and rotate the object, it is possible to get a good geographic overview of an area and also a detailed view on the city street. He also made it clear that he already uses four different pieces of software, and they don't "speak to each other," meaning they don't necessarily work with one another. If a cartographic dashboard were to be designed for his team, he'd want all the required functionality to be included. Adding another piece of software to his tech stack would not be beneficial.

The expert from the field did not see as much value in the AR dashboard. Because he uses maps mostly for navigation, AR does not play as much of a role in that. He did, however, say that if a building had a QR code on which he could scan and get an indoor AR model, that would be useful.

Drawbacks and Limitations

While the answers from the user requirement survey were informative, it would have been better to have a larger sample size. It was difficult to recruit people to take the survey. After having such successful interviews, I would also add interviews into the user requirement phase to get a better qualitative feel for how to design the prototype. The answers from the interview provided more detailed answers than the qualitative questions asked in the survey.

It should also be understood that the infrastructure and work it would require to take this from proof-of-concept to an actual working product would be immense. It would likely take a team of developers to build a fully functioning, custom cartographic AR dashboard, which was out of the scope of this thesis. AR relies either on 3D models for buildings or of taking pictures and then adding additional layers of data. Thus, 3D models would need to be created for the desired buildings. There are other options like Mapbox's AR functionality, but that is limited to tabletop or location-based AR. An AR application would therefore need to be highly technically advanced, which is why not that many products are currently seen on the market.

6 Conclusion and Outlook

The final chapter will conclude the topic by addressing the research questions and hypothesis. It will also explore the future of cartographic AR dashboards.

Research Questions

1) What is important to disaster risk professionals when designing a cartographic product?
    a. What part of disaster risk management can AR support?

To answer the main question, data quality and ease-of-use are important to disaster risk professionals when designing a cartographic product. Since they are often in high-pressure situations, time is important and, therefore, an easy-to-use product is crucial. After that, it is important for them to be able to get an overview of situation and also specific details. Being able to see the whole picture of disaster is vital to good decision-making, and thus a map should be able to provide both.

Per the sub-question, AR can be used in all stages of the disaster risk management cycle – mitigation, preparation, response, and recovery in the form of maps used for hazards, exposure, and vulnerability/capacity. For mitigation and preparedness, AR can be used for hazard recognition and safety training. For response, AR can be used for human evacuation and rescuing people from (mass) casualty incidents. And for recovery, AR can support damage detection and building reconstruction.

2) Within the context of a dashboard, how can an AR element be integrated?

Since dashboards are web-based data visualization tools, an AR solution needs to integrate with it in that way. There are several ways to integrate AR into a dashboard. The one presented in this paper is not the only one. The prototype in this paper used markerless AR to give users the flexibility to view the AR object at their desk. Another possibility is projection AR. The technology is still a bit early, but it is possible to have the AR image come directly from your computer camera. This would require 3D viewing glasses. Other applications include outlining and superimposition AR. This would be implemented by capturing data in the field via a drone, for example, and creating AR images from the field that could be sent to a dashboard in a command center. In the future, there will likely be fully functional holographic AR dashboards, but the technology does not provide a fully functional experience yet.

3) Does an AR element within a dashboard improve the communication of information to a user about a disaster, and if yes, how?
    a. How does the dashboard layout impact the user?

Per the main question, yes an AR element within a dashboard improves the communication of information to a user. By increasing the amount of information a disaster risk professional has about a disaster area, the better decisions can be made. AR provides that additional information by giving an additional way to view the map.

Dashboard layout definitely impacts a user. If a dashboard is poorly designed or too complex, it will hinder a person's ability to use it. While there are visual rules that should typically be abided by, the functional aspects should be specific to the group or person using it.

Hypothesis

- There are multiple ways to integrate AR into a cartographic dashboard.

    - This hypothesis was proven to be true. Cartographic dashboards have the ability to integrate AR in different ways.
- An AR cartographic dashboard can improve the communication of information to a user within the context of disaster risk management.
    - This hypothesis was also proven to be true. AR can improve the communication of disaster risk information to a user and improve decision-making.
- A well-designed and intuitive dashboard layout is necessary for user comprehension.
    - This hypothesis was also proven to be true. Dashboard design is imperative for user comprehension.

Future Outlook

The future of cartographic AR dashboards is promising. Augmented reality, while not technically a new technology, has recently been getting to the point where it is more commercially applicable. With the ever-increasing threat of disasters, the field of disaster risk management will have more responsibility than ever to address these issues. Any new application of technology that increases capacity to deal with these threats is welcome.

As learned from the expert interviews, having an application that addresses all of the needs of a disaster management office would be preferable than having many different softwares. With increased focus on developing software specifically for not only the field of disaster management, but customized to the specific disasters being addressed, more research and development should go into creating advanced solutions. A great example of this would be for disaster management entities or the government to create 3D models for buildings considered "critical infrastructure" to be able to have on hand. If there is ever a disaster affecting one of these buildings, then the disaster risk office that is dealing with the issue can pull up AR model of the building for improved information about transportation access to the building, setting up ingress/egress and triage zones, as well as the possibility for indoor AR navigation and evacuation. The next step of research would be to do a specific case study of this type. As stakeholders get more comfortable with modern technology such as AR, its uses can become more widespread and adoptable.

With the increasing amount of data used in decision-making processes, dashboards have staked in a claim as a data visualization method to help disaster risk professionals do their job. While dashboards are an excellent modern solution to visualizing data, their design and implementation can continue to improve. While it established that they are effective for communicating spatiotemporal knowledge, a dashboard needs to be custom-designed each time, taking a scientific approach, to meet the users' needs. Dashboard design largely overlaps with the field User Interface (UI) design, which is major and growing field.

Adding AR functionality into the disaster management cycle is already starting to happen and has a bright future. The technology is still limited by hardware capacity and adaptability to existing workflows. While it provides more information to the user, it is hard to say if it could completely replace 2D or 3D digital maps on desktops. It's possible that with the severity of contemporary disasters that the technology in the field will progress more quickly as it is needed.

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Appendix 1 – User Requirement Survey

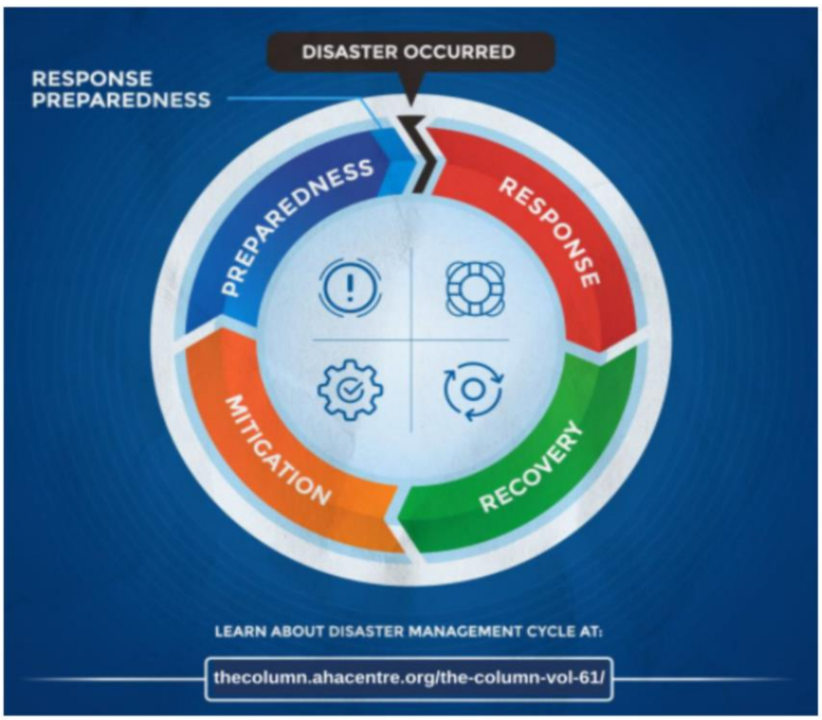
Page 01

User-Requirement Survey for Cartographic Dashboards in Mixed Reality in the Field of Emergency Management

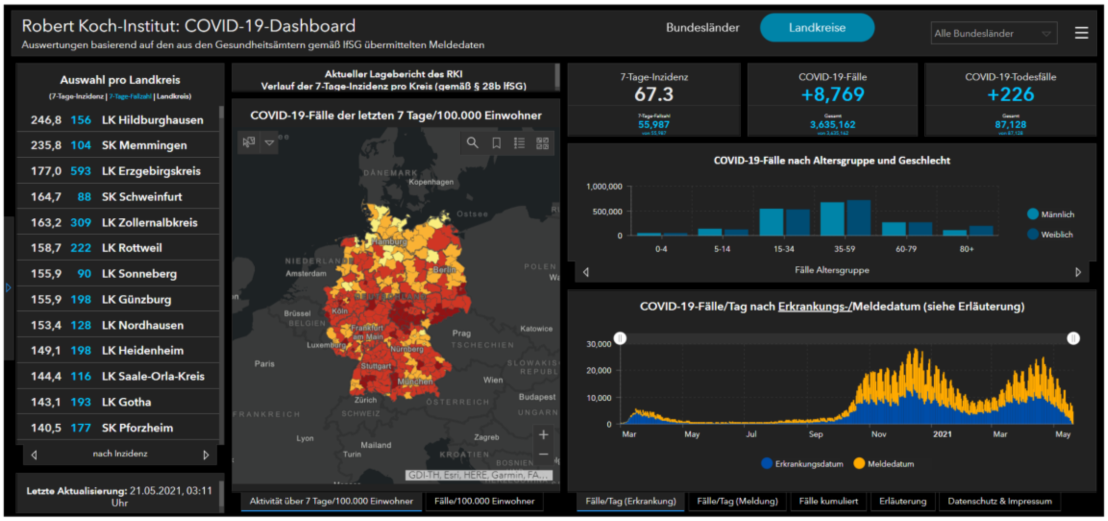
Welcome.

Thank you very much for participating in this survey. You have been selected because you work in the disaster management cycle (see picture below). Your answers support my master thesis and hopefully contribute to the field of disaster management.

The questions will be regarding the use of cartographic dashboards in a mixed reality environment (augmented and/or virtual reality). It should only take 5-15 minutes.



If you are unfamiliar with the term "dashboard" please see the image below from the Robert Koch Institute as an example.



Page 02

Please enter your age:

[Please choose]

Who is your employer?

1. What is your job title?

2. What is your experience level?

○ Novice ○ Advanced beginner ○ Competent ○ Proficient ○ Expert

Page 03

3. What map-related products do you currently use in your job?

- [ ] 2D printed maps
- [ ] 2D digital static/non-interactive
- [ ] 2D digital dynamic/interactive
- [ ] Information Dashboards (digital)
- [ ] 3D physical landscape/city models
- [ ] 3D digital
- [ ] Map products using augmented reality or virtual reality
- [ ] Other

4. What devices do you use to view maps?

- [ ] Analogue (print)
- [ ] Digital desktop/laptop
- [ ] Digital mobile (smart phone or tablet)
- [ ] Holographic (augmented or virtual reality devices)
- [ ] Other (please describe)

5. How important are maps to your job?

○	○	○	○	○
Not important	Somewhat important	Moderately important	Very important	Critically important

6. How often do you use maps in your job?

○	○	○	○	○
Never	Less than once a week	1-2 days a week	3-5 days a week	Every day

7. What do you use maps for?/How are maps used in your role?

8. What type of information is displayed on the maps you use?

9. If you have already worked with either dashboards, virtual reality, augmented reality, or mixed reality technologies at your job, please explain your experiences shortly (include the device you were using).

Page 04

10. What are the biggest problems with your current cartographic products?

11. What are your most important needs from a cartographic product?

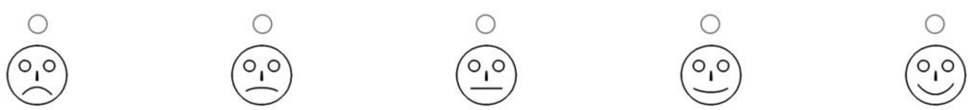
12. What information that a cartographic product can provide is most important to you?

Figure 32: Tabletop-MR-Scene 2: Istanbul

13. Do you see benefits in using new technology such as virtual reality, augmented reality, or mixed reality technologies (e.g. holographic overlays providing additional information on top of a 2-D map) in the field of emergency management?

(See image above from previous M.Sc. student K. Helzel)

14. How would you rate the potential benefits of virtual reality/augmented reality/mixed reality technologies in the field of emergency management/disaster response?



15. Is there anything else you want to contribute to this study which was not covered in this questionnaire? Feedback?

Last Page

Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

Your answers were transmitted, you may close the browser window or tab now.

M.Sc. John McCall, Technische Universität München – 2021

Appendix 2 – Expert Interview #1

Expert interview from 7.28.2021 – American Medical Response

I = Interviewer

E=Expert

I: Tell me about your experience relevant to disaster management.

E: I was an emergency medical technician for 7 years in the Bay Area. I worked for a company called American Medical Response. I would get called to casualty incidences, sometime mass casualty incidences, and attend to victims. I was part of team who would travel in an ambulance to wherever we got called.

I: What kind of maps and cartographic visualizations do you currently use?

E: We basically used a map book and GPS for navigation. For mass casualty, we use the print maps to plan our approach.

I: Are the current visualization techniques adequate and capable of facilitating an effective management of disasters?

E: I would say so.

I: How and from where do you receive up-to-date information and data about a disaster?

E: Pager. Then radio.

I: [presents prototype]

I: Do you see the object?

E: Yes, looks like a map of baseball field.

I: First impressions?

E: Little bit glitchy. Seems useful for zooming in on. Nothing too shocking. Would be great for buildings to have QR codes, so you could scan, and get an AR model.

I: Does this add anything more to your current ability to use cartographic products?

E: Using it for buildings would be useful, but not navigation.

I: How useful would you consider technologies like AR in disaster management?

E: Possibly. If it's implemented right. Saving any number seconds is valuable in emergency services.

I: Okay, let's move on to the dashboard layout. [Presents menu/toolbar options] Do you have a preference for the location of a menu or toolbar for a dashboard?

E: It seems strange to put the menu bar on the bottom or the left. They are usually at the top or the right-hand side, right? Yea, doesn't make too much of a difference to me as long as it's usable.

I: Okay, thanks. We are going to move onto the dashboard layout now. I'm going to show you several different dashboard layouts with a different number of panes. One pane is for the map. The other panes are for whatever data visualizations you are used to seeing. Tell which layout makes it easiest to understand for you. [Presents dashboard layouts]

E: Honestly, I like the one that's half and half. Where half the page is a map and the other half are data visualizations. Simpler the better for me. Seems like if you keep adding more panes, it just gets harder to understand, no?

I: I see what you are saying. Some people feel that way, some don't. Okay last question. Do you see how the AR model could be used within the dashboard?

E: Hmmm, it would be cool to be able to get an AR version of whatever is happening in the map. That seems like a good combo of the two.

I: Great. Thanks for your time.

Appendix 3 – Expert Interview #2

Expert Interview from 3.8.2021 - Paramedic Supervisor for San Mateo County EMS 911 System & State of California – Deputy Director of COVID-19 Response

I = Interviewer

E=Expert

I: Tell me about yourself

E: I've done a lot. Currently, my full-time job is paramedic supervisor for the San Mateo County EMS 911 system. I was the deputy director for the state of California for the COVID-19 response last year as well and have been the incident commander of number large scale events. I'm also a FEMA incident manager for emergency management for the federal government on call for deployment of national disasters.

I: What kind of maps and cartographic visualizations do you currently use?

E: I have 4 different tools; basically a GIS-based mapped, geofencing around ambulances when they are at a post in the county. I have geo-posts where the vehicles are staged, waiting for a 911 call. Using also Versaterm, a law enforcement CAD, hate it, and logisIDS which is primarily mapping tool. It speaks to CAD on facility site. Unit will get prescheduled a transport, and the map will identify which is closest and send info of recommended directions of travel.

I: Are the current visualization techniques adequate and capable of facilitating an effective management of disasters?

E: Versaterm has too many layers. You see available units by using color-coded status system, red means at a hospital, blue is in service, yellow is available but making a post-move, etc. I don't know the other colors. There's no legend or key. It's lots of trial and error; there's a bad delay on it as well. It updates about every 2 minutes, which is slow. Logis can look at both sides and moves and leaves breadcrumbs for the units as they are moving in almost real-time, refreshes 6-7 seconds. I need all these different softwares to do one thing, but they don't talk to each other. Livemum maps country-wide 911 coverage. If there are 5 ambulances, it will show percentage of how likely it is to meet the contractual agreements. Purple means no chance of making a call. I don't even use this one because it's so useless. If the softwares don't talk, I can get on the radio and identify a closer unit.

I: In what way is it possible to interact with your maps?

E: The dashboard is a web-based CAD, which is part of Versaterm. I can toggle between fire resources and EMS resources. The web-base simplifies information. Other data getting I can do includes response time, a delay or weather anomaly, they can prove their location and speed in real-time with a geofence of around 6 feet. There is useless information, and I need to scroll down to see everything. I have to put in a code every time I want to see it.

I: Okay I'm going to show the AR prototype now [presents prototype] First impressions?

E: Ohh it's 3D and it can zoom. Very cool.

I: Does this add anything more to your current ability to use cartographic products?

E: This would be extremely useful. I can see TEMS operator (tactical EMS) or swat medics using this.

I: Does TEMS stand for tactical EMS?

E: Yea exactly.

I: Ok. Do you see other uses for it?

E: For law and fire, if they are responding to an active shooter or fire, indoor navigation would really valuable for ingress and egress. For EMS, if they had a scene of a large-scale event to establish a triage treatment and transport zone, to look at targets, for ingress and egress on iPads, in a multi-casualty incident. We're currently just using arial pics and google maps. They don't have the ability to see layers in a building or 3D. You don't realize how big a space or building is when looking at regular maps. With 3D and the ability to turn it around, it would really helpful. Make our decision easier to make. Google maps doesn't provide info for an airport for example, because it's restricted to the public. If it were able to integrate that info, it would be helpful, like gates and entrances.

I: How useful would you consider technologies like AR in disaster management?

E: Extremely.

I: Okay, thanks for your responses. Great. Let's move on to the dashboard layout. [Presents menu/toolbar options] Do you have a preference for the location of a menu or toolbar for a dashboard?

E: I actually don't care where you put something like a menu or toolbar as long as I know where it is. I have dashboards with menus and toolbars all over the place and it makes it hard to locate them sometimes. If a software is designed well, this shouldn't matter.

I: Got it. We are going to move onto the dashboard layout now. I'm going to show you several different dashboard layouts with a different number of panes. One pane is for the map. The other panes are for whatever data visualizations you are used to seeing. Tell which layout makes it easiest for you to understand. [Presents dashboard layouts]

E: Hmm interesting. I work with a dashboard every day that has the map on the right and information on the left. That layout works for me. I feel like the more panes, that's the word you're using right? I feel like the more panes you add, the more of a chance for confusion you get. I don't need my attention being pulled in all different directions. The map being surrounded on all sides is definitely way too much. I don't see why that would be necessary. Even the layout with map surrounded on three sides seems to be pushing it, but I don't necessarily think it would be that bad.

I: Great. Anything else?

E: Kinda just like I mentioned, I wish I could have one tool that does everything instead of using multiple different ones. The software working correctly and quickly is most important. I really think the augmented reality is cool though and hope it can be worked into a product one day.

I: I hope so too! Thanks for you time. It was really nice chatting. By the way, can you please send me the pictures of the softwares you use that I could see in the background of this call?

E: Sure, no problem.

I: Thanks, have a good one.