RubbleViewer

Communicating for Situation Awareness in the Urban Search and Rescue Domain

Master Thesis

By Maarten van Zomeren
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RubbleViewer

Communicating for Situation Awareness in the Urban Search and Rescue Domain

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Cover picture: “Collaboration at the worksite” by Maarten van Zomeren

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Abstract

Rationale: Observations of field exercises of Urban Search and Rescue (USAR) teams showed that the current way of communicating worksite information to other responders with sketches is not effective in complicated situations. The current sketches for these complex situations are in 2d, but the problem, locating victims and discussing of attack plans, are tasks in 3d. This translation adds to the cognitive load of responders.
Research question: This research proposes a solution to communicate worksite information and build a shared frame of reference in a way that will be effective in more complex situations. The research question therefore is: “How to support a Search and Rescue (SAR) group using 3d mapping techniques for the purpose of (1) communicating information from one SAR group to another SAR group during a change of shift and (2) the internal collaboration of a SAR group on a worksite?”.
Method: The research question is answered with a design and an evaluation of the prototype, as is described by the situated Cognitive Engineering methodology that is followed throughout this research. It is an iterative methodology designed to result in a sound requirements baseline that the resulting technology has to meet.
The design phase aims to establish scenarios, functions, claims, and a requirements baseline based on a thorough work domain and support analysis. The requirements baseline and design rationale was used to create a prototype called RubbleViewer. The evaluation phase aims to refine and validate the design rationale. Evaluation of the requirements baseline and prototype was done with six USAR responders. The main task for the responders in the evaluation was to create an attack plan based on the information provided to them by the prototype. The evaluation was done with three pairs of two responders following the co-discovery method. The first two participants participated in a pilot study. Four people filled in a Questionnaire.
Results: The design phase resulted in the prototype RubbleViewer that was implemented as proposed solution using photogrammetric algorithms based on Microsoft’s Photosynth technology. It is an implementation of five out of the six core functions found. USAR personnel can add imagery to the prototype, taken from the worksite with an Unmanned Aerial Vehicle following a rule set. This will result in a 3d map where USAR personnel can annotate mission critical information on.
The evaluation revealed that all participants were capable of producing an attack plans. If such an attach plan could be made, that means that the responders must have a situation awareness level of at least two – comprehension of the current situation. This would mean that RubbleViewer was successfully used to communicate the necessary information. Important results from the questionnaire are: Four out of four supported the research rationale; Four out of four thought RubbleViewer would make the SAR mission more effective; Four out of four would put effort in creating a 3d map if the situation would acquire that.
Conclusion: The six core functions, as implemented in RubbleViewer, are proposed as a solution for the research question. An evaluation suggested that RubbleViewer was effective as solution. It also resulted in an update of the requirements baseline.

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Preface

This research is done as part of a larger collaboration at a distance project sponsored by IOP Senter*Novum*. The goal of this project is to “develop support systems that will make future Urban Search and Rescue teams more successful in reaching their goals by enhancing collaboration at a distance.”. Collaboration at a distance can be collaboration at a spatial, temporal, or hierarchical distance.

This project supports the collaboration at a spatial and temporal distance. The temporal distance is supported by a prototype, called RubbleViewer that supports the communication of worksite information between different Search and Rescue (SAR) groups that work on the same worksite after each other.

The same prototype supports collaboration at a spatial distance. A SAR group can request for expert knowledge on the scene, for example a structural specialist can be necessary to inspect the buildings stability for safety issues. A structural specialist can be at a large spatial distance to the SAR group. A small step is done to support the structural specialist with the analysis of the building. One day this step might result in a support system for the SAR groups that supports structural inspection reachback.

The research is done at the Delft University of Technology (TUDelft) and Texas A&M University (TAMU). This gave the researcher the possibility to combine the Human Computer Interaction knowledge at the TUDelft with the Human Robot Interaction and domain knowledge at TAMU. This resulted in a fruitful collaboration, sometimes at a distance.

Pushing human knowledge forward, or in my case just scratching it, is a process that you don’t do alone. I’m very happy to have set my first steps under the excellent supervisory of Stijn Oomes, Robin Murphy, and Tjerk de Greef. Thanks guys!

Stijn, ik hecht veel waarde aan de gesprekken die we gevoerd hebben. Vooral toen het concept RubbleViewer vorm begon te krijgen en jouw liefde voor glimmende applicaties naar boven kwam. Dank je wel voor alles. Op het moment van schrijven verwacht ik nog wel twee dingen van je. Een traditionele vraag over markers op het moment suprême en dat ik je nog een keer op een biertje mag trakteren.

Americans, it was an honor to be in your neck of the woods. Special thanks due to Robin, not only for inviting me to do research at your laboratory, but also for teaching the small things research is all about. For example without you I would have never known that taking your participants out to lunch could be so valuable. Kimberly, you made the silent days in the lab fantastic. Timothy and Laura you have been great for me and Bashar showing us around. Thanks! Oh and Aggies something from Texas in this thesis is bigger than the same thing from the Netherlands. The little drops of maroon blood in my forced me to do it, cannot help it.

Tjerk, thanks a lot for agreeing to be my daily supervisor for the last months. You know what you have done, and you know how I feel about that.

USAR responders, your openness to new technology has been great. It was awesome for a simple master student to have been welcomed at all the varying exercises. Jan Bron thanks for allowing

usar.nl assets to participate in the evaluation and for believing in the technology RubbleViewer might one day bring back to the field.

Lab rats, it was fun to learn how to do research side by side with you. Not only the practical jokes, SOG activities, or stress relieve were fun. Also very interesting were the intelligent discussions. I now know everything about Indonesian family values; fruit salads for lunch; and more. You know I value it.

There are a lot of images in this thesis. Most of them are not mine. Peter Groenewegen, thanks for the first version of the image of the organization chart of usar.nl. Nike, thanks for all the images you took at the exercise in the Czech Republic.

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A strong base of operations is necessary when going on an endeavor like this one. Where “this” refers to live in general. Thank you Marian and Frans for providing such a strong base of operations in all the varying ways you did. Esther je begrijpt dat ik jou niet meer dankbaar ben, je bent een schat :D.

Maarten van Zomeren
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24th June 2009

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1 Introduction

After an earthquake, like the earthquake in central Italy on the 6th of April 2009, there can be a lot of people entombed inside collapsed buildings. The rescue of these victims is the task of highly trained teams, called Urban Search and Rescue (USAR) teams. Victims can only survive for a limited amount of time, so the Search and Rescue (SAR) groups will work round the clock to rescue as much victims in the shortest possible time. Effective around the clock work will result in the rescue of the entombed victims, as the Italian case demonstrates. The rescue workers claimed to have rescued around 100 people (Hooper et al. 2009) and after 42 hours a woman was pulled alive from the rubble (Newton et al. 2009).

The 24-hours operation requires fresh teams to relieve teams that have been operational. This is in order to overcome fatigue mistakes and exhaustion by rescue workers. As the SAR groups operate in collapsed buildings, dangerous enough in itself, in an area where aftershocks might happen. It is crucial to have the team operate safely and fatigue can endanger the team when working for a prolonged time.

The moment a new SAR team relieves the SAR at work, a briefing should communicate enough information in order to have the new team to start working quickly and safely on the rubble. Said differently, the briefing should provide the new SAR group commander a detailed description on the situation, scientifically known as situation awareness (Endsley 1988). Often these briefings occur verbal allowing a SAR team commander to construct a mental representation. However, verbal communication doesn't work in all situations and more complicated situations necessitate additional tools to communicate information such as sketches and drawings.

Currently, there are two different ways to communicate information. The rescue workers can sketch the information on paper. The other way is to use spray paint to paint on the building. This can be done locally on the entrance of a victim to annotate this entrance or to provide overview. Rescue workers are seen to have painted maps on large flat areas **Figure 1-1** and they have painted building summary information on the whole. The sketches and spray painted overviews can be cluttered, as USAR responder Steven Sparks puts it: "Whether the sketches on the forms are useful heavily depends on the one who is drawing these forms."

Figure 1-1 Sample sketch after one SAR groups shift

Field observations have demonstrated that the current way to communicate information does not sufficiently communicate the situation thereby having a commander of a SAR group to reconstruct situation awareness. It has happened for example that the new SAR group commander had to physically crawl on the rubble pile and check every victim himself to understand the situation at hand. This is dangerous and time consuming. The optimization of this process would increases the chance to locate and rescue entombed victims.

The current sketches are a 2d representation, where a 3d representation might have better results. As (Haskell and Wickens 1993) put it in a general way: 3d perspective views lead to better results when "the tasks to be performed using the display are integrated three dimensionally or whenever the method of performing the task with the display bears a strong resemblance to a similar task performed without a display". Additionally according (John et al. 2001) "3d views are useful for shape and layout understanding" and "2d views are useful for judging relative positions".

For building situation awareness in the USAR setting the 3rd dimension is found a useful addition. During the mission shape, layout, and relative positions are necessary. The understanding of relative positions is necessary to understanding the overview of the worksite. Shape and layout understanding is for example necessary to understand the collapse patterns and be able to reason about the best path to a victim as is done in real live without a display. In addition the third dimension is also necessary to visualize information that cannot be visualized in a 2d plan view like elements below other structural elements.

We therefore question:

"How to support a SAR group using 3d mapping techniques for the purpose of (1) communicating information from one SAR group to another SAR group during a change of shift and (2) the internal collaboration of a SAR group on a worksite?"

"Additionally, can the same technology facilitate constructing situation awareness for other disciplines that are useful for the Search and Rescue process, when arriving at the worksite?"

The first part of the question follows directly from the introduction. The second part "How to support a SAR group using 3d mapping techniques for the purpose of the internal collaboration of a SAR group on a worksite?" is relevant because on larger worksites discussion where observed between SAR group members about victim located somewhere on the rubble and ways to rescue these victims. Well designed technology might make these discussions more efficient.

The second question is relevant, because external experts will arrive at the scene to advice the SAR group. Advice can only be given when the situation is fully understood, in other words, these experts need a high level of situation awareness. The SAR group commander might not have sufficient time to verbally explain the situation. In addition, as said earlier, this verbal explanation might not be sufficient.

Both questions are design and evaluation questions. To support a SAR group or other discipline doing something a design has to be made. Without evaluation this design has limited value. Therefore a prototype is created called RubbleViewer. It contains the basic functionality to test the technical feasibility of the design and evaluate requirements with the domain experts. It is intended that someday RubbleViewer gets down and dirty presenting the SAR group an excellent view on the rubble pile and aiding them in building situation awareness as can be seen **in Figure 1-2.**

Figure 1-2 RubbleViewer's intended use image

1.1 Methodology

A lean situated Cognitive Engineering methodology (Neerincx and Lindenberg 2008) was used to answer the research questions. It is an iterative approach developed to create a sound requirements baseline for an application that can be used in the wild **Figure 1-3**. It starts with a Work Domain and Support analysis to gain knowledge about the domain and the human factors where the envisioned technology has to provide support for**.** Secondly from this Work Domain and Support analysis the requirements baseline and rationale is distilled. The third step in the situated Cognitive Engineering methodology is an evaluation of the requirements baseline in two ways, by a prototype evaluation and by usability and domain experts review. The three steps are iterated until the requirements baseline is sound and all the functions are tested with the prototype.

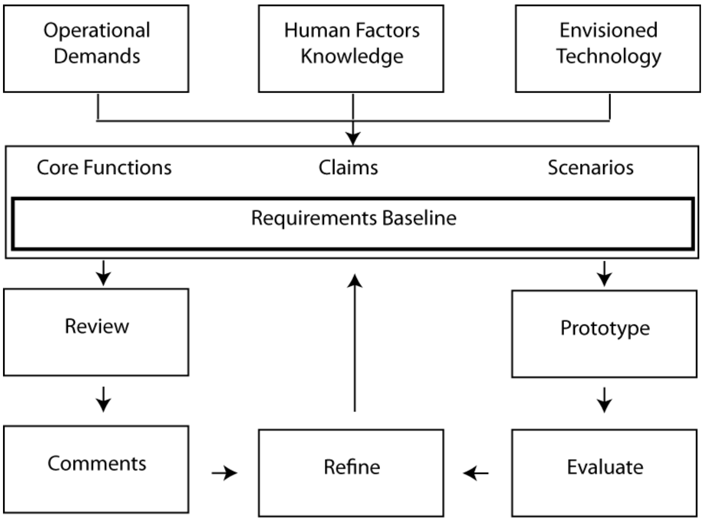


Figure 1-3 situated Cognitive Engineering methodology

(adapted from (Neerincx and Lindenberg 2008) by Tjerk de Greef)

First a very thorough Work Domain and Support analysis is done focusing on how the SAR groups work on their worksite. This is described in chapter 2 Domain Analysis complemented with a brief Human Factors and relevant technology analysis. The second part is the description of the requirements baseline with its rationale in chapter 3 Design**.** As third part the requirements baseline is evaluated with a prototype named RubbleViewer. The development of the prototype is described in chapter 4 Implementation, the test methodology in chapter 5 Test – Expert Review**,** and the results of the test are discussed in chapter 6 Results. A very first design written down in another format is described in Attachment 1: First design RubbleViewer**,** containing a rapid prototype.

1.2 Related Research

Naturally this research builds upon the shoulders of others which is further explained below: Fortunately there is research in 3d modeling from data that is feasible or is becoming feasible to be captured by SAR groups; How this data is to be captured is also an interesting field of research; Robots inside building equipped with laser scanners can provide a view of the internals of the rubble.

There are two ways of trying to create 3d overview models from information that can be captured in the wild. These two options are with photogrammetric technology, and with laser scanning technology. At the moment there is not yet a system that is able to gather laser scanner data in a feasible manner for USAR operations. Because this has to be quick, is performed without a lot of training, and the equipment that is used for it must be light weight. However it is expected to be only a matter of time before someone equips a man packable Small Unmanned Aerial Vehicle (SUAV) with a laser scanner and bring it to a rubble pile. Unfortunately this equipment is not yet available for this research.

The photogrammetric technology where 3d models are constructed out of sufficiently overlapping images is coming out of the laboratories and is finding its use in the wild (Goesele et al. 2007). There is a gap in the current research body. There is no research known that feasibly has constructed a 3d map with photogrammetric or laser scanning devices and evaluated its use with USAR responders in a task setting designed for real use.

In December 2007 the Berkman II Plaza garage place collapsed, the following structural inspection mission was performed with a Small Unmanned Aerial System (SUAS) (Pratt et al. 2008). Unfortunately the collapse claimed one live of a construction worker. After the USAR effort there was a need for a structural inspection mission to try to determine who was guilty of the collapse of the building. There was a need for plan images for the forensic investigation and to document the state of the collapse prior to the removal of rubble. For this mission dr. Robin Murphy and her team flew a SUAS to take pictures of the rubble pile. The system used was a tethered iSensys IP3 miniature helicopter.

Apart from the interesting Human Robot Interaction results, this work also resulted in the quest for another way to visualize the images. The structural engineers requested for a better visualization system for interpreting the images. There was a need for an overview of the collapsed area with the high resolution images to be displayed on demand. In another study (Murphy et al. 2008), there was also a request for an overall context of the structure in relation to the images taken with an UAV. This research provides such a view.

It has been found difficult to estimate the location of a robot searching for a victim in a rubble pile. This information is vital for determining the most efficient route to the victim once found. At the time the only source of information was the camera view and the distance the robot had traveled. (Ohno and Tadokoro 2005) proposed a robot laser scanner to create a 3d map of the surroundings of the robot. In the future a good overview 3d map of the rubble pile with the local robot sensor information registered to it is expected to help the responders in more effectively locate the robot and thus the victim that has been found.

2 Domain Analysis

This study applies the situated Cognitive Engineering methodology to establish a requirements basline for a RubbleViewer. Consequently this study requires an extensive analysis of the urban search and rescue domain. This chapter follows the international guidelines created by the International Search and Rescue Advisory Group (INSARAG) (OCHA 2006) in the light of the Dutch USAR team usar.nl {Bovens, 2002 #9}. We used the People (2.1), Activities (2.2), Context (2.3) Technology (2.4) (PACT) model to describe the domain extended with information about Human Factors as this is currently not embedded in the PACT model. The information that is currently known relevant to RubbleViewer is described with this methodology. Throughout the chapter the relevant implications for RubbleViewer are described in a blue italic.

The domain analysis is based on a literature review and two visit to a field exercise of usar.nl that lead to the discovery of more practical implications. It is the author's view that without contact with the domain experts it is not possible to design for them. Every year a full USAR team (see section 2.3.2 for a description) is going on an international exercise. This exercise covers the whole spectrum of an USAR team's task, from logistics, contact with local people till the actual Search and Rescue activities on a "fake" collapsed building. The first exercise entailed a two day visit starting at 27th may 2008 in the Check Republic and the second exercise entailed observations lasting eight days during an exercise in the Dubai region starting the 12th of May 2009.

During the first visit we stayed in a hotel near the usar.nl base camp. The visit started with an informal tour on the base camp and the different worksites. After this tour the researchers were set free to investigate at their own interest. The two different main interests where

- Worksite activities. How do the Search and Rescue SAR groups really work on an actual worksite when they are locating and rescuing a victim?
- Management. How is the information processed throughout the organization?

These interests where observed with a natural history methodology.

During the second visit the researchers were embedded in the usar.nl team. This trip was on request of usar.nl the team and had three specific purposes:

- Management. How is the information processed throughout the organization? How are decisions made?
- Physiology: What is the impact of the climate on the team? This was focused on the heat in Dubai.
- RubbleViewer's expert review: Does the prototype created in this study answer the main research question?

2.1 People

In this section the intended user group of RubbleViewer is described. Designs are always meant to be used by someone. The designs must fit these users and the needs these users have, to be user friendly and relevant at all. So if a design is meant to be user friendly and relevant for the users then it is important to describe the users thoroughly. The main user groups are the members of the SAR groups see (Figure 2-1). They are the people who get their hands dirty and do the actual search and rescue task and who directly support the SAR group on the worksite. As written before this is specifically written for the case of usar.nl.

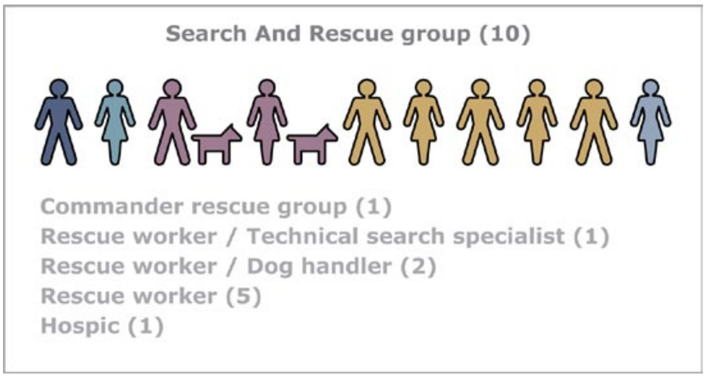


Figure 2-1 Search and Rescue personnel

These SAR group consists of ten people from different emergency services. Specialized expert knowledge can be “flown in” if necessary. Every person in a SAR group has the basic USAR training and has the same health requirements as fire men. USAR training also promotes team members to teach each other their specific skill set. So that the team as a union is more resilient and people understand the difficulties other face.

The core of a SAR group are the five rescue workers, they do the hard rescue work. The people specialized for the search are the two dog handlers and the technical search specialist. For the health of the rescue personnel and the victims is the hospic responsible. Ultimately responsible and person in charge is the commander of the rescue group. (Bovens et al. 2002) These experts and skill types are described below in more detail.

The rescue workers are the backbone for every SAR group. They are the primary people who do the hard work; they handle the heavy equipment to breach the reinforced concrete walls. They will carry the victims of the rubble pile with a brancard to the place where all the victims are gathered, in addition they will coach local residents or local contractors on how to be of assistance to the USAR mission.

Rescue workers are drafted from within the fire department. Because the USAR mission will be in very difficult circumstances, these people have to be seasoned and probably are instructors or commanders in their daily job. Safety is a factor that is always important during USAR missions. As seasoned responders they will mind their own and others safety. If it is necessary they can assist the medic with basic live support knowledge. It is expected of the team members to be able to work in a different culture.

Figure 2-2 Dog handler

Rescue workers will probably use RubbleViewer to obtain information about a victim they are going to rescue. It might be the case that they add progress information about this specific rescue effort. Getting an overview of what is happening at different locations is not really important for them.

One of the two specialism’s that are in charge of finding the victims are the dog handlers (Figure 2-2) and the second is the search specialist. Each team brings at least two dog handlers and two dogs with them to the collapsed building. This is important, because if one dog finds a victim, the other dog has to confirm the existence of a victim in the rubble pile (see section 2.4.1). The dog handler's primary task is to assess whether there are victims somewhere underneath the rubble pile with the use of their dog. For this reason they have to understand the subtle signs a dog provides the handler.

Drafted from the police corps these police officers work with their dogs at a daily basis. It is important that they are in charge of the dog at all times. During transportation, when the dog is ill or had an accident, when the dog needs food, or just want to play the dog handler is the person to take care of it.

The technical search specialist is the other specialism in charge of finding victims. Recruited from the fire department these persons are technical specialists and will work with the more advanced search equipment like search cams and microphones (see section 2.4.1). As a victim localization expert these people advice the commander of the rescue group on the mission strategy and the possible locations where victims are expected to be. Once a victim is found the search specialist will mark this on the rubble pile (as is described in section 2.4.2). Another task for this person is to try to repair the equipment that breaks on the scene.

Both the dog handlers and the search specialist are in charge of the search part of the mission. They will be the first people who know about the victim's exact location. They will probably enter this information in RubbleViewer. It is important for both specialists to have an overview of all victims. It might be the case that the search equipment and the dog behave differently when there are more victims around. This overview is also important when they are going to advice the SAR commander about how to handle this situation. The fresh search specialists and dog handlers need to know where there was already searched when they are to relieve another SAR group. Especially when the search is not already done they need information the search sensors had already provided the old team.

One of the most important things for usar.nl is that all personnel returns safely after a mission. The primary task for the medic, drafted from the ambulance system in the Netherlands, is to take care of the medical needs of the members of the SAR team. The health of the victim of the collapse, and possible other victims' health is of secondary importance. Normally the health issues of the SAR personnel are restricted to stress and fatigue. So most of the time is spent with the health of the victims of the collapse. To say the least those people really need them. After a structural element is lifted of the body of the victim, the victim only has one golden hour to make it to a hospital or die anyway. Reality…

So the task of a hospic is really important and difficult. Usar.nl will take care of the victim until handed over to the local medical system and brought to the hospital. This means the victim must be stabilized as good as possible. There can be multiple victims in one worksite, so the hospic has to help each victim in turn and help the SAR commander triage the victims.

To be able to circulate the victims the medic needs an overview of all their locations. RubbleViewer must provide this. It is vital for a fresh medic that relieves the tired one that they know the medical situation of all the victims. Also information about the medicines that are already administered is important for the medic.

The person in charge of the USAR mission at the local worksite is the commander rescue group, or SAR commander. This person is an officer in the fire department and is in charge of repressing semi big fires. All the other specialisms will support the SAR commander for their specific task. But the SAR commander is responsible in the end. Safety of the team and the bystanders is the highest priority. With this constraint the SAR commander has to decide what the best strategy is to rescue the most live victims and monitor the progress.

Communication is also the responsibility of the SAR commander. There is a need to communicate with higher command, to arrange the relief and possibly the things or people they need at the moment. Situation reports help higher command to plan this. Communication is also necessary with the local emergency management authorities (LEMA) for example to arrange ambulances for the victims. It is important that different SAR groups when working after each other get briefed correctly. This is done with mapping techniques (see section 2.4.2). These maps are also used in the logging of the mission for the debriefing.

The SAR commander is in charge of everything that happens on the worksite and the communication. This makes him or her also responsible for the information in RubbleViewer. This person will not turn to RubbleViewer to get an overview of the situation. Having this overview is his job. Unless there is a new SAR team that needs to get the overview. At that moment RubbleViewer can be vital for the SAR commander. Apart from the overview the SAR commander also have to decide on how to rescue the specific victims. So he needs a quick detailed look on each victim. This can be provided by the search specialist and dog handlers. For triage purposes there needs to be medical information with each victim.

There are two experts in the USAR team who can assist the SAR groups when necessary. The structural specialist and safety officer are both important for the safety of the SAR group. They will travel independently from the rest of SAR team. This traveling from SAR group to SAR group might take fast amount of time.

The structural specialist helps the SAR group in assessing the stability of the building. This is an important factor in the strategy on how the rescue the victim. For example one does not want to make a hole in a supporting structural element causing a further collapse. This is micro evaluation, but it is also important for the structural specialist to obtain a broader view. To assess whether parts of the building are safe enough to work in or and need further shoring. This information can be annotated on the building.

Since the structural specialist will probably not arrive together with the SAR group, RubbleViewer will need to provide the building expert with the possibility to quickly obtain situation awareness. Pictures from above the worksite will help the building expert build situation awareness. An UAV can provide this imagery. RubbleViewer must present these images in such a way that the detail imagery is displayed relative to the overview (Pratt et al. 2008). Since the structural specialist will normally mark the building about stability factors, it is expected that he or she can add information about this to RubbleViewer. One can think of no go areas.

The other expert assisting expert is the safety officer. This person is responsible for the safety of the USAR team in the broadest sense. Examples are safety during transport, safety of the base camp, and hazardous materials. For the SAR team this person will be of assistance when there are hazardous materials in play. The safety officer can measure the quantities of these materials and find a way to remove the threat. Or help design a rescue plan that minimizes the risk.

When something might happen the safety officer is also the person who registers the accident and will develop measures to prevent the same accident from happening again. The safety officer also has the power and duty to stop the USAR activities and evacuate the work site.

The safety officer once arriving at the scene needs to build situation awareness quickly. Doing this with RubbleViewer will not bother the team with their current activities. The safety officer can help the team create evacuation plans and possibly add them to RubbleViewer. No Go areas can also be added by the safety officer.

It is expected that the majority of the USAR responders are novice computer users. They are not expected to be used to 3d computer environments. It is expected though that they have experience with word processing and internet browsing. Especially the SAR group commanders, because they are expected to have completed a Higher Vocational Education. However, performing 3d modeling tasks will be out of reach for them.

2.2 Activities

The task that RubbleViewer will support is the communication of Situation Awareness from one SAR group to the other. This section describes how Situation Awareness is communicated while they are performing they work to reach their goal.
The goal of the SAR groups is to search and rescue victims from underneath a collapsed building in a reasonably safe manner. The USAR task is a task which is fundamentally different from the normal activities of the firemen. Normally firemen would rush to a scene and do a very quick assessment and save the people as quickly as possible. During a USAR mission the building is already collapsed and the people in it are there for at least a few hours, so considered stable. Time is of the essence though, but it is more important to prevent more accidents to happen. Locating the victims and rescuing them is a task that takes from 4 to 20 man hours to complete.

The activities are divided into 5 phases by the search and rescue community(OCHA 2006). Important to notice is that the building must be stabilized or found reasonably safe before any person or animal from the USAR team enters or walks on top of the building. These activities are described for the usar.nl case.

There can be important activities worth stopping what the person was doing at the moment. The medic for example can be needed immediately. The search specialist can be called to immediately help with a search cam.

The person who is working with RubbleViewer at the moment might suddenly do something completely different. RubbleViewer must be designed for this flexibility.

Phase 1: Reconnaissance
On arrival in a large disaster area the USAR.NL team decides whether a reconnaissance team is to be dispatched. The goal of this team is to perform triage on the whole area which has been assigned to usar.nl and communicate this with the first commander. Important aspects are the amount of victims who can be in the collapsed building, the structural integrity of the building (for safety reasons) and the presence of hazardous materials. Of course there is a need to communicate this efficiently. For this reason the reconnaissance team either starts compiling a map of the entire disaster site with multiple worksites or adds information to a map that already exists. In the end of this phase an action plan is made. It is possible that victims are found immediately on arrival in the disaster area. The reconnaissance team will determine whether there is an immediate need for help and communicate this to higher command.

Whether there are victims buried in an area is the most important information for the SAR groups. When there are dogs present in the reconnaissance team they can be utilized to search large areas for victims. It is also possible to estimate the number of victims in a collapsed building according to information about the use of the building and common sense. Victim survivability is also necessary information for performing triage. The bigger the empty spaces in the collapsed building, or voids, are the higher is the chance the victim has survived the initial collapse.

After information about the number of victims is known it is important to know whether it is safe to perform the actual search and hopefully rescue. An important aspect in this is whether the structural integrity is sufficient especially when there is heavy equipment needed to free the victim. Other important aspects are the possibility of leaking hazardous materials or fire. Each of these aspects can lead to a no go decision. It is necessary that this decision is done by two persons separately and that the decision is reevaluated when the situation changes.

The scope of this phase is over multiple worksites or rubble piles. RubbleViewer is designed for a view of one specific worksite. It is possible though that if it is decided that a worksite will probably be visited by a SAR group that the reconnaissance team starts to create a map with RubbleViewer, otherwise this has to be done in Phase 2.

Phase 2: Rescue easy accessible and visible victims
Once it is decided that a SAR group will work on a certain worksite they will first rescue easy accessible and visible victims if the local residents did not already do this. This is the phase where the rescue personal itself can become a victim, because collapsed buildings which seem to have sufficient integrity might not have. So stabilizing the building if necessary is vital. The surface of the building is searched thoroughly and victims which are easily accessible are rescued. These victims often do not need immediate medical care.

The safety aspects will be communicated to the whole team. These situations where the SAR group commander briefs the rest of the SAR group will be done verbally perhaps supported by sketches on paper.

This is the phase where there can be image acquisition for RubbleViewer, when the worksite is so large that good maps are necessary. A UAV can be flown over the area and take pictures from varies angles and positions.

Phase 3: Search in accessible spaces (Figure 2-3)
This is the most difficult search phase, where the victims are found deep inside the building. There are lots of techniques used in this phase, which will be discussed in a separate section (2.4.1). Personnel of usar.nl make use of search dogs, cameras on sticks or on fiberglass. It is also possible for the personnel to physically crawl into the building. Only highly trained personnel may perform this type of search.

Figure 2-3 Search in accesible spaces with Search Cam

In this phase there is no help from locals allowed, because it is so important to search thoroughly and the locals won't be able to use the specialized equipment. When a living victim is found the place will be marked and part of the team moves on to the next phase while the rest keeps on looking for more victims.

If a victim is found then the SAR group will use spray paint to annotate these findings on the building itself. It is possible that the SAR group commander will annotate the finding spot on a sketch or drawing on the wall. There is no route to a victim described at the moment. Someone who is going to rescue a victim will get direct orders from the SAR group commander where to drill. These orders are probably given after a brief discussion with the whole group about the best way to rescue a victim. The information necessary for the discussion is communicated verbally supported by sketches if necessary.

It is expected that during this phase there is information added about victims, health status and possible routes that can be used for the rescue. RubbleViewer can be used as a discussion tool for the decision process on how to continue the mission. If RubbleViewer is to assist for team changes during the search part of the mission, then RubbleViewer must also keep track of what the search sensors have told their operators.

Phase 4: Rescue obstructed victims
In this phase the actual rescue takes place. It can last from two hours to approximately a full day. The amount of time needed for the rescue depends on how deep the victim is located and how well the victim is connected to the outside world with voids or empty spaces. For the voids it is important to know the exact location of the victim and how the building collapsed. In this phase the team will make use of their special search equipment. The removal of debris can be done with heavy equipment, man power, and whatever is available to the team. The team will circulate through its people every 20 minutes or so, since this work is very hard. The responders who are not digging at the moment take their deserved rest. The locals can also help during this phase. Naturally the overview of all the effort is a responsibility of the SAR group commander.

As safety is an important factor during every phase of the USAR mission it is also important during this phase. The structure has to be sufficiently stable so it won't just collapse further. One should watch out for aftershocks. Naturally it is import not to cut through supporting structural elements or support them sufficiently. Once every victim is rescued or the chances of saving live victims are diminished the team moves on to phase five.

The progress off the rescue is communicated vocally to the SAR group commander.

Every now and then the SAR group members discuss on how to continue their mission. RubbleViewer can assist in there discussion by providing an overview of the victims and safety information. RubbleViewer should also support the responders when the focus is just one victim. RubbleViewer must provide the responders with a way to annotate and view the best way to rescue that specific victim. On team change RubbleViewer should supply the new team with both perspectives. The detailed victim view will provide the fresh team with the knowledge on how to perform the rescue.

Phase 5: Clean up
The removal of debris is done after all the victims are rescued or they are deceased. This is not a primary responsibility for usar.nl. Phase 5 is even removed in the new handbooks. There have been occasions though where usar.nl has helped the local residents with excavating deceased victims.

2.2.1 FEMA

The teams from the Federal Emergency Management Authority (FEMA) in the USA work differently in a number of ways than the INSARAG teams. It is of importance to know that the FEMA teams have a structure where the search part of the USAR teams work separately from the rescue part of the USAR team. This means that a good mapping of where the victims are is more important than for usar.nl where those parts of the team are in one SAR group. The way FEMA teams map the rubble piles is also different than how the INSARAG teams do it (see section 2.4.2).

If RubbleViewer is to be used by FEMA and INSARAG teams than RubbleViewer must support the different ways of mapping for these teams. However mixing these ways of mapping can lead to unnecessary casualties, as is described in section (2.4.2).

2.3 Context

The SAR groups where RubbleViewer is developed for is not a standalone group of people there are other people that support their work. If there is a disaster where international aid is requested then the international teams like usar.nl (2.3.2) are coordinated by international actors (2.3.1). This coordination is on the level of getting the right people at the right place. The right place is the worksite where they can save as much victims as possible and is described at (2.3.3).

2.3.1 (International) Actors

Urban Search and Rescue is performed by specially trained teams after a disaster. Disasters can be of the scale of one collapsed building or a whole country that is affected. The big international teams, like usar.nl, will only assist another country when that country has asked the UN for international help. This is because ultimately the inflicted countries local emergency management authority (LEMA) is in charge of the disaster relief activities. The inflicted country is probably depleted of resources like food and man power to coordinate the international aid. There will be chaos and lootings. The incoming aid has to cope with this. The incoming aid also has to respect the cultural values of the inflicted country.

The international authority is the UN OCHA. This organization is mandated to coordinate international assistance in disasters and humanitarian crises exceeding the capacity of the affected country. The UN OCHA works with lots of organizations and tries to use the international organizations as well as possible. The UN OCHA sends a team of emergency management specialists, the United Nations Disaster Assessment and Coordination team (UNDAC team). This team assists the LEMA with the coordination of the international response. For the assessment of priority and information management the UNDAC team sets up an On-Site Operations Coordination Centre (OSOCC). In this centre the actions between the different teams and agencies are coordinated. There is also a Virtual OSOCC (vOSOCC) to coordinate between the affected country and the responders before they have arrived in the affected country.

Teams and agencies which can be coordinated by the UNDAC team can be (OCHA 2006a):

- USAR teams (rescue people from collapsed buildings)
- UNICEF (protect children and women)
- UNDP (strengthen risk management and support post disaster recovery)
- UNHCR (survival of refugees)
- WFP (provide food)
- WHO (health matters)
- Red Cross and Red Crescent (health matters)
- The Army
- Etc.

Above are the organizations described who try to help. There are also other actors. The victims are of course the most important group. They can be entombed in buildings or be wounded. There is also a large group of residents who are not harmed by the disaster directly, but can get injured because of the aftermath of the disaster. Another important group is the press, from the inflicted country or countries the international response came from.

2.3.2 usar.nl

A SAR group is a part of a larger USAR team see Figure 2-1**.** The USAR team's purpose is to get the SAR groups at the worksite as efficiently as possible. The USAR team will communicate with the LEMA, help with logistics, provide a good base camp, and take care of health issues of the team members. The SAR groups operate with a spatial distance with the staff and probably experts where they need information from. There is a temporal distance to other SAR groups that will or have relieved them.

Command Group:
This group consists of a commander and the substitute commander. They are responsible for leading the entire operation. The contact with the media and writing combined situation reports for the people left at home and the Country Operational Team (COT).

Four SAR groups:
These groups are responsible for the actual Search and Rescue and need to be supported by the other groups as well as possible. These groups should be self supporting, because they can be far apart from each other and the base camp. So they need to bring their own equipment and medical personnel. Some team members have an additional specialty. One team member is a technical searcher and two team members are dog handlers. (Bovens et al. 2002).

Staff group:
The staff group of USAR.NL supports the Command group with the administration, the contact with other organizations, the gathering of information and the control of the base camp. The SAR groups are also supported by the staff group for example with medical problems, structural evaluation and safety issues.

Support group:
Next to the staff group is the support group, its main goal is to take care of the equipment, the food, the transport means and the base camp.

Quartermaster – group:
This group consists of team members from the other groups. It is the first group to leave to the disaster area and will try to smooth the arrival of the other groups. So contact other organizations, setting up a base camp and when possible do a triage of the designated disaster area (see section 2.2)

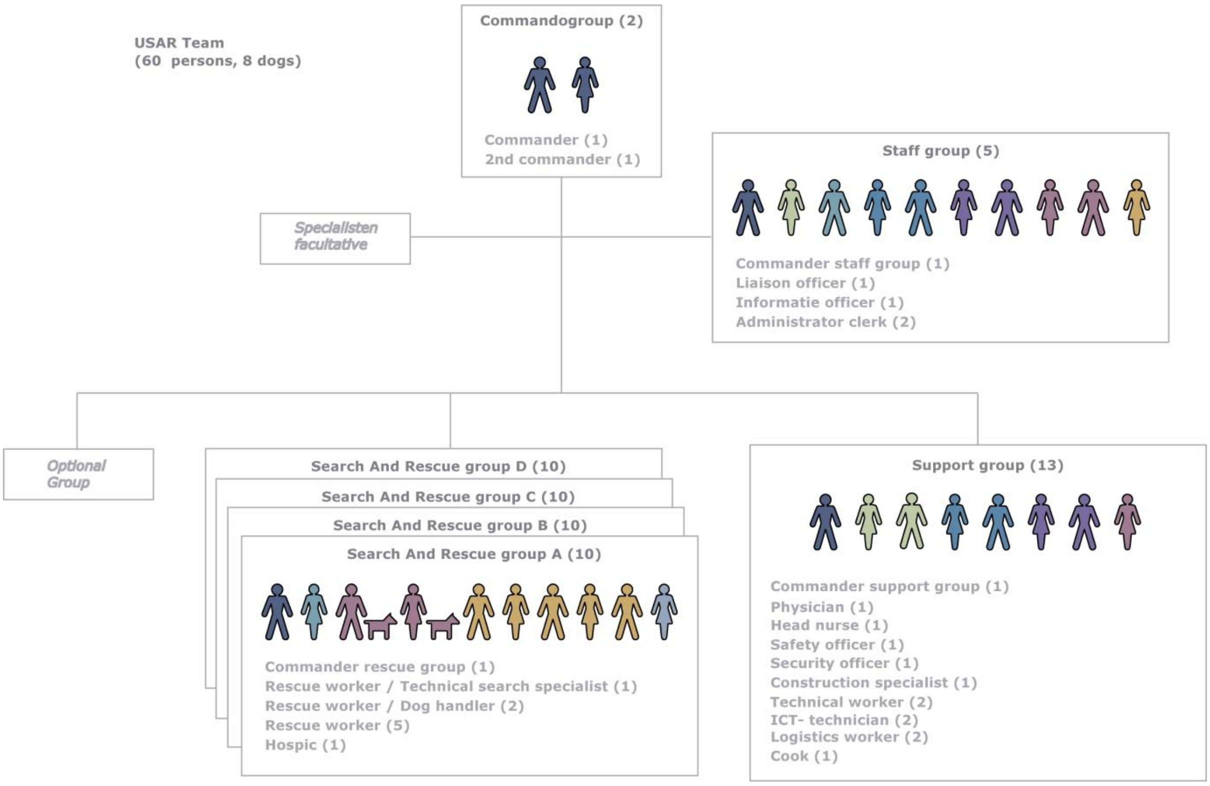


Figure 2-4 usar.nl organization chart

If RubbleViewer is to support for expert reachback, then RubbleViewer will be the sole source where situation awareness has to be build upon. A type of expert reachback can be the structural specialist. In the case expert reachback is used the information in RubbleViewer must be accurate and exactly enough to support that type of reachback.

2.3.3 Worksites

The context of the USAR domain is very dangerous and asks for a quick responsive action. It has a high consequence of error and the USAR personal is probably sleep deprecated during the mission. Buildings can collapse further because of aftershocks or without an apparent reason. The surface is dangerous to walk on. There are hazardous materials like gas leaks. There can be fires within the building. Coping with the dangers is in conflict with the need for a speedy rescue. Since the first 72 hours are critical for the rescue of the victims. The percentage of victims that survive the collapse decreases rapidly as is illustrated in Figure 2-5. But the safety of the USAR team members is even more important.

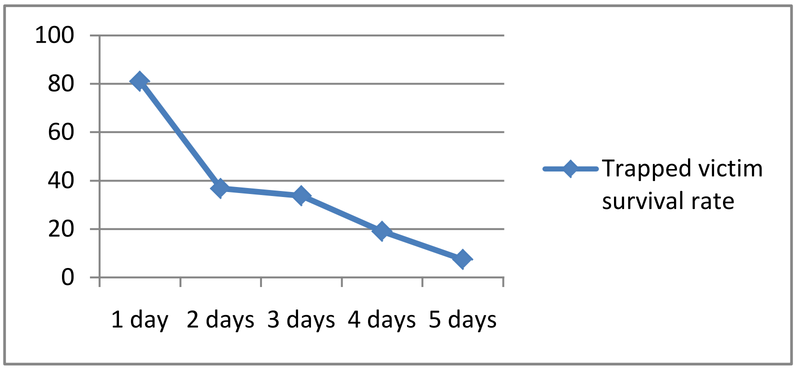


Figure 2-5 Trapped victim survival rate. (Murphy et al. 2001)

The set up of RubbleViewer must be reasonably fast and easy, since time is on the essence and the SAR group members are expected to be tired. The SAR group won't spend a day mapping the worksite or disaster area and then start their search and rescue effort.

There has been research on building collapses and it has been found that buildings often collapse in a pattern (Schweier and Markus 2004; Schweier and Markus 2006). This provides useful information in the planning process. The patterns are also described on the void level. This helps the SAR group on deciding where to look for victims first.

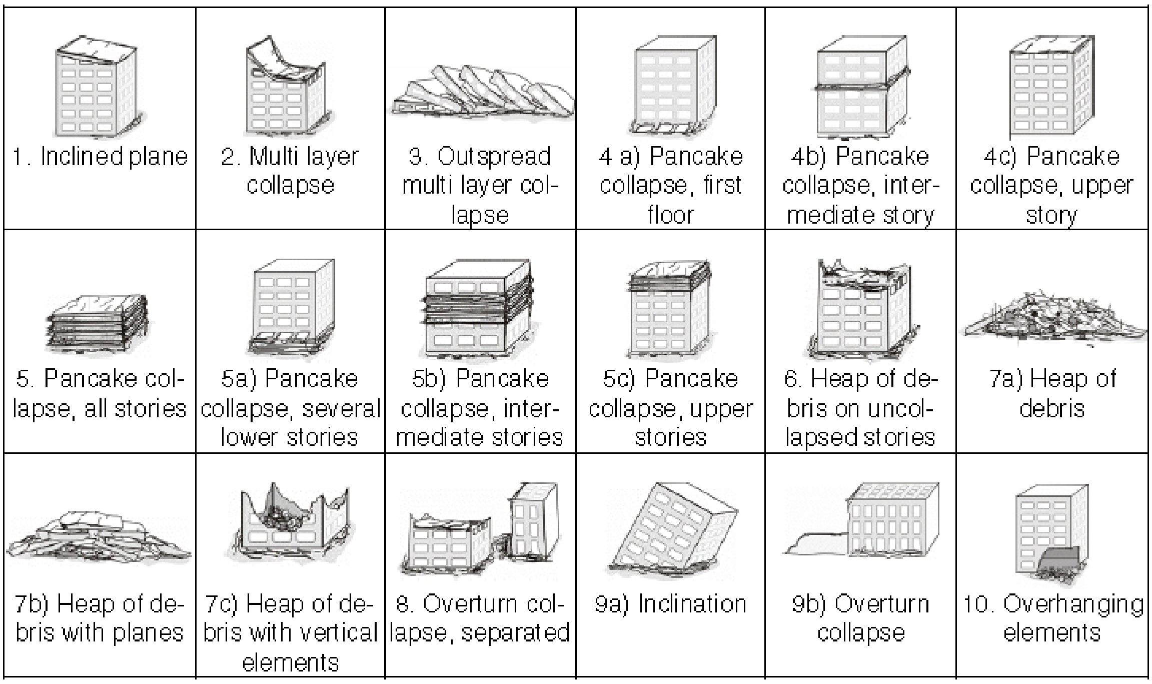


Figure 2-6 Compilation of damage types (Schweier and Markus 2004)

When it is known which collapse pattern see Figure 2-6 has occurred at a certain location it is possible to estimate a number of variables (Schweier and Markus 2004). The estimated amount of man-hours needed to save a trapped victim can be estimated. Trapped victims are divided into two kinds, the heavily entombed victims and the light entombed victims. Depending on the collapse pattern the estimated time to save a heavy entombed victim is varying between two and 20 hours. For light trapped victims the amount of man hours to rescue a victim is varying between 12 minutes and eight hours. The percentage of heavily entombed victims is depending on the volume reduction per floor and whether the building is used commercially or residentially. This is useful information for the planning process in the aftermath of an earthquake.

If a RubbleViewer is to be successful, then RubbleViewer must work in all situations a SAR group can encounter. Otherwise it is expected that the SAR groups won't use it all, it needs to be there when they need it. So RubbleViewer must support at least all the collapse patterns described in Figure 2-6 .

Another way of describing collapse patterns is to describe them on a smaller level, the level on which voids can be identified. (Murphy et al. 2001) (EMA 2006). It is possible that different collapse patterns are found in a collapsed building. In the image below are the possible voids marked with yellow. These spaces should have a search priority for search and rescue personnel, because that is the location where victims can be found. The bigger the voids are the larger is the chance that the entombed victim will survive the collapse. The path taken by the rescue people will also go through the voids if possible, going trough voids is easier than digging trough structural elements.

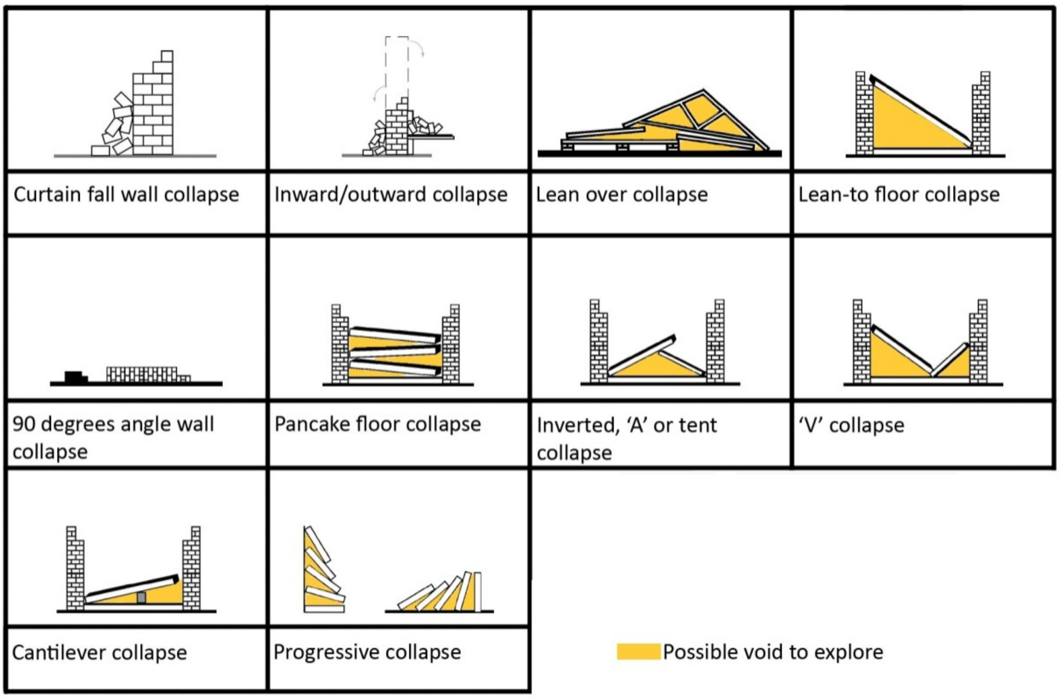


Figure 2-7 Compilation of different collapse patterns with void information (EMA 2006), altered by the author.

If these voids can be mapped than that will be a good source of information for the SAR groups.

2.4 Technologies

In this section there are two different types of technologies described, the technologies currently being used by the SAR groups and the technology that might provide a base to build RubbleViewer on. The SAR groups use USAR search equipment and tools (2.4.1). Search and other information is communicated with maps (2.4.2).

Technology that is described for possible base to build RubbleViewer from are photogrammetry (2.4.3), the possibility of downloading pre disaster models from the internet (2.4.4), laser scanning (2.4.5) and sketch technology (2.4.6). The review of these models is done in chapter 3 Design.

2.4.1 USAR search equipment and methods

While searching for victims a lot of senses will be used. One can smell, see, hear and possibly feel a victim. But the human senses are often not good enough and need to be augmented by technology or animals. Our sense of smell is not good enough to find living victims in the rubble. A dog can do just that and is often used in USAR activities (2.4.1.1). Our sight is good enough to see victims situated on top of the rubble, but to see in the rubble technology must be used. Pole mounted camera's are used to look under the rubble (2.4.1.2). Robots can be used to extend our sight even further and perhaps use other sensors to collect information (2.4.1.4). The best upgrade of our sight can be the through the wall radar (2.4.1.5). To upgrade our audition special microphones can be used. Equipment that feels vibrations and is able to sense victims over larger victims are seismic devices (2.4.1.3). All these techniques are used while trying to grasp what is going on under the rubble. So the USAR teams are trying to build situation awareness (2.5.1).

2.4.1.1 Dogs

The sense of smell of dogs is estimated to be between hundreds and hundreds of thousands better than human sense of smell. This makes a canine very capable of searching scent. The scent of living beings is for the USAR role very important. A canine can be trained to detect this scent. The distance a dog can smell a victim is said to ranges from 400 meters (Pritchard 2008) to 0,3 meters (Murphy 2003). Important factors which determine the distance scent can flow are explained in scent theory.

Dogs are used to search large area's quickly {Bovens, 2002 #9} for example during the triage process and while searching for heavily entombed victims (Nuttall 2008). A dog is able to find unconscious victims. Unfortunately a dog is not infallible. A dog can be distracted by for example another rescue worker's scent. The quality of the search also depends on the handler's ability to interpret the information the dog is providing. To overcome these problems dogs always work in teams of two, where the other dog can serve as a second opinion for the first one.

There are roughly two ways a dog can search: free search and systematic or grid search. With free search the dog can search on its own, without the guidance of the dog handler. The dog handler can take over the search when the dog starts to request assistance. Systematic search is there to search an area quickly and efficiently. The handler can direct the dog over a pattern with its hands and body language.

Dogs are living beings, require rest and can get injured. Every 24 hours a dog requires a minimum of 6 hours undisturbed rest. A dog can work for a maximum of 20 to 30 minutes at a collapsed structure. Unfortunately the collapsed structures contain sharp objects which can hurt the paws of dogs. Hazardous materials can also reduce the sensing capabilities of the canine.

For a canine to detect a human the scent of the human must be at a place the dog can reach. In a building the scent chooses the path of least resistance (Nuttall 2008). So the place where the scent is picked up by the canine does not have to be the location where the victim is.

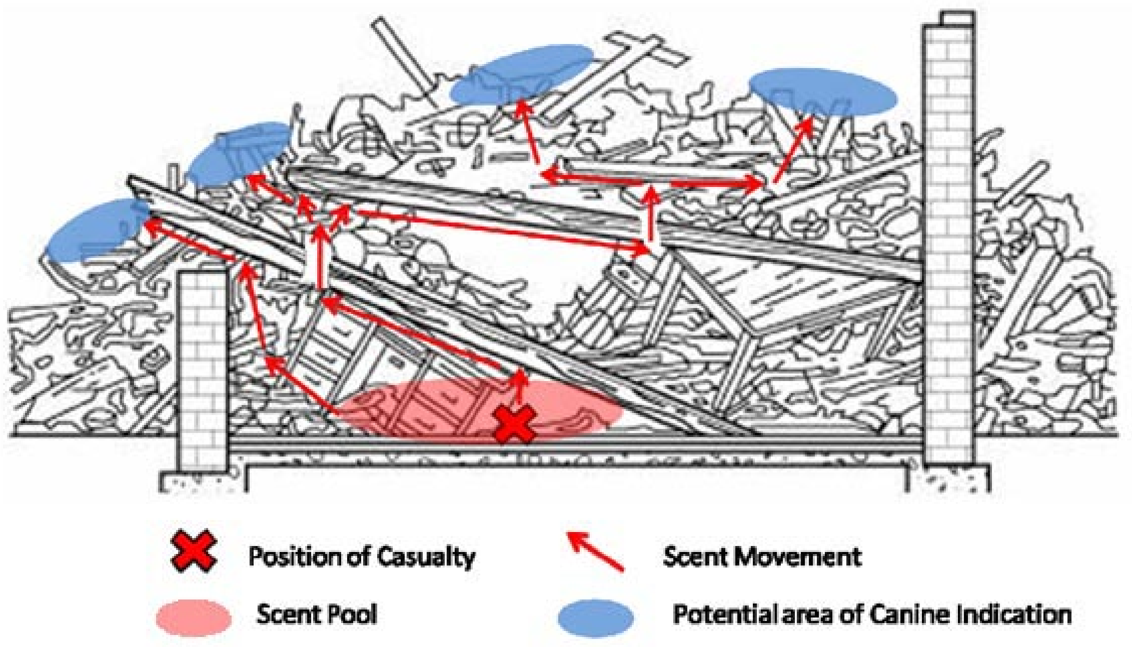


Figure 2-8 Example of scent dispersal within a collapsed structure (Nuttall 2008).

The environment can affect the flow of air and thus the location the scent can be picked up by the dog. Important factors are:

- High temperature causes air to rise where cold temperature let the air sink.
- Pressure differences causes wind and thus scent transportation.
- Wind can cause wind shadows where a pool of scent can form.

The topography of the collapsed buildings can also be a large factor of scent transportation. Scent can get trapped in the building or flow along paths for example created by concrete slabs.

2.4.1.2 Pole mounted camera

Vision is an important modality in search and rescue activities. When a victim is visually identified there is no doubt left there is a victim at that precise location {Bovens, 2002 #9}. The problem with vision is that it is not possible to see underneath the rubble. A technology that improves this vision is the Pole Mounted Camera. This makes it possible to drill small holes in the rubble and see behind it (Figure 2-10) (FEMA 1999).

The pole camera is used for a variety of reasons. For example when it is known there is a victim the camera is used for precise location, so the rescue team does not drill into the victim. It is also used to communicate with the victim with the microphone and speaker. This is important, because the status of the victim can be evaluated with sound.

Search Systems incorporated is a supplier of such systems (Search_Systems). Search System's "SearchCam 2000 VLS" will be discussed here. It does not only supply the Search Specialist with color vision, but also with hearing capacities underneath the rubble.

The SearchCam 2000 VLS can be inserted in a hole with a diameter of 4.4 cm and has a length up to 234 cm. The camera head has an articulation travel of 180 degrees from left to right. This is controlled in the pistol grip and the articulation is shown in the screen. The camera has a viewing distance of 15 cm to 6 meter and a view angle of 235 degrees (Figure 2-9). This is including the articulation angle. So the camera itself has an angle of 55 degrees. The screen size of the system is 5 inch.

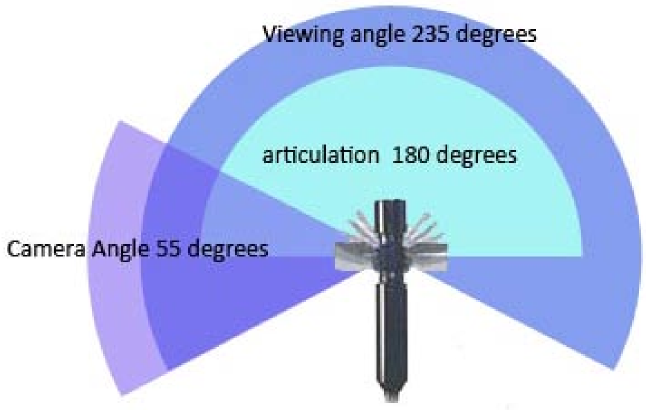


Figure 2-9 SearchCam 2000 VLS viewing angle

Figure 2-10 Video footage of victim by a SearchCam of USAR.NL (RTL_Nieuws 2008)

2.4.1.3 Listen / seismic device

To locate the victim by means of sound or vibrations there is equipment to listen very carefully to the faint noises a victim can produce (FEMA 1999). This equipment usually consists of multiple sensors. It should be possible to switch between sensors to assess which sensor has the highest gain. This sensor with the highest gain will probably be located closest to the victim. It is possible to locate the victim by relocating the sensors around the sensor with the highest gain. The sensors are placed on larger structural parts, because they are the most likely to serve as a good medium for sound. It is advised not to place the sensors according a theoretical search pattern, because it is most important to listen on these large structural elements.

To be able to pickup sounds of a victim, the victim should be making them and thus be conscious. The victim can be asked to make repetitive sounds with the use of a bull horn. While listening the whole rescue area must be quiet, so the amount of noise is minimized. Because of the noise in the sensor output and the difficulty in interpreting this results there is a need for a second opinion while localizing the victim. So the technical search specialists must work in pairs on this device.

Noise is a drawback for this device. The USAR teams have sound signals to ask for silence on the worksite (OCHA 2006). Even with this silence noise from heavy equipment in nearby areas may interfere with the search results. The microphones where not used in all the exercises the author has been, because of this limitation.

2.4.1.4 Robots

There is a lot of research going on to support Urban Search and Rescue teams with robot capabilities. USAR is chosen as domain for the robot research, because it is a challenge in multiple ways. The environment is unpredictable and unstable. It is not possible for a human to reach places a robot can reach. This is because of the size of a human and the possibility of hazards. So the robot serves as an extension of the human. It is still difficult to operate a robot, which makes Human Robot Interaction (HRI) a challenging field (Murphy and Burke 2005). Also interesting is the new robot propulsion techniques that are invented.

So a robot can be steered to places a human cannot come. But what can it do there? It can bring sensors into the rubble where other devices cannot come. And so collect information over for example hazardous materials or victim location. Once a victim is found it can do Robot-Assisted Medical Reachback (RAMR) (Murphy et al. 2004). It is also possible to use robots to automatically stabilize a building, by bringing shoring equipment to certain places.

It is possible to let a robot perform some medical actions, where it is not possible for a paramedic to reach the victim (RAMR). All the robots created by the Center for Robot Assisted Search and Rescue (CRASAR) are capable of two way audio. So it is possible to assess whether the victim is conscious and talk with him or her. This is important for the triage process. There are robot sensors to measure CO_2 differences around a victim to conclude whether the victim is breathing and thus alive. It is also possible to let a robot bring supplies to a victim. These supplies must be transported in tubes. So it is possible to bring fluids (food or drinks) or gasses (air).

A robot can be used as an extension of a pole mounted camera(Casper and Murphy 2003). So it is possible to see where a human cannot see. The range of robot is much further than the 2.35 meters a pole mounted camera can reach. For this use and for navigation the robot must have a camera on board. This must be a color camera, because “anything that isn’t gray is important to look at” (CRASAR 2008). Pursuit vision, a kind of active night vision, seems very useful as well. Heat vision can also be useful. When a robot has found a victim it is useful to be able to communicate with the victim. For this reason two way audio is build in into CRASAR’s robots (CRASAR 2008).

All these sensors are designed to make teleoperation possible. There are number of issues known with teleoperation, including time delay, sensing and display difficulties (diminished depth perception, camera viewpoint and the lack of proprioceptive feedback), communication bandwidth, operation safety & errors, and operator training. These problems are not due to navigate in the environment, but it is rather difficult to build and maintain situation awareness (Murphy and Burke 2005). The robot is only operated 51% of the time, in the other part are the operators trying to determine what they are looking at. It was difficult for the operators during the World Trade Center response to determine where the robot actually was in the rubble (Casper and Murphy 2003). An information source for the rescuers was the length of the tether line in the building.

RubbleViewer could be extended to view inside the rubble and locate the robot.

For a human is it difficult to build situation awareness in this domain. In field studies it was found that 60% of robot operator communications where related to building situation awareness and only 28% was pertained to activities using situation awareness. It was also found that rescue teams with a high situation awareness where nine times as likely to find victims as rescue teams with low situation awareness. Since it is so difficult for a human to create situation awareness, this is even harder or impossible (at this date) for autonomous robot perception (Murphy and Burke 2005).

It is important to know for an incident leader what a robot has found in the rubble. Currently the robot provides information to only the operator. During the World Trade Center response this information was shared by the operators manually. Often the information needed by the incident commander took 12 hours to get there. So “INTF-1 task force leader, Justin Reuter, requested the development of an Incident Commander laptop that could display maps of who was working where and provide updated event information”. (Casper and Murphy 2003)

USAR operations are a challenge for robot scientists, because there are a lot of demands on the robot to be able to survive (CRASAR 2008). It must work in all extreme weather conditions and at day and night. Another important thing is communication with the robot. Wireless communication may fail and decreases the trust rescue workers have in robots (Casper and Murphy 2003). That is why robots often use a tether line to connect the robot with the controls. There are more requirements opposed by the situation a building can be in. There may be:

- Contaminated fluids
- Smoke
- Dirt, mud and or fecal materials
- Fire. The robot doesn’t have to be able to withstand fire for longer periods, but the tether line must.
- Dust. The robot propulsion system is not allowed to kick up dust. This can be dangerous for the victim respiration, when the robot is navigating around the victim.

During the World Trade Center response there were a number of crawling robots used (Casper and Murphy 2003). There are other types of propulsion systems for robots in the USAR domain. Some are experimental and don’t have any sensors integrated. Robot types which are useful in the USAR domain:

- Crawlers Robot
- Shape shifter
- Marsupial
- Serpentine or snake robot
- Unmanned Air Vehicles (UAV’s)

The robots used during the World Trade Center attack utilized tracks to move (Casper and Murphy 2003). Tracks are really useful to drive fast in the open over difficult terrain. Their size makes it sometimes difficult to navigate through small cracks(Wright et al. 2007).

Another type of robot is the serpentine or snake like robot (Wright et al. 2007) (Figure 2-11). Snake and serpentine does not mean the same. A snake robot is defined as a modular robot that is propelled by motion of the joints relative to each other they define the latter as a modular robot propelled and a serpentine robot is propelled by components such as wheels, legs, or treads. A big advantage for such robots is that it is possible for them to fit in small openings and they have redundant manipulators. So when a propulsion component fails, the robot is still able to propel itself.

Figure 2-11 View of a snake robot climbing the inside of a pipe (Wright et al. 2007).

A Shape Shifter robot can transform its shape for getting higher mobility (Ye et al. 2006). The robot described in that paper tries to combine the advantages of a crawler or track robot with the advantages of a snake robot. Its name is Amoeba II and it has three degrees of freedom. Two are shown in (Figure 2-12) and the third makes it possible to climb stairs.

Figure 2-12 Shape Shifter Robot: Amoeba II (Ye et al. 2006)

Marsupial robots is not a type of propulsion for a robot(Murphy et al. 1999). It is a type of robot cooperation. In such cooperation a mother robot aids at least one daughter robot. In the USAR domain these relations can be beneficial. A large robot is for example not able to enter small voids, but is able to travel large distances. For a small robot this is the other way around. For example the mother can bring the small robot in to a void entrance in an area affected by hazardous materials. A human might not want to do this.

The mother robot can have different roles in the relationship. The mother can be a Coach, Manager, Messenger or Courier for one or more daughter robots. As a coach the mother robot can actively aid the dispensed daughter robots, by providing sensor information. If the mother has a manager role then she will do all processing for the daughters. As messenger the robot will only bring the daughter robots to their point of deployment and relay information to somewhere else. The courier role is the simplest role where the mother only brings the daughters to their point of deployment.

Apart from ground robots there are also aerial robots or unmanned air vehicles (UAV's) being developed (Onosato et al. 2006). The intended purpose of these robots in the USAR domain varies from independent damage estimation over an larger area in the first hours of a disaster to obtaining views of the rubble the SAR group did not have available before. Independent damage estimation is intended to be independent from human intelligence, but this must be made possible first. This research topic is discussed in (Schweier and Markus 2006). They use laser data before and after the disaster to calculate the damage.

UAV's can also be utilized to take pictures from the USAR worksite from different angles. Both structural specialist and USAR specialist for example will need wide shots to create an overview of the current situation. Images from details of specific damages are also needed. (Pratt 2007) The images must be high resolution to interpret the imagery correctly, so the video from these cameras is only useful to obtain an overview of the situation. The structural specialist requested for some sort of an application that shows an overview of the collapsed building and with the high resolution detail images on demand (Pratt et al. 2008).

It is expected that a building is surveyed with a number of flights, because regulations enforce line of sight flight. For the mission there are at least three specialists needed: one pilot to fly the UAV, one problem holder to frame the shots, and one flight director to oversee the operation and take care of safety matters. (Murphy et al. 2008; van Zomeren et al. 2009). It is a research goal to make the UAV fly more and more autonomous, this could reduce the amount of people necessary for the control of the UAV. (Pratt 2007)

2.4.1.5 Through Wall Radar

The through the wall radar is a low frequency radar (Don 2008) that can penetrate concrete. The design of this system is followed with great interest by the USAR society. The system is able to detect and persons through two walls at a distance of 150 meters. These persons can be localized in a 3d position.

Another through the wall radar, primarily made for the law Enforcement, is able to "*detects motion as slight as breathing*" (Miles 2007). This makes it possible to assess whether the victim is still alive and thus help the USAR team to rescue only living victims. The device makes it possible to see through more than 30 cm of concrete.

2.4.2 Mapping techniques

There are three types of USAR mapping guidelines. First it is possible to make a sketch of the general area where the team performs its mission. Secondly it is possible to make a sketch of one worksite and one third can mark the building with spray paint. The latter two are important for RubbleViewer, since its scope is only one building, and thus will be described here.

2.4.2.1 Building sketches

During SAR missions there are sketches made of the rubble pile to annotate information like: where are hazards, safe havens, evacuation routes, and entrances to victims. It can also be important to describe the search progress. SAR teams use their mapping jargon to map consistently. They have numbering or lettering for the sides, depending on whether the FEMA (Figure 2-13) or INSARAG (Figure 2-14) guidelines are followed. The FEMA guidelines are for American USAR teams whereas the INSARAG guidelines are for International USAR teams. Both guidelines, number the floors of a building differently. The inner quadrants of a building are lettered the same. In the FEMA guidelines is also a description of how to annotate columns. Usually this must be done according the building floor plans. If they are not available then the columns are lettered on the side of the street and numbered on the perpendicular side.

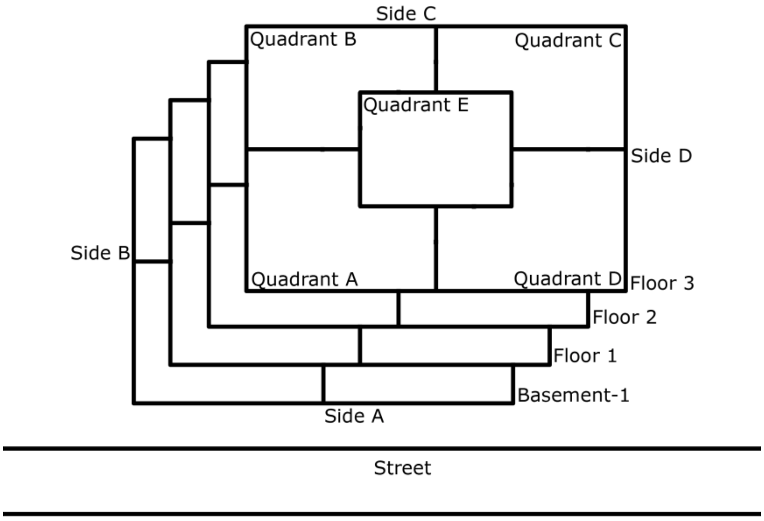


Figure 2-13 FEMA Mapping guidelines

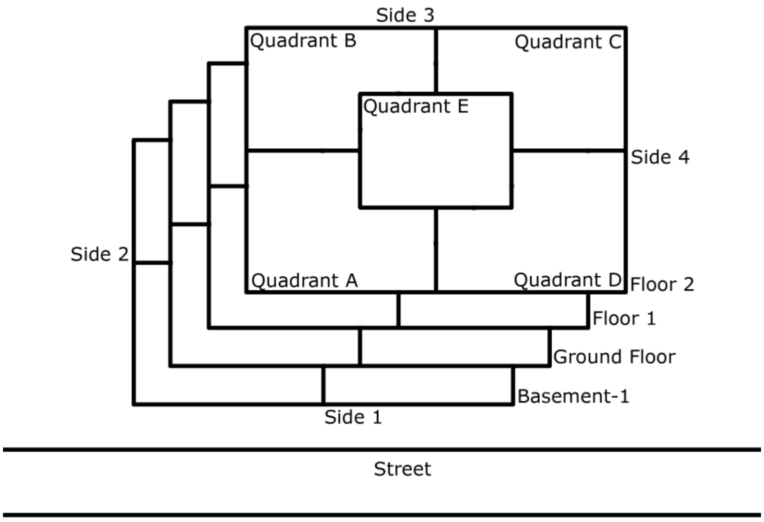
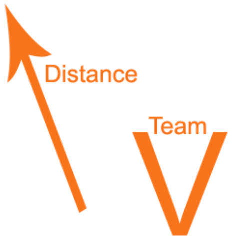
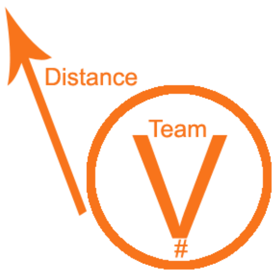
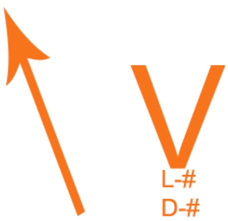
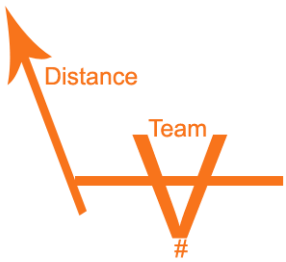
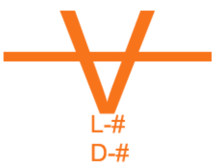


Figure 2-14 INSARAG mapping guidelines

2.4.2.2 Spray paint markings on the building

USAR teams use spray paint markings on a building to mark places where they found victims. This is for the teams themselves to remember the exact location and for new teams to tell what they have found. For the new teams the SAR groups also spray paint a summary on the building. There is an international way to do these markings, according the INSARAG guidelines. The FEMA teams have another marking system. Reading a marking with another system in mind can introduce fatal errors. First the Victim Location Marking system:

	FEMA (U.S._Army_Corps_of_Engineers 2005)	INSARAG (OCHA 2009)
Potential Live Victim	 **Figure 2-15 FEMA Potential Live Victim**	 **Figure 2-16 INSARAG Potential Live Victim**
	Arrow points to the entrance of the void if this is unclear. Distance is in foot. Team is the team callsign	# behind L is the number of live victims. # behind D is the number of deceased victims.
Confirmed Live Victim	 **Figure 2-17 FEMA Confirmed Live Victim**	 **Figure 2-18 INSARAG Confirmed Live Victim**
	The circle around the V means the victims are confirmed The # below the V denotes the number of victims.	The arrow means that the entrance to the victim is clear and thus the victim is confirmed.
Deceased Victim	 **Figure 2-19 FEMA Deceased Victim**	 **Figure 2-20 INSARAG Deceased**

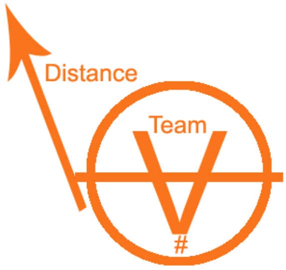
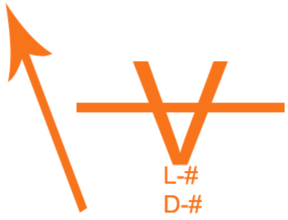
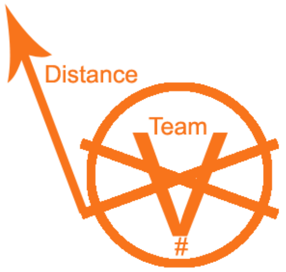
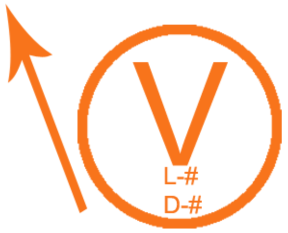
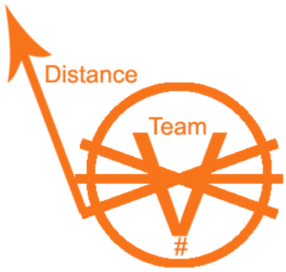
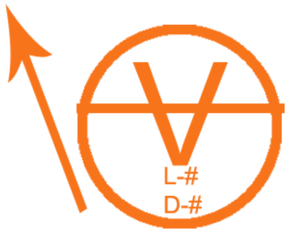
		Victim
	The line trough the V means the victim is deceased. If there are both deceased and alive victims then use a separate V for the victims that are alive.	The line trough the V means the victim is deceased.
Confirmed Deceased Victim	 **Figure 2-21 FEMA Confirmed Deceased Victim**	 **Figure 2-22 INSARAG Confirmed Deceased Victim**
Extricated Confirmed Live Victim	 **Figure 2-23 FEMA Extricated Confirmed Live Victim**	 **Figure 2-24 INSARAG Extricated Confirmed Live Victim**
	The cross through the V means the victim is extricated	The circle around the V means the victim is extricated.
Extricated Confirmed Deceased Victim	 **Figure 2-25 FEMA Extricated Confirmed Deceased Victim**	 **Figure 2-26 INSARAG Extricated Confirmed Deceased Victim**

Table 2-1 Victim annotations according FEMA and INSARAG guidelines

Important to notice is that the circle around the V for the INSARAG signs would mean that the victim is extricated and is not there anymore. For the FEMA signs this means that the victim is confirmed and the team knows for sure there is a victim. So an INSARAG team would ignore a victim that is there and a FEMA team would spend a lot of effort in trying to rescue a victim that is not there anymore. Both situations can lead to more victims than would be necessary.

A FEMA arrow just point to the entrance of the void, the INSARAG arrow also means a victim is confirmed. So if an INSARAG team finds an entrance marked with a FEMA potential live victim annotation the team would start to try to rescue the victim instead of trying to confirm the victim and thus might put too much effort in a victim that is not there. The other way around would mean that the team would first try to confirm there is a victim.

Both marking systems have a quick summary of the results of a mission. The FEMA teams have different parts of the organization that do the building assessment, the search, and the rescue. For the first two there is a separate summary marking. The rescue has no summary marking on the building and to the best knowledge of the author there is no way mark that the rescue mission is completed.

Figure 2-27 FEMA Sign after hazmat and structural assessment mission (FEMA 2003)

When a FEMA responder paints (Figure 2-27) marking it means that the building actually is too dangerous to perform USAR operations in. Precautions have to be taken before USAR operations start. If there is only one slash in the square that would mean that the structure is reasonably safe, but in some parts shoring might be necessary. Without slashes the building is pretty safe and USAR operations can be done without stabilizing the structure. The arrow points to the closest safe entrance into the building.

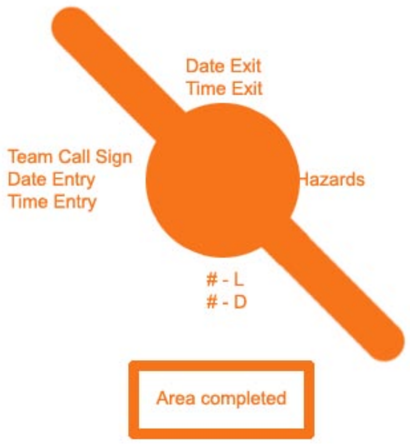


Figure 2-29 Search Assessment Marking, search incomplete. (FEMA 2003)

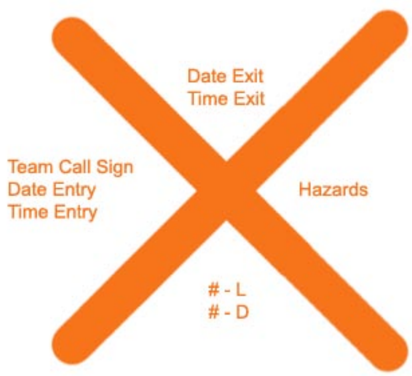


Figure 2-28 Search Assessment Marking, search complete (FEMA 2003)

A FEMA search team would draw the back slash when entering the building, along with the information in the left quadrant. On exit they would draw the rest of the information and the second slash. In the lowest quadrant are the number of live victims and death victims notated. If the team must leave the area without completion of the search they would draw a dot instead of the second slash. In that case it is important to note what part of the building has been searched. The area can be notated in quadrants or floors.

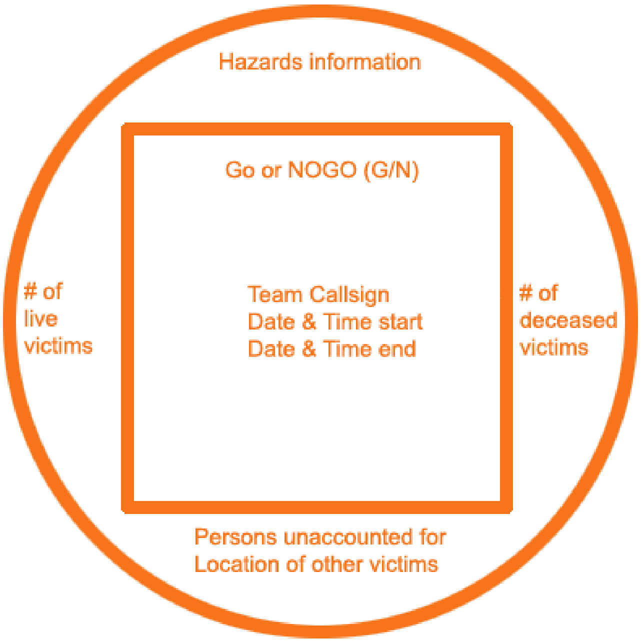


Figure 2-30 Structural marking (OCHA 2006)

This sign (Figure 2-30) is drawn by an INSARAG team. On arrival they draw the box. The other parts of information are added once they are known. The circle means that the operations are finished.

The INSARAG and FEMA teams already have mapping guidelines. It would be the easiest for the SAR group members if a new way of mapping, RubbleViewer, uses the signs they are already acquainted with.

2.4.3 Photogrammetry

Photogrammetry algorithms are algorithms were geometric properties of objects are calculated from images, this is promising technology for the problem as described in chapter 1 Introduction. In the quest for a way to stitch imagery from a rubble pile together, Photosynth came up. Photosynth is technology based upon Photo Tourism (Snavely et al. 2008), which makes it possible to view images as it were in their original 3d position. Other images with enough overlap will be placed in the same relative position as they were in the real world when the picture was taken. Another result of the algorithm is a point cloud of the objects visible in the images fed to the Photo Tourism algorithm.

The process tries to find the same objects in different pictures. Scale Invariant Feature Transform (SIFT) keypoints (Lowe 2004) are features found in images with a local descriptor. Meaning, with SIFT features the same object can be found in different images even if the images have a different scale or view the object from another angle. Naturally the change of size and change of angle is limited. The SIFT features that describe the same object are ordered in tracks, this is sound for the whole image dataset.

The two images with the most tracks together will be stitched together first. This is followed by an iterative process where the image with the most tracks in common with the set that is already stitched together is added. The new image adds its own tracks to the set so more images can be added. This results in a set of camera positions in a 3 dimensional coordinate system and camera parameters (i.e. focal length) corresponding to the same image. The tracks result in a 3d point cloud in the same coordinate system as the images. These points in the scene contain a position, the color representation of that point in the scene, and information about which camera is able to see that point.

This Photo Tourism algorithm is tested with a number of image datasets from Flickr by multiple users (Snavely et al. 2008). These datasets consists out of photos from different cameras, zoom levels, resolutions, and different times of the day or seasons, illumination, weather and differing amounts of occlusion. This means that the Photo Tourism algorithm must be pretty robust. A robustness that is needed for everything created for the USAR domain.

It would be nice if one could create 3d models from these images, the technology to create these models is called multi view stereo. A lot of research (Seitz et al. 2006) is done for laboratory datasets. In (Goesele et al. 2007) is a method proposed to create these models from community photo collections. The algorithm starts from the Photo Tourism algorithm (Snavely et al. 2008). The model is further developed using multi view stereo algorithms. The result is a model once compared with laser scanner data the error was within 0.128 meter for 90 percent of the samples, for a building of 51 meters tall.

2.4.4 Download models of buildings from the internet

Google and Microsoft are busy with 3d modeling the world with their programs Google Earth and Microsoft Virtual Earth. These programs are evolving from a 2d mapping application with only maps and satellite imagery to a 3d mapping application with 3d models of the buildings on the map. It would be possible to download these models and use them to annotate information on them. It would also be possible to add new images if the gps location and compass information of the image is made available.

It is very useful for USAR responders to see how the building was before the disaster. For example knowing how many floors a building had before a collapse is important information for responders. It gives them a clue on how dense the collapsed building is. This provides information on how much voids there are for victims to survive in.

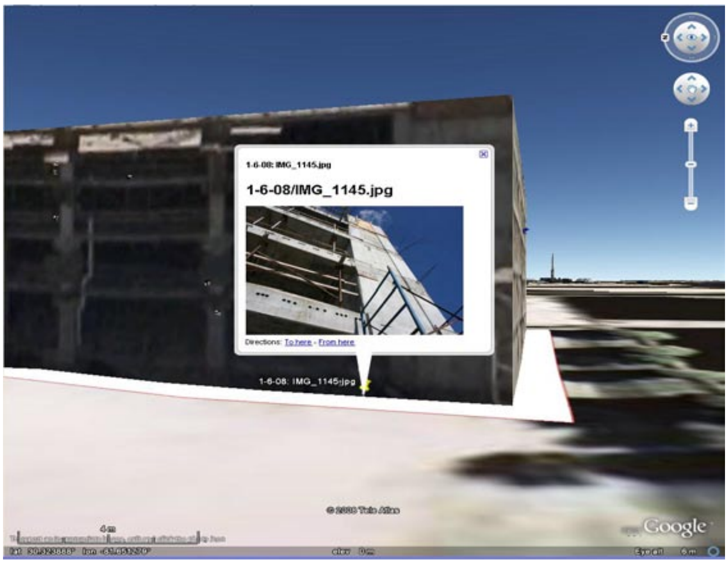


Figure 2-31 Elevation picture on Google earth model (Weber 2008)

2.4.5 Laser scanning

Laser scanning is a technique that has great potential for 3d mapping of a rubble pile. A laser scanner measures the distance from the device till the closest object. A lot of these measurements from different angles together combined are one scan. This is a large point cloud around the scanner. It is possible to combine multiple point clouds into one larger point cloud describing the whole scene. Such a point cloud can be used to create a 3d model of the surface of the object.

(Schlenoff et al. 2007) describes the gathering of laser scan data at Disaster City training facility at College Station, TX. The gathering of the point clouds took three days for three different worksites. The data was gathered to gather information about the type of terrain, later use as terrain in USAR simulations for robots, and can serve as a preview of what robot scanning devices might deliver in the future.

In the field of archeology (Lambers et al. 2007) imagery from UAV's and laser scanner data from the ground are already used to create 3d models in a time expensive, combined manual and automated method. For the models there was a need for horizontal perspective modeling for example the walls and a vertical perspective to model the ground plan. For the horizontal perspective the laser scans where used and for the vertical perspective the imagery from a UAV was used. The different laser scans where registered with the use of markers in the scene. The markers were also useful to tile the images, six control points had to be measured for each image pair to do this. After data processing they created a detailed 3d model that can be used by archeological research (Eisenbeiss et al. 2005).

2.4.6 Sketch

Sketch technology (Hammond et al. 2008) allows people to sketch on a tablet pc. Parts of the sketches can automatically be recognized. This enables people to add information on a natural way without burdening people to learn some sort of input language. This technology makes it possible that information is send to other people easily and searchable.

2.5 Human Factors

This part describes important Human Factors background. Situation Awareness is an important term for RubbleViewer, it is described in section (2.5.1).

2.5.1 Situation Awareness

In the world we are living in there is a lot of data and the challenge for people is the turn this data into information (Endsley et al. 2003). A key term in this process is situation awareness (SA). It is defined as "The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley 1988). There are three levels of situation awareness defined.

- Level 1 – perception of the elements in the environment
- Level 2 – comprehension of the current situation
- Level 3 – projection of future status

Having a high level of situation awareness is important, because it is possible to make better decisions with a higher level of situation awareness. Good decision making will in its turn improve the performance of the process. It is found in a study that 88% of human error was due to problems with situation awareness. So improving human performance can be done by improving the situation awareness.

Level 1 – perception of the elements in the environment

“The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment”. (Endsley et al. 2003) The techniques explained in this chapter are designed to perceive the status of the rubble. Some of the techniques are more reliable and precise than other techniques.

Level 2 – comprehension of the current situation

“The second step in achieving good SA is understanding what the data and cues perceived mean in relation to relevant goals and objectives.” (Endsley et al. 2003) Combining the data into information and comprehension is mentally demanding. It requires weighting and prioritizing of the data elements. It requires a good mental model of the situation, which novices or people new to the kind of situation do not have.

An example of this level of SA in the USAR domain is trying to understand where the victim actually is with the data provided by varies search methods. It might be concluded that a dog signals in a certain area and combined with void information this can mean that the victim is at a certain location.

Level 3 – projection of future status

The third level in obtaining SA is understanding how the situation will evolve in the near future. This level of SA cannot be achieved without an accurate understanding of the situation (level 2 SA) and knowledge about the functions and dynamics of the current system. Projection of the future status can be used to cope with the changing environment and have a number of strategies ready which can be put into action fast when the situation needs it.

In the USAR domain for example can it be that a victim is found under the rubble but the construction is very instable. While drilling to rescue the victim the structure might give clues about the stability of the building. Using these signals to estimate whether the building will collapse further is a projection based on level 3 SA. It is possible to act with this knowledge and come up with a number of strategies to cope with this problem. For example strategies like drilling a hole in another part of the construction or shore the construction to make it safer.

2.6 Domain analysis conclusion

This chapter describes the domain using the PACT model where RubbleViewer is intended to operate. The PACT model was complemented with a Human Factors section to describe a relevant theory in the Human Factors domain as the PACT methodology doesn’t take Human Factors explicitly but it is relevant to man machine interfaces.

The SAR group members are the main people to interact with RubbleViewer, different team members will have different perspectives on the collapsed building specific for the task they are doing. The SAR group members are the people who work on a collapsed building to rescue people. The overview perspective is important for people whose task is relevant for multiple victims. There is also detail information necessary for every victim, for the people only concerned with one victim (or who have a task for that specific victim).

RubbleViewer is intended to support the SAR group while they are communicating. At the moment they communicate verbally, with maps, and with spray painted markings on the building. The easiest way for the SAR group members is to use the map and marking methods they are already acquainted with, only then in a way that is not full of clutter.

The SAR groups will probably work in an international setting on a high risk environment. This high risk environment is a collapsed building that can be collapsed through multiple patterns. RubbleViewer is to be developed to visualize all these patterns if it is to be successful in real use. The collapse patterns also deliver information about voids, empty spaces where victims can be in, providing this information to the SAR group will be useful for them. Useful in the search phase, cause these voids needs to be searched for victims, and useful during the rescue phase, because these voids can be easy routes to a victim.

The technology necessary to create a RubbleViewer is also reviewed in this chapter. There are a number of promising options that will help creating 3d maps of the collapsed building. These options are: downloading pre disaster models from the internet, laser scanning, photogrammetric algorithms, and sketch recognition. One of these options has to be chosen in later chapters.

RubbleViewer will be designed to provide high levels of situation awareness quickly to people who just arrive at the worksite. Having a high level of situation awareness means that you can predict what is going to happen in the future. This is important, because this means that you can make better decisions.

With this domain analysis some interesting findings were obtained to be better equipped to design a good view on the rubble with RubbleViewer.

3 Design

The former chapter analyses how USAR personnel communicates spatial information, it is also established that this can be improved. This chapter proposes RubbleViewer, a solution to improve the communication of spatial information. First the scenarios are described (3.1), they served as the discovery process to discover the core functions necessary for a RubbleViewer. Hence, there are explicit references (i.e., links) to the core functions that are described in detail in the second part of this chapter (3.2).The requirements description for RubbleViewer is the third element of the design that is described (3.3). The last part of this chapter (3.4) envisioned technology describes the decision path to the backend of RubbleViewer.

3.1 Scenarios

The five scenarios described in this section cover the envisioned main parts of the use of a RubbleViewer. There is some work needed before a view on the worksite can be visualized by RubbleViewer, scenario one – model creation describes this part. The second scenario – search phase describes the use of RubbleViewer while the SAR group is finding a victim. RubbleViewer will prove its use during a shift change of a SAR group, this is described in scenario three Change of Shift. Normally structural specialist would have to physically go to the scene to give advice. In scenario four the Structural Instability the expert is able to give advice while viewing the scene with RubbleViewer. RubbleViewer is not really necessary during the debriefing, but can provide information as is described in scenario five – Debriefing.

In the scenarios six different personae are used. Two scenarios includes two different SAR groups, in these scenarios the personae are also given a surname: Alpha for SAR group alpha and Bravo for SAR group bravo. The personae are:

- Daniel, Commander Rescue Group
- Rex, Dog Handler
- Constantin, Search Specialist
- Jim, Rescue Worker
- Grey, medic
- Frank, structural specialist

Scenario one – Model creation (functions 1, 3, and 6):
SAR team Alpha arrives at a collapsed building with a truck. A part of the team starts with the setup of all the equipment while Daniel and Rex make a reconnaissance tour around the building. They take overview pictures and pictures of interesting details. Constantin, the search specialists trained as pilot, sets up the UAV to provide an Aerial view of the surroundings.

Daniel gives some orders to the time when he gets back to the truck. In the mean time Constantin is ready to fly the UAV. Daniel takes the roll of problem holder and directs the pilot to the points of interests. Daniel takes pictures of these points of interests and annotates some important information on those pictures. Rex takes on the roll of safety officer during the flight. He takes care that the UAV is not to close to the building and the personnel is not in danger.

After all the UAV is back on the ground the pictures are loaded into RubbleViewer. Constantin, Daniel, and Rex return to their normal duties while RubbleViewer is calculating some sort of a model of the worksite's rubble pile. After RubbleViewer is done calculating the model and Jim has a little bit of time left he adds landmark information to the system, for example there is an important road or are there adjacent buildings. also adds information on how they have numbered the sides of the collapsed building.

Once Daniel is done commanding for a while he walks to RubbleViewer and is glad he can see what the structure of the building is. And he sees the annotations he has made earlier in the system. He decides it is important to add some information about the safety in the system. There is a gas leakage in a part of the building. He adds a proximity warning to RubbleViewer, and orders his team mates not to pass this proximity. He also adds a safe haven to the system, so his personnel quickly know where to evacuate to when the situation arises.

Scenario two – Search phase (functions 4, and 5):
Suddenly Daniel hears a call for him through the intercom. A victim has been found with a Search Cam, so the victim does not need an extra confirmation. Together with Jim and Grey, he decides whether it is smart to proceed to rescue this victim and how this is best done. They take pictures with the Search Cam inside the void and together identify the structural elements that keep the void intact. They also annotate the entrance to the victim on the concrete of the collapsed building.

Jim returns with the pictures to RubbleViewer, he annotates a new victim in RubbleViewer and adds the pictures to the victim information. On the pictures he annotates the areas where it is expected to be smart to drill in and which structural elements are supporting the void.

In the mean time Daniel calls the big boys together. With RubbleViewer Daniel quickly explains the situation at hand and how the victim is supposed to be rescued, safety factors are briefly explained. After the briefing everybody knows how to rescue the victim and they start doing it efficiently. When there are breakthroughs new pictures are taken and added to RubbleViewer.

Scenario three – Change of Shift (functions 2, 4, and 6):
After SAR team Alpha has worked for hours and hours they are replaced by team Bravo. Daniel Bravo, SAR group commander of team Bravo is overwhelmed by everything he sees on the scene. He is taken to Rubble Viewer and Daniel Alpha quickly explains all the parts of the building. He rotates around the building and sometimes he shows a picture of an interesting part of the Rubble Pile.

After Daniel Bravo knows what the important parts of the rubble pile are, he gets a safety brief Daniel Alpha is glad he had quickly annotated it to the system. Once all the safety information is known by Daniel Bravo, an overview of all the victims is shown to him. After that he has the choice to look at the victims in more detail. Looking at the pictures and the annotations, so he knows what the paths to those victims are.

Scenario Four – Structural instability (functions 1, 2, and 6):
While discussing the structure of the rubble pile Daniel Bravo gets the feeling the structure is not safe enough to work on. He knows when his knowledge about buildings is not sufficient anymore to assess the situation. And he calls the structural specialist for an advice. Unfortunately the structural specialist Frank is hours away in the base camp and Daniel Bravo needs an advice and he needs it now.

Unlike in other disasters there is sufficient bandwidth at the moment. Daniel Bravo uploads the model of the worksite to Frank and Frank takes his time to evaluate the buildings structural integrity properly. It would be best if Frank would be on the scene, but that is not feasible right now. Frank asks Daniel to do some extra measurements and takes some extra pictures. After Frank knows enough about the building he makes some annotations in RubbleViewer about the buildings stability and calls Daniel. The SAR team has to keep away from a part of the building where they have not found victims yet. So they can continue their work safely.

Daniel is relieved to have received such expert feedback about his problem so quickly. Normally he would have to wait for Frank to be available.

Scenario Five – Debriefing (functions 2, 4, and 5):
After a good night rest, after the complete operation. Team Alpha and Bravo come together to discuss this specific mission. What are the lessons learned of this mission. Jim Alpha wants to know whether victim x has survived the situation. He fires up Rubble Viewer, loads the correct mission and zooms to the specific victim and asks whether this victim has survived the collapse of the building. Daniel Bravo, who quickly remembered the specific victim, can give a positive answer. They had to dig through thick slabs of reinforced concrete. Jim sees the pictures which are attached to the victim node. After evaluation of the images he wants to know why they did not take another route…

3.2 Core Functions

This section describes the core functions of RubbleViewer. The functions are deeply embedded in this thesis. Not only in this chapter, were the scenario's leaded to the discovery of the core functions, and the requirements describe the core functions more thoroughly. In chapter 4 Implementation is described how each core function is implemented. The results are described per core function in chapter 6 Results.

These functions are described as functions for the user, as something the user must be able to do or be able to use. This is in contrast with the situated Cognitive Engineering methodology, where the core functions ought to be described on another conceptual level these core functions must also be measureable. A core function for RubbleViewer according the situated Cognitive Engineering methodology could for example be: "Prevent construction of faulty situation model". This can be measured and one can for example claim that the user has less often a faulty model of the situation compared to the old way.

To create a good RubbleViewer six core functions have to be implemented. These core functions range from the technology to make it all possible to the type of information that can be added.

- Function 1: Capture data and convert into a Model (3.2.1)
- Function 2: Show Model (3.2.2)
- Function 3: Enable adding navigational aids (3.2.3)
- Function 4: Enable annotating USAR information spatially ordered by points (3.2.4)
- Function 5: Describe the rubble pile internally (3.2.5)
- Function 6: Enable annotating USAR information spatially ordered by regions (3.2.6)

3.2.1 Function 1: Capture data and convert into a Model

There are a lot of pictures of a rubble pile where a SAR team must work on. Some work must be done to prepare the pictures to be viewed. After that they must be loaded into RubbleViewer by the user and RubbleViewer must create the model from this input. The model must be created automatically with as less user interference as possible.

3.2.2 Function 2: Show Model

The created model must be visualized. The responder wants a good grasp of important features of the rubble pile. The responder must be enabled to see an overview of the worksite and investigate details on demand. RubbleViewer must support the creation of a mental model about the worksite.

3.2.3 Function 3: Enable adding navigational aids

Helping the user to keep track of the orientation of the 3d model is of utmost importance. Failing to do this properly will result in wrong understanding of the model and possibly errors. A disaster site might not provide enough clues for the orientation of the model. The INSARAG and FEMA mapping guidelines describe signs that help de user to orientate the map. These signs must be visualized and extended with the possibility to annotate other landmarks.

3.2.4 Function 4: Enable annotating USAR information spatially ordered by points

To provide information to the next responder using RubbleViewer, the current responder must be enabled to annotate information to a position on the rubble pile. Important information can be victim locations, and hazmat locations. The locations must be made immediately visible and the visualization of the location must also show the state the victim for example is in.

3.2.5 Function 5: Describe the rubble pile internally

After a victim has been found it is important to show the internal path to the victim. This should be related to how the victim is shown on the rubble pile. Annotating this information can be done by adding a picture scenario or adding the information inside the 3d model. The user must be able to annotate information to the image scenario for example by digital spray paint.

Design for resilience: users might want to annotate more things then enabled this way. So enable user specifiable information elements to be added internally.

3.2.6 Function 6: Enable annotating USAR information spatially ordered by regions

It must be possible for the responder to assign regions on the rubble pile. Such regions can be a proximity alarm, because of a hazardous material or instable rubble part. Another possibility is a safe haven for the responders when the rubble pile needs to be evacuated. The regions which are the same must be easily recognized and other types of regions must be distinct.

Design for resilience: users might want to annotate more things then enabled this way. So enable user specifiable information elements to be added spatially ordered by regions.

3.3 Requirements

The requirements are described as requirement per function (function 1: 3.3.1, function 2: 3.3.2, function 3: 3.3.3, function 4: 3.3.4, function 5: 3.3.5, and function 6: 3.3.6). Gathering of these requirements is an iterative process as described in the situated Cognitive Engineering approach. The results of the evaluation (chapter 6 Results) of the prototype RubbleViewer also helped in the requirements gathering. Consequently the current prototype of RubbleViewer does not meet all the requirements.

The requirements are described as guidelines, or elements that must be present. For example the data capture must work fast, this means that effort should be put into making the capture of data as fast as possible. A harder requirement would be must be achievable within an hour. However describing it like this will result in a lot of arbitrary numbers that will be different for different types or sizes of disaster sites. Therefore it is opted, at this point of research, to keep these types of requirements a bit vague.

3.3.1 Function 1: Capture data and convert into a Model

Data capture

- Must always work
- Must work fast

Converting the data in a 3d model

- As less user interaction as possible
- Must always work
- Must be optimized to work as fast as possible
- Must enable adding more data later on in the process

3.3.2 Function 2: Show Model

3d model visualization

- Provides overview
- Must be textured
- Provides insight in the type of building
- Provides insight in the type of collapse
- Visualizes large structural elements
- Provide a way to estimate distances

Images

- Are aligned with model
- Provide detail information
- Can be zoomed in

Spatial navigation

- Easy to learn
- Provides insight in height map
- Does not unsettle user

Design for resilience

- Enable possibility of only 2d map

3.3.3 Function 3: Enable adding navigational aids

Enable adding

- INSARAG mapping guideline elements

- FEMA mapping guideline elements
- Wind vane
- Compass rose
- Description of neighboring buildings

The signs used must be explained in writing

Enable registration method to
- Map
- Satellite image
- GPS coordinates

3.3.4 Function 4: Enable annotating USAR information spatially ordered by points

Enable annotating victim information
- Apply INSARAG or FEMA guidelines (Don't mix both guidelines)
- Enable victims status annotation
- Describe victim status also in words
- Enable ordering victims
- Enable adding source of information

Enable annotating Hazardous Materials
- Sign must be informative of what type of hazmat there is
- Enable adding source of information
- Related Hazardous Materials to danger region

The signs used must be explained in writing

Enable describing the source of information

Design for resilience
- Enable adding new information types spatially ordered by points

3.3.5 Function 5: Describe the rubble pile internally

Enable extending of 3d model with internal 3d representation
- Goal directed
- Enable textured geometry
- Enable detailed images
- Must be done automatically
- Scale and orientation must be correct relevant to function 1 and 2
- Enable adding robot path
- Enable adding victim position
- Design user interaction of 3d internal information separately from overview.

Enable adding images to describe rubble pile internally
- Enable zoom functionality
- Enable spray can like annotation on images

- Motivate user to add enough images so all steps are clear

Enable describing the source of information

The signs used must be explained in writing

Design for resilience
- Enable adding new information types in 3d representation

3.3.6 Function 6: Enable annotating USAR information spatially ordered by regions

Enable annotating safety information
- Enable adding no go areas
- Enable adding proximity warnings
- Enable adding safe havens
- Enable annotating instable elements

Enable annotating search progress
- Enable adding region that are already searched

The signs used must be explained in writing

Enable describing the source of information

Design for resilience
- Enable adding new information types spatially ordered by regions

3.4 Envisioned technology

Based on the Scenario (3.1), Core Functions (3.2), and the Requirements (3.3), it was chosen to create a RubbleViewer with the photogrammetric method Photo Tourism or Photosynth (2.4.3). Naturally this is not a conclusion that is reached without careful deliberation and research. The decision process is described in this section and visualized with a flow chart (Figure 3-1).

The first choice was to determine whether we would want a pre or post disaster model. A pre disaster model is a model that is stored in some sort of an (online) accessible database before any disaster had occurred. Once a building has partially collapsed the pre disaster model is visualized and USAR teams are envisioned to annotate information on it relative to the old state the building was in. Post disaster models are created after the disaster by some sort of a technical solution or man modeled, on which the USAR team can then annotate information on.

Pre disaster models once available are a fast way to show a model, but there are two critical reasons for deciding to create a post disaster model. First the pre disaster model does not represent the current situation. What would a pre disaster model be of use when the building turned into a heap of debris (Figure 2-6)**?** The second reason is that it cannot work as a standalone application. The application would need to obtain the model somewhere. A connection will not always be available, during a disaster and one cannot count on receiving a DVD of all the buildings in the disaster area during the chaos of a disaster. The solution must always work out of the box where it has been waiting for a while, the pre disaster solution won't.

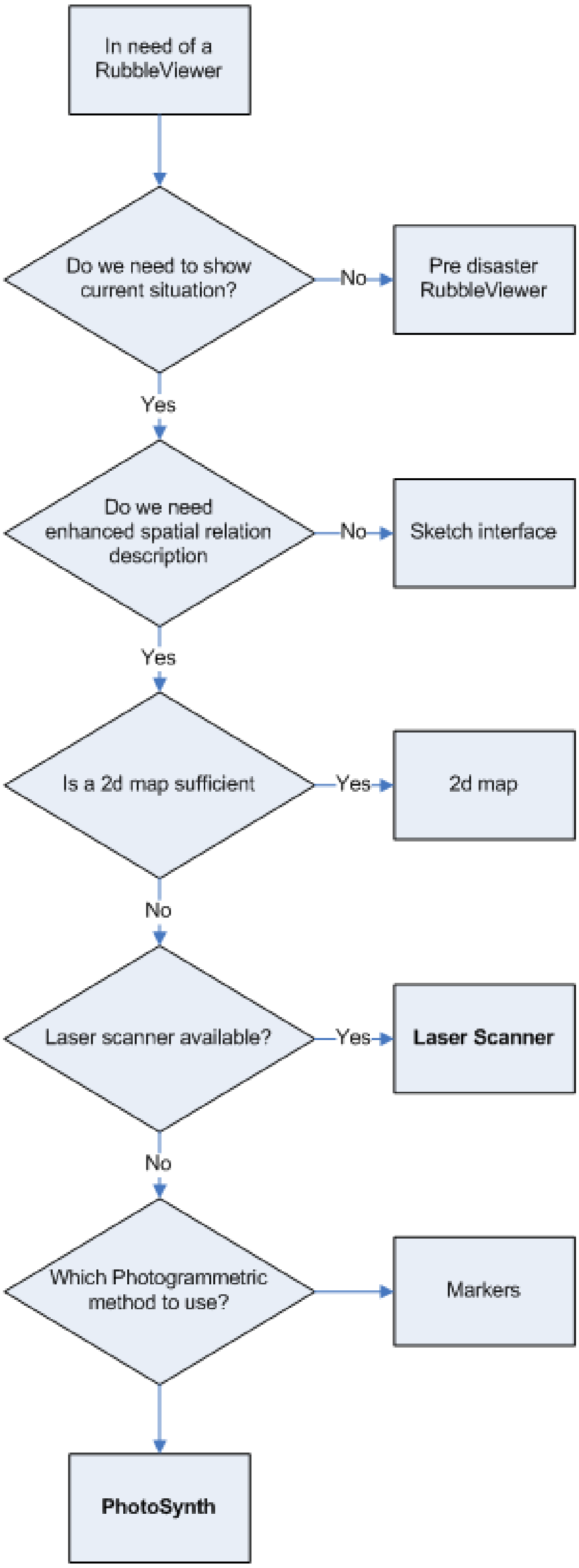


Figure 3-1 What kind of technology is used to create RubbleViewer

The second choice is whether we want to support them by automatically obtaining information from the sketches, or create some sort of sketches that are understandable by others. It is envisioned that responders sketch different views of the rubble and add information to it. This is already done for all types of collapses by USAR teams. The information on these sketches can be digitally recognized, and send to higher command when necessary. This (2.4.6) is great technology that enables the responders to work in the way they already work.

Unfortunately digital sketching does not prevent any visual clutter on the sketches themselves, so we need to look for another solution. Sketch recognition also does not aid the responder in creating better spatial relations than is possible now. Just exchanging paper with digital paper will not be a solution for this problem. The quality of the sketch is still depending on the skill of the responder. It would be an option though to use the sketch technique as an efficient input modality on an existing map.

Is 2d mapping enough or do we need a 3d model to annotate the information on? A 2d map could be a plan view taken with an UAV from the worksite. It depends on how 3d the collapsed building is whether it is enough. If there are in a vertical part of the collapsed building multiple things to annotate than a 3d model is preferable above a 2d map. So a pretty flat heap of debris, could be described by a 2d map whereas a pancake collapse with multiple storey's involved, but not all would require a 3d map. Apart from this the long term vision does also include 3d spatial information, like the position of a robot or victim underneath the rubble.

A laser scanner would be a good way to use to create the 3d model; unfortunately this is not feasible for the prototype. A laser scanner was not available at the time of deciding how to create the prototype. This is also sound for the USAR teams. At the moment they do not have access to a laser scanner. Naturally this might change when the technology has proven itself. However being resilient and have two ways to reach the 3d map is a good thing. For a further description about laser scanner technology and 3d mapping, please refer to (2.4.5).

The other way is by using photogrammetric algorithms, the options considered are a system based on markers (Attachment 1: First design RubbleViewer) and a system based on the Photo Tourism algorithm (2.4.3). Both systems will deliver the camera position of each shot relevant to the other shots. The marker system is based on recognizing 3 of the n markers positioned in the scene and calculating the relative position from this. The Photo Tourism algorithm recognizes camera standpoints based on the other standpoints and thus need pictures that overlap enough.

The main reason to continue with the model based on the Photo Tourism algorithm is, because of the fact that the marker system always needs three markers in each photo. As is described earlier both the overview images and the detail images are necessary for the responder and structural specialist. So there must be a lot of markers in the scene. With the Photo Tourism algorithm this extra work is not necessary.

After these deliberations it is decided that the RubbleViewer prototype will be based on the Photo Tourism technology and will result in a 3d map where USAR responders can share information on. It is envisioned that once the SAR group arrives at the scene a part of the team will start with creating a model by flying a UAV over the worksite and taking pictures. After downloading these images into RubbleViewer, RubbleViewer will create a 3d model of the scene. Different responders with different tasks and technologies will (automatically) annotate mission critical information on the 3d model. RubbleViewer will serve as an information sharing piece of technology.

3.5 Conclusion

Based on the scenarios and the Work Domain and Support analysis six core functions where distinguished:

- Function 1: Capture data and convert into a Model
- Function 2: Show Model
- Function 3: Enable adding navigational aids
- Function 4: Enable annotating USAR information spatially ordered by points
- Function 5: Describe the rubble pile internally
- Function 6: Enable annotating USAR information spatially ordered by regions

In the envisioned technology is the decision process described for the technological back end that will make the functions 2 till 6 possible. The back end is designed to be based on the Photo Tourism algorithm. This algorithm places images in an image dataset in a 3d position relevant to each other. On top another output is a point cloud where a 3d model can be based upon.

4 Implementation

The implementation chapter describes the processes of RubbleViewer (Figure 4-1) necessary to compute a 3d model from an image dataset. Along with these processes the user interaction required for to make this happen is described. This chapter is ordered along the core functions of the design (see chapter 3 Design). Naturally the discovery of this process was not without dead ends and decision making. However, this is not described in this thesis.

Two out of the five core functions that are implemented in RubbleViewer at the time of writing consist out of more elements. The function capture data and convert into model is the most complicated element of RubbleViewer. It ranges from the capture of the data to the smoothing of the point cloud. The processes Delaunay triangulation and Rotate require user action the first run for a new dataset. Show model is the other function that consists out of more processes. The user interaction process is the process where the user gets to navigate the 3d model. The other 3 functions are processes started by the user to add USAR mission relevant information on the 3d model.

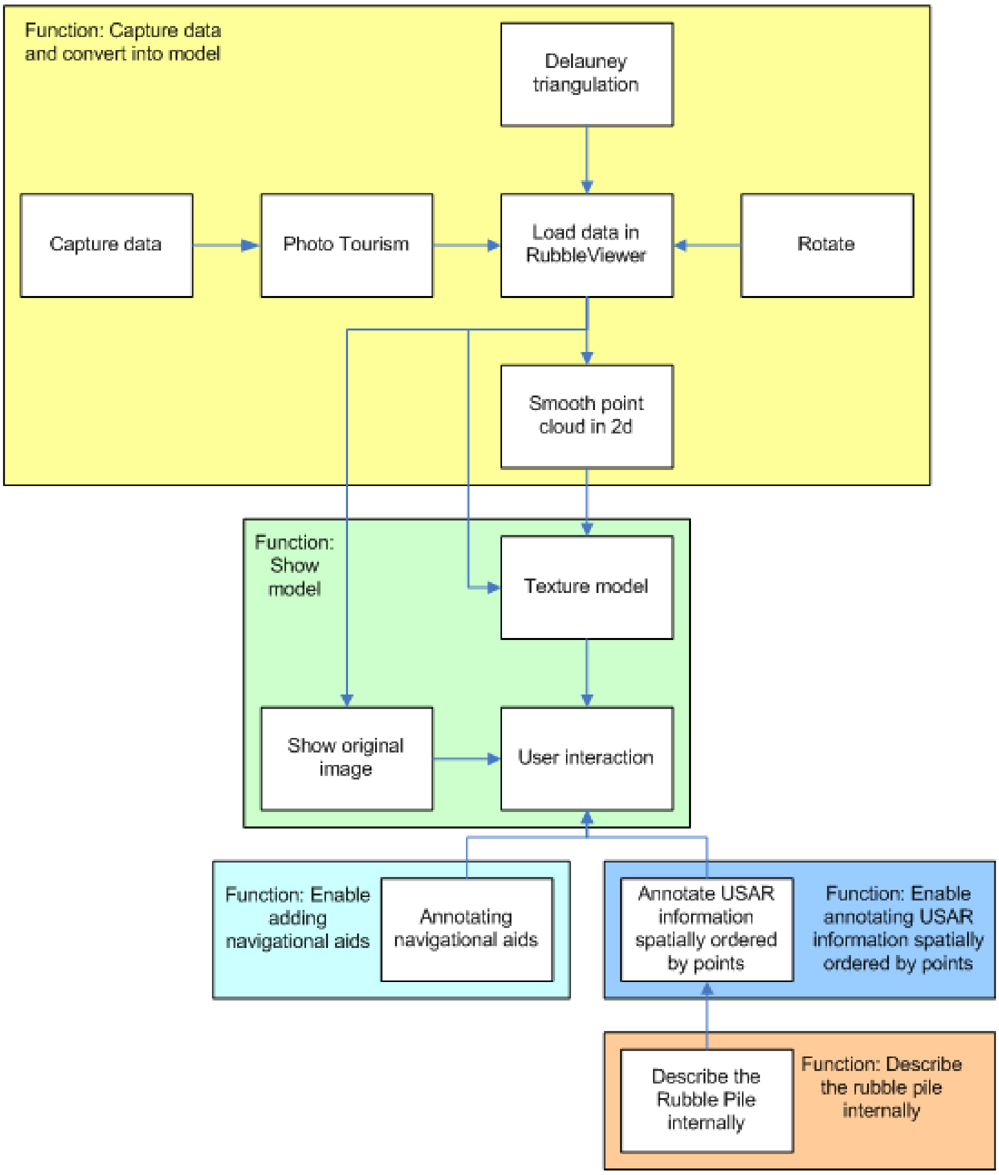


Figure 4-1 Processes in RubbleViewer

RubbleViewer was created in Unity3d (Unity_Technologies 2009) a commercially available 3d engine for the Mac and now for windows. The companies motto is “Unity Technologies – taking the pain out of game development” (Unity_Technologies 2009). The motto was achieved for a large number of aspects like loading 3d models, user interaction, and visualization purposes, although unity3d was not really developed for purposes like RubbleViewer. The engine is very well documented, there is a large user group, and the helpdesk responded quickly to question.

4.1 Function 1: Capture data and convert into a Model

Another name for this section could also be “taming the photo tourism algorithm”, because that is the core algorithm of this section and all the work done is to get the most out of the Photo Tourism algorithm. The description varies from capturing the data to create the model until a 3d model is created. In the prototype RubbleViewer there is still user interaction necessary to complete this process.

The steps for the user that are necessary for the first run for a dataset taken with a camera that has not been used before:

- Camera calibration
    - Photo tourism algorithm sensor size (4.1.2)
    - RubbleViewer sensor size(4.1.2)
    - RubbleViewer magic image plane size thingy (4.1.3)
- Take images correctly (4.1.1)
- Batch downscale the images(4.1.2)
- Rotate point cloud (4.1.4)
- Store point cloud out of RubbleViewer (4.1.5)
- Run qhull algorithm (Delaunay triangulation) (4.1.5)

4.1.1 Capturing data

The Photo Tourism algorithm (Snavely et al. 2008) and Photosynth application (Microsoft 2009b) prerequisites a dataset that suffice a number of thumb rules. Unfortunately the discovery process of these rules came with the cost of a few high fidelity image datasets taken in Disaster City, USA. The rules (Microsoft 2009a) are translated and complemented for RubbleViewer’s purpose:

1. Each part of the worksite must be visible in at least three images.
2. Start with an overview from positions uniformly distributed on a dome over the worksite.
3. The images need 50% overlap between images.
4. The angle difference should not exceed 25 degrees.
5. Shoot as less background objects as possible.
6. The details in the detail shots need to be visible in 50 percent of another image.

Creating these image datasets can be done feasibly for the SAR group with a sUAV. For these kind mission there is need for three people: one flight director or safety officer who will have an overview on what happens, one pilot, flying the UAV, and one mission specialist in charge of taking the right pictures and obtaining the necessary information from the Rubble Pile (Murphy et al. 2008; van Zomeren et al. 2009).

This resulted in two successful image datasets: one image dataset was captured with a sUAV after the Berkman Plaza II collapse in Jacksonville, USA (Pratt et al. 2008) and the other dataset was captured after hours of lumberjack work. The first could actually be used for USAR missions or simulation thereof. The second was used for explanation purposes in the expert review (Chapter 5 Test – Expert Review).

Figure 4-2 Example image of Berkman Plaza II Collapse dataset (Pratt et al. 2008)

Figure 4-3 Example image of the Woodset dataset

4.1.2 Photo Tourism algorithm

The Photo Tourism (Snavely et al. 2008) algorithm can be downloaded from the project website (Snavely 2008). The algorithm converts an unordered image collection to a point cloud of the surface of the object and the images of the dataset relevant to each other and the point cloud. The version used was “Bundler-v02” and was run on cygwin (Red_Hat.inc 2009) on a Microsoft Windows XP machine.

Running the algorithm on full resolution images is not feasible so one has to batch convert the images to a lower resolution containing the EXIF tags of the images. The datasets in this thesis were converted to a resolution that worked with the largest dimension of 900 pixels. EXIF tags are a useful resource for the Photo Tourism algorithm.

Extra information stored in the image (EXIF tags) and sensor size information from the camera is found necessary for the algorithm to work correctly. Providing this information to the algorithm improved the results dramatically from useless to usable. The algorithm estimates a number of variables. Less unknown variables will improve the result. In the EXIF tag is an estimation of the focal length and the name of the camera stored. The sensor size of the camera can be stored in the data file the algorithm uses.

The output of the algorithm is a description of a point cloud of the surface of the object and the relevant position and angle of the images in the original dataset. The positioned are all relevant to each other since there is no GPS information involved. This results in a point cloud that is incorrectly rotated. This makes it also impossible to automatically estimate the size of (parts of) the object.

4.1.3 Load data in RubbleViewer

Challenge of this part of RubbleViewer was to read the Photo Tourism output correctly and thus align the images with the model. This was a time consuming task, but not so interesting to describe from a scientific point of view. There is one manual input variable necessary to load the images correctly.

Two time consuming concepts to figure out were for example the handedness of the coordinate systems used and the way or rotating. It took a while before it was known that Photo Tourisms output was in a right handed coordinate system and data was to be visualized in RubbleViewer which is created with the engine Unity3d (Unity_Technologies 2009) in a left handed coordinate system. The conversion of the description of the rotation from matrix transformation to quaternions was time consuming. This was also due to a very small typo in a matrix multiplication function by the author revealing the need for thorough function testing.

The debugging process was difficult because of the fact that there was no comparison material that showed whether the output of the Photo Tourism algorithm was correctly visualized. So a test dataset was constructed**.** This test dataset helped in numerous ways. The understanding of the file format of the Photo Tourism algorithm was improved. The calculations necessary to visualize had to be done the other way around and thus helped in the understanding of these algorithms. It also helped to evaluate whether all the calculations where done correctly.

There was another way to evaluate the results of the algorithm. The description of the points in the point cloud consisted of a 3d position and a position in the image. So the other test method was to overlay the positions of the points in the images of the dataset. It could be evaluated whether the images were placed correctly by displaying the images slightly transparent with the point cloud visible through the images. The points in the point cloud should align with the points in the overlay of the image, an example where they don't align can be seen in (Figure 4-4).

Figure 4-4 Aligning the points in the image shown in red with the points in the point cloud shown in white in. The image from Kermit is from a test dataset included with the software (Snavely 2008).

After the relevant position and the rotation of the image was correct for the position of the model the scale of the image plan still had to be done. All the images of the same camera were the same factor of. This factor is to be manually added per dataset.

4.1.4 Rotate

The result of the Photo Tourism algorithm will not be rotated correctly; this is to be corrected once, manually for the 3d model to be displayed correctly**.** The Photo Tourism algorithm positions the photos of the dataset and the point cloud relevant to each other. The result will not be correctly scaled or rotated. This rotation error is to be corrected by hand to create a 3d model.

4.1.5 Delaunay Triangulation

The surface of the 3d model is estimated with an external 2d Delaunay triangulation (Barber et al. 1995), that is available at (Barber 2009). This is an estimation of the actual surface and is not optimal. The 3d point cloud (original) is first translated to a 2d representation by removing the height dimension (step 1). A Delaunay triangulation is done on the 2d data (step 2). After the Delaunay triangulation the 2d point data is translated back to 3d (step 3), by adding the height dimension again. The important elements of this process are illustrated by (Figure 4-5). The fact that 3rd dimension is ignored at the surface calculation step can introduces errors (Figure 4-6)**.**

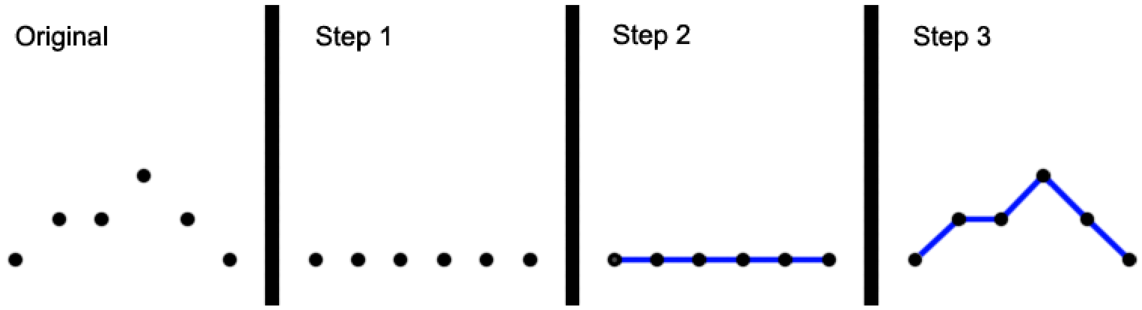


Figure 4-5 Delaunay triangulation without errors

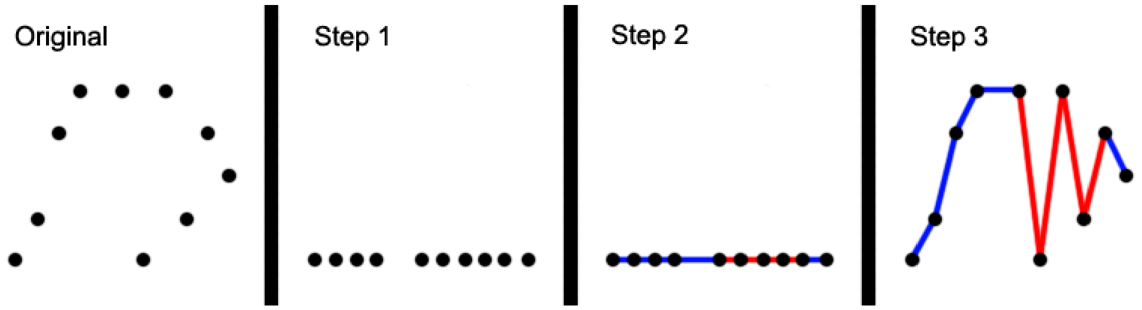


Figure 4-6 Delaunay triangulation, with errors. Correct elements of the surface in blue, errors in red.

Errors like described in (Figure 4-6) can and will introduce errors for certain collapse patterns and a point cloud with a wrong rotation. Overhanging elements won't be triangulated correctly; this can happen for example at the collapse patterns inclination and overhanging elements (Figure 2-6)**.** The original in (Figure 4-5) can be rotated in such a way that the triangulation process behaves similar to (Figure 4-6)**.** Thus a correct rotation of the point cloud is important.

4.1.6 Smooth Data

The triangulated surface is pretty rough; a Gaussian smooth function was utilized to smooth the surface. This resulted in a more appealing surface at the cost of accuracy. After the smooth function the relevant position of the objects in the images and the same objects in the model are slightly off.

4.2 Function 2: Show Model

The show model core function contains three elements: first the model calculated in (4.1) is textured, secondly to view the model there is a user interaction, and third the original image can be shown relevant to this model.

4.2.1 Texture Model

An easy and improvable texture is used. The 3d points used to create the 3d model from, hold color information. This information is also output from the Photo Tourism algorithm. Each vertices of each triangle in the model is such a point. On the triangles are the color values of these vertices interpolated and stored as texture.

4.2.2 User interaction

The user can interact with the model by rotating the model around a point. The point where the model is rotated around, or needle, can be repositioned by the user. The camera is always rotated towards the needle. This user interaction was chosen to make the understanding of the 3d elements of the 3d model better.

Once the needle is repositioned the camera is not looking directly at the needle anymore. Changing the view direction instantly will unsettle the user. Therefore it is opted to have a smooth transition from one viewing direction to the other. The smooth transition has a smooth start and end.

4.2.3 Show original image

The user can visualize the original images were the model was made of. Which image is shown is depending on the position of the needle. Once chosen the camera has to translate smoothly to the positioned the picture is shown from. This is done through a slow start and slow end smooth linear translation to the new position.

Choosing the best image to show is done according the position of the needle.

- The closest points in the point cloud to the needle are taken
- The Images are collected where these points are present in
- The resulting image list is sorted on how many points are present in the image and what the distance of these points is to the center of the image.

4.3 Function 3: Enable adding navigational aids

The current implementation of RubbleViewer enables the user to place the side numbering according the INSARAG guidelines as is described in (2.4.2). Blender (Stichting_Blender_Foundation 2009) was used to create the numbers in 3d. A fast way to add the four numbers in one go was developed. Once placed, the numbers will always be shown in the direction of the camera.

4.4 Function 4: Enable annotating USAR information spatially ordered by points

According the INSARAG guidelines (OCHA 2006), the victim signs (see Table 2-1) can be placed on the 3d model. These signs are constructed in Blender (Stichting_Blender_Foundation 2009) and will always be rotated in the direction of the camera. The same is done for the letters HM which is an unofficial acronym for Hazardous Materials. Detailed information can be found in a menu when one clicks on such a victim sign. In this menu it is made possible to change the status of this specific victim.

4.5 Function 5: Describe the rubble pile internally

In the current version of RubbleViewer the internals of the rubble are not described in 3d, they are described as a collection of images like in a comic book. The images can be added and sorted. It is made possible to add remarks for each picture.

4.6 Function 6: Enable annotating USAR information spatially ordered by regions

This function is due to time constraints not implemented and left for the next iteration.

4.7 Conclusion

This chapter describes the development of RubbleViewer ordered by core function. RubbleViewer is a prototype used to review the requirements baseline and the technical feasibility of the design. Unfortunately the implementation of function 1 ”Capture data and convert into a Model” is not completely autonomous after input of the image dataset. It requires limited user feedback. Rules of thumb to capture images from the worksite that can be used to create the model are described in this chapter. It can be said that there should be enough images, with sufficient overlap, and the difference in angles to the objects should not be too large.

Creating the model was done with two already existing algorithms: the algorithm behind Photosynth (Photo Tourism) and a 2d Delaunay triangulation. The input necessary for the Photosynth algorithm is a good image dataset of the worksite. As a result the original positions of the images relevant to each other are returned. In addition there is a sparse point cloud representing the surface of the worksite. This point cloud can serve as input for the 2d Delaunay triangulation creating a surface out of the point cloud.

Although RubbleViewer has flaws, this prototype is the first known prototype of a system that can feasibly be used during real USAR missions. It can be used to support the responders in building a shared perspective and use it to communicate information to other SAR groups about the worksite. RubbleViewer is specifically designed for the members of the SAR groups.

5 Test – Expert Review

Two expert reviews are done to validate the core functionality embedded in RubbleViewer. The first expert review focuses on SAR group members and the second review focuses on a structural specialist. The current prototype of RubbleViewer is reviewed by participants who are members of SAR group and are in the user group where RubbleViewer is intended for (5.1). Two of these participants participated in the pilot study. The other expert review was done in an informal fashion with one structural specialist (5.2).

Both expert reviews were done according the IMPACT model described in (Benyon et al. 2005). This model forces the reviewer to describe the expert review according six categories. What is the *intention* of the experiment? What is *measured* during the experiment? Who are the *people* that participate in the experiment? What are the *activities* they have to do? In which *context*? Which *technology* is used for the experiment?

5.1 Expert review SAR group members

All the documents used for this expert review can be found in Dutch in (Attachment 4 Questionnaire results).

5.1.1 Intention

The central question for this thesis is: "How to support a SAR group using 3d mapping techniques for the purpose of (1) communicating information from one SAR group to another SAR group during a change of shift and (2) the internal collaboration of a SAR group on a worksite?"(Chapter 1 Introduction) Observations during two training session has demonstrated that in more complex environments one SAR group failed to communicate information to another SAR group (or commander) efficiently. Consequently it is intended to measure whether RubbleViewer is an answer to the central question.

This expert review is not seen as a full blown experiment that will generate statistically significant data. For now it is important to show that RubbleViewer is developed in the right direction, obtain even more relevant domain knowledge, and most important update the requirements baseline. Practically, there are not so many SAR group commanders in the available user group of usar.nl.

5.1.2 Metrics and measures

When performing an expert review there are three important categories to measure. Is the product *effective (i.e.,* can the users perform the intended tasks?). Is the product efficient (i.e., Can the users do these tasks fast?). How satisfactory is the product, (i.e., do the users like to work with the product to achieve their goals?)

The research question can be measured by measuring the effectiveness, efficiency, and satisfaction. To be able to be effective RubbleViewer must be able to support the participants in creating an attack plan for a scenario described with a 3d map in RubbleViewer. It is not about creating the best possible attack plan, because they know better than anybody else what the best attack plan is for a specific situation. It is important that they retrieve the information stored in RubbleViewer and use this to create the attack plan.

The efficiency is measured by analyzing the steps the participants take to obtain their knowledge. The Thinking Aloud method that is utilized let the responders formulate their goals. It can be checked whether the participants take the shortest path to achieve their own goal. It can also be seen whether the participants have trouble performing an action by the amount of mouse clicks necessary to reach a goal. In addition surprise can also be a determining factor to show whether the thing that happens is also the thing that is expected by the responder.

Satisfaction can be measured by checking whether the participants want to use the product again. In the case of this experiment this is done with questionnaires. In these questionnaires they are asked to answer the question for whom they would create a view of the rubble using RubbleViewer.

5.1.3 People

The participants must be USAR personnel, since the main question is related to real USAR operations. Plus it is important to test the usability with people with the same computer skill set as USAR personnel. During USAR responses it is envisioned that the SAR group commander works together with the search specialist, together they construct situation awareness. When arriving on a scene where no USAR activities were done before the search specialist is expected to be a key player in adding information to RubbleViewer together with the commander.

There is no functionality implemented for the medic yet, so for this person an expert review is not relevant yet. It is expected that the search specialist is capable of providing enough information about the search and will be more effective as participant than a dog handler at the moment. It is also expected that the SAR group commander and search specialist can serve as delegates for the rescue workers.

The pilot was run with two SAR group commanders, the only two people who were available at that time. The actual expert review was performed with two groups of one SAR group commander and one search specialist.

5.1.4 Activities

The description of the activities consist out of three parts first the scenario's are described that are visualized in RubbleViewer; secondly the pilot is described; followed by the third part where the actual research is described. Naturally there were some changes to the research after the pilot.

Scenarios

The primary scenario, or Jacksonville scenario, is the scenario that is used to evaluate how well SAR group members can obtain situation awareness (Figure 5-1). This scenario is based on the Jacksonville dataset and contains USAR relevant information to base the attack plan on. The scenario contains five victims, named $V_{crushed}$, $V_{deceased}$, $V_{rescued}$, $V_{smiling}$, and V_{dog}. There is also one hazardous material in the scenario.

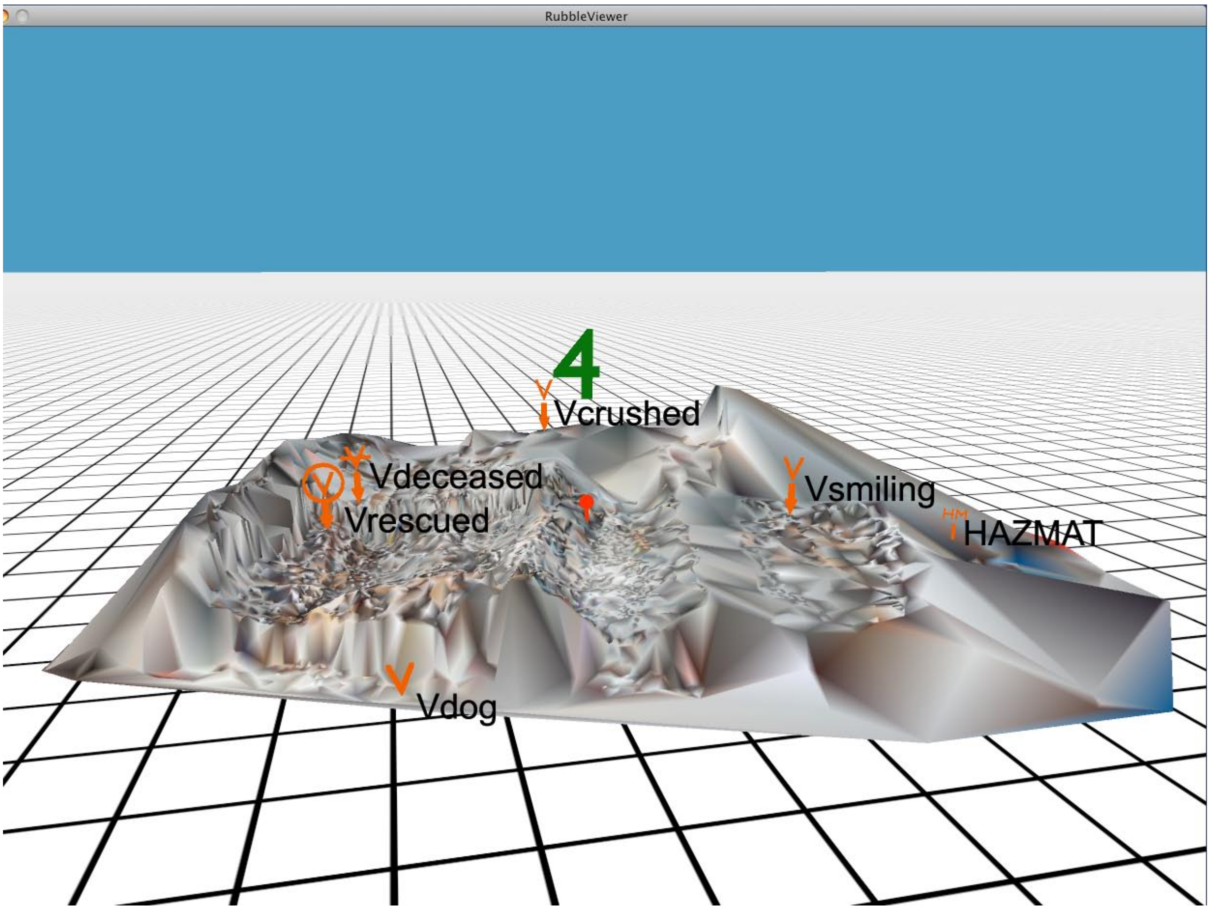


Figure 5-1 Overview of the primary scenario with information elements

The $V_{deceased}$ and, $V_{rescued}$ are in the scenario for the responders to immediately discard, because they are already rescued or not a priority to excavate. The priority of SAR groups is with the people they can still rescue.

The hazardous material is placed to test whether that is the correct sign and to make the scenario more challenging for the participants. The hazard is: hydrochloric acid. It is expected that the SAR group asks for help of the safety officer on this one.

There is also a location where there is still something left to do for the search personnel of the SAR group. The V_{dog} victim is not really found. There are only signs that there should be a victim somewhere in the neighborhood of that victim sign. It is expected that the search specialist is send to that location to try to find the victim.

$V_{crushed}$ is expected to be the highest priority for the SAR group members. Because it is a victim that needs medical attention and the researchers think that person should be easy to rescue. Figure 5-2 shows the path to rescue that specific victim. The signs that are drawn in the picture are designed to make the comprehension of the path to the victim easier.

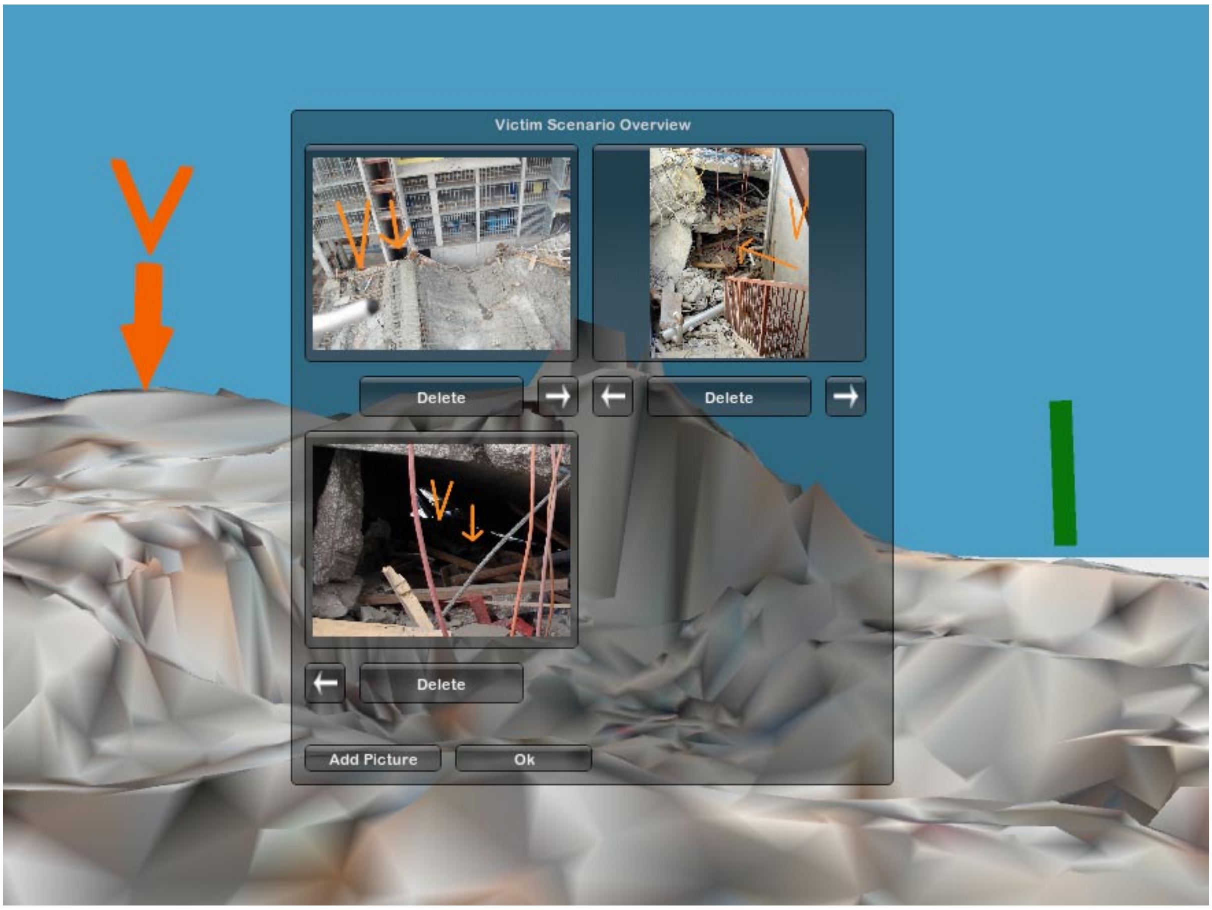


Figure 5-2 The route description to Vcrushed as described in RubbleViewer

$V_{smiling}$ is a victim in good health below two layers of 15 cm thick concrete. This makes him easy to rescue. However the victim is also in good health so the victim can be expected to be able to stay alive for a while. Figure 5-3 shows the path to rescue that specific victim. There are no signs drawn in this picture to assess whether these signs are missed.

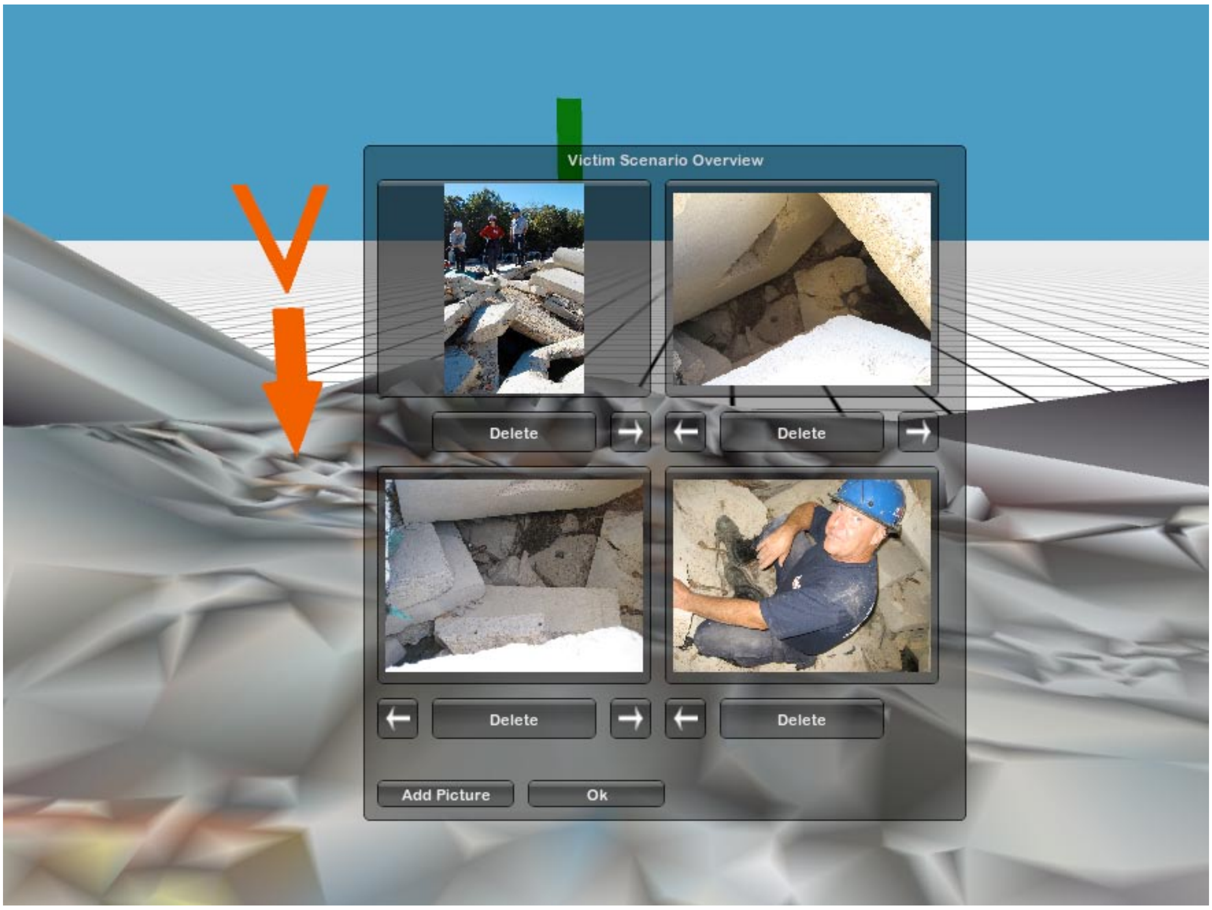


Figure 5-3 The route description to Vsmiling as described in RubbleViewer

For the second scenario is the woodset dataset used (Figure 5-4 and Figure 5-5). It is made of an image database of chopped wood and will not be used in a situation awareness task. In the pilot the set is used to add information to a 3d model and test how well RubbleViewer supports that. In the actual expert review the dataset is used to guide the user through all the functions needed to evaluate the main scenario.

A description of all the elements in the scenario is deemed not necessary. One just has to notice that all the elements necessary for learning the user interface for the actual expert review are in place.

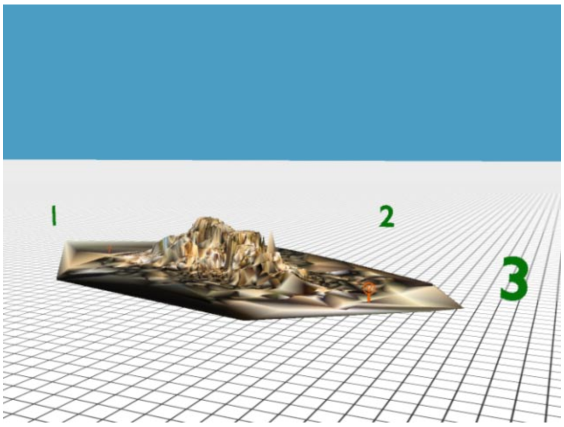


Figure 5-4 Overview of Woodset in RubbleViewer

Figure 5-5 Image in the Woodset dataset

Pilot Expert Review

The pilot study is done to evaluate the scenarios and the paradigm (Table 5-1). After the set up of all equipment the pilot study will start with an introduction of the research by the researcher, which will be followed by the same introduction in writing to make things clear, an informed consent form is delivered to the participants for signing. Before RubbleViewer can actually be used the manual is handed to the participants for immediate reading and for reference during the expert review. During the whole expert review the researchers are available for questions.

The main part of the expert review is divided into two separate tasks. The primary task is to provide the USAR responders with a scenario in RubbleViewer, the Jacksonville scenario. In this scenario there are multiple victims and hazards described. The goal for the participants is to create an attack plan to rescue as much victims as possible. The constraint is that there is only one SAR group available (2.1). After that a brief discussion will follow about RubbleViewer.

The second task was to explore whether it is easy to annotate information using RubbleViewer. This is guided by sub tasks like add victim next to “place description”. For this task the woodset was used, a dataset of pictures of chopped wood.

A discussion about RubbleViewer is the last part of the pilot.

Time in minutes	What
0 till 5	introduction by researcher
5 till 15	Read Description of research in writing Fill in Informed Consent form Read Manual RubbleViewer
15 till 45	Create an attack plan from the primary scenario (Jacksonville)
45 till 55	Brief discussion
55 till 75	Add information to the Woodset scenario
75 till 100	Discussion

Table 5-1 Time frame pilot expert review

Expert Review

The activities of the expert review are planned similar to the pilot study with some changes (Table 5-2). The research was explained in the introduction by the researcher and the description of research in writing. This is because it is important for the SAR group members to know how a 3d map is created with RubbleViewer before the SAR group members are able to give an opinion about the product. For example the answers to the questionnaires may change radically if creating a 3d map is as easy as sketching on a piece of paper. This is still unchanged with the pilot as is the filling in of the consent form. After which a Questionnaire is added to ask specific questions to the participants

Time in minutes	What
0 till 5	introduction by researcher
5 till 15	Read Description of research in writing Fill in Informed Consent form Fill in Questionnaire beforehand Read Manual RubbleViewer Read INSARAG Guidelines Cheat Sheet if necessary

15 till 25	Do RubbleViewer trainings scenario tasks
25 till 30	Brief discussion
30 till 50	Create an attack plan from the primary scenario
50 till 55	Discussion
57 till 60	Fill in Questionnaire afterward

Table 5-2 Time frame expert review

The goal of the questionnaire that is filled in before the participants had the chance to see RubbleViewer is to understand their current way of mapping and their way of providing information to others. There are multiple choice questions about the quality of the information they receive when they come to relieve another SAR group. This is to support the fact that the problem RubbleViewer is intended to solve is really a problem perceived by the actual responders. It is also necessary to know for whom they sketch so RubbleViewer can be designed for these people, and the purpose that suits them best. A thorough domain analysis revealed a number of constraints RubbleViewer must comply before RubbleViewer can be used, but the domain experts might have some extra constraints. In the questionnaire the responders can tell what their expectations of a 3d map are.

After the manual was provided to the participants, they also got a cheat sheet on which the most important INSARAG mapping symbols are described. These symbols convey victim status information and are thus vital for the understanding of the scenario described with the 3d map in RubbleViewer. During the pilot experiment was found that the responders did not know the symbols by heart. So the cheat sheet was deemed necessary.

It was decided to cancel the task where responders are asked to add information to a map, instead a trainings scenario were the responders are guided through the process of information gathering to be able to create an Attack Plan was added. For this scenario the woodset was used. This means we won't get information about the usability of adding information on the 3d model. But the expert review still does provide information about the usability of gathering information with RubbleViewer. To speed up the process the responders are stimulated to ask for help while they are guided through the process of information gathering. After the training scenario a brief discussion will follow about RubbleViewer.

The primary task is, similar to the pilot, provides the USAR responders with a scenario in RubbleViewer, using the Jacksonville scenario. In this scenario there are multiple victims and hazards described. The goal for the participants is to create an attack plan to rescue as much victims as possible. The constraint is that there is only one SAR group available (2.1). After that a discussion will follow about RubbleViewer.

Both assignments are done according the Co-discovery technique (Kennedy 1989). So two participants work together to complete the tasks presented to them. This elicits discussions about the task and thus presents an insight for the experimenter on how the participants complete the task and why they do it that way. It is expected that the participants discuss their attack plan, and thus tell the experimenter the information that is important for them to make their decisions. If usability problems arise the participants will probably discuss these problems.

The questionnaire that is filled in after the expert review is created to evaluate RubbleViewer's performance. Here they can provide information about how useful they thought RubbleViewer was for different purposes. It is expected that sketching is better if a responder wants to remember spatial relations for himself, because sketching is a low cost solution compared to RubbleViewer. So the questionnaire provides the opportunity for the participants to explain for whom they would create a 3d map in RubbleViewer for which purpose.

5.1.5 Contexts

The experiment is done in the context of a USAR exercise in Dubai. The first two days the USAR personnel were kept on a military base to acclimatize for the extreme heat in May in Dubai. They were only allowed to do light physical activity, classes, and rest. During the rest periods the participants were available for the expert review in a nice air conditioned room.

The room was a conference room with one desk. The two participants were placed behind the desk with one Macintosh computer running RubbleViewer. The computer was running screen capture software, apart from the screen the internal webcam, and microphone was also captured. There was also video camera running, since the internal webcam did not capture both participants

For the experiment there were four people present: the two participants, the experimenter who also developed RubbleViewer, and the experimenter's supervisor who also handled the camera.

The pilot was done under similar circumstances. As big difference was that the experiment was done in the fire station, roughly a week before the exercise in Dubai.

5.1.6 Technologies

The scenarios in RubbleViewer were already computed, so the participants did not have to wait till the 3d model was calculated. There was a small load time though, when the scenarios were changed.

RubbleViewer is run on a MacBook 3.1 with a 2.2 GHz Core 2 Duo processor and, 4GB of ram, and a two button mouse.

The video was captured with a video camera.

5.2 Informal expert review structural specialist

In contrary to the expert review with the SAR group members the Informal expert review with a structural specialist was not to evaluate RubbleViewer, but to elicit information on how the structural specialist would want the information to be visualized. As a preliminary answer to the following research question: "Additionally, can the same technology facilitate constructing situation awareness for other disciplines that are useful for the Search and Rescue process, when arriving at the worksite?"

5.2.1 Intention

This session is intended to provide the researchers with more knowledge on how structural specialists would want a collapsed building to be visualized when they want to advice a SAR group. Before they can advice the SAR group they need a high level of situation awareness, because they have to project the future status of the building when a specific action is performed.

5.2.2 Metrics and measures

It will be “measured” what the tools are the structural specialist is going to use to obtain situation awareness about the collapsed structure. The information these tools provide the specialist is also something of interest, so it is possible to design a better support tool for the structural specialists.

5.2.3 People

We intended to do this informal expert review with one structural specialist. This would mean that the results are inconclusive, but will provide an inside on how the structural specialist works.

5.2.4 Activities

The task of the structural specialist is to use RubbleViewer to inspect the Jacksonville dataset. This was done with the think aloud strategy. This way the participant explains what he thinks while doing the expert review. Providing the researcher the possibility to learn what the important aspects are and which goals the participant is trying to reach.

5.2.5 Context

The experiment is done in the context of a USAR exercise in Dubai. After the exercise the personnel was waiting for their plane back to the Netherlands. During this time it was possible to arrange a small setting with two beds. One bed did function as a desk for the laptop and the other functioned as a chair for the structural specialist and the experimenter, sitting next to each other.

5.2.6 Technologies

The only technology that is used is RubbleViewer with the pre computed Jacksonville dataset. RubbleViewer is run on a MacBook 3.1 with a 2.2 GHz Core 2 Duo processor, 4 GB of ram, and a two button mouse.

5.3 Conclusion

In this chapter two expert reviews where described. The first expert review was to test RubbleViewer as a communication tool for the SAR groups. The other expert review was to obtain knowledge about how a structural specialist obtained data about a collapse and what such specialists are looking for in their information sources.

The expert review for the SAR groups has a co-discovery learning approach. The main part of the expert review was a scenario where two SAR group members have to design an attack plan. The participants are first given an introduction in the user interface of RubbleViewer. Before and after the expert review the participants are given a questionnaire to answer a few questions about RubbleViewer.

The expert review for the structural specialist was informal and aimed at discovering the workflow of a structural specialist. The specialist was given a dataset of a collapsed building, and the specialist had to evaluate the building as he normally would for when asked to give advice to the SAR groups. This was done using the think aloud strategy that reveals the thoughts an expert has during the completion of the task.

6 Results

The result of our expert review showed that the SAR group members were able to create an attack plan for the scenario designed as information source for a shift change of SAR groups. This means the participants were effective in retrieving the information stored in RubbleViewer and thus RubbleViewer is an answer to the first part of the research question "*How to support a SAR group using 3d mapping techniques for the purpose of communicating information from one SAR group to another SAR group during a change of shift".* The results of the evaluation with the SAR groups, leading to an update for the requirements baseline, are further described in section (6.1).

The structural specialist could also use the pictures visualized in RubbleViewer and build a mental model on how the building was collapsed. So that could be considered a success. In addition the expert review revealed a number of improvements to improve RubbleViewer's capability to aid the structural specialist in building high levels of situation awareness. The evaluation with the structural specialist is described more thoroughly at (6.2) and also resulted in an update of the requirements baseline.

The Expert Review revealed a lot of usability issues, as was already expected, because RubbleViewer was still an academic prototype and the usability issues were not fully addressed. Three issues are mentioned in this paragraph to illustrate the type of findings; the other issues found are listed and seen as not relevant for this thesis. The first issue was that RubbleViewer does not show what it is doing while performing large calculations, this can be annoying for the user who is waiting till RubbleViewer is ready to interact again. The second issue was that it was found difficult to click on the victim signs. The third issue was that it was too easy to delete things in RubbleViewer, and this could be done accidentally.

6.1 Results Expert Review SAR group team members

All the participants who are members of usar.nl could use the information retrieved from RubbleViewer to have a tactical discussion. They had no other source of information. All discussions leaded to an attack plan. All the participants groups focused at some point in the review on the three relevant victims for them $V_{crushed}$, $V_{smiling}$, and V_{dog}. The participant 2, 3, 6, and 7 found $V_{crushed}$ the highest priority while participants 4 and 5 planned to do a quick assessment by the search specialist for victims $V_{crushed}$ and $V_{smiling}$. This was to get more information to make a better decision.

Information thrust is an important factor. For certain information the participants wanted to know who added this information. Was it the safety officer who made the assumption that the hazardous materials were only dangerous in a radius of three meter or someone who was less capable to make these decisions?

Another thing was that the participants (4, 5, 6, and 7) said that it would be a good idea to send this information to higher command. They could for example decide to send another team to execute the rescue they could not execute at the moment. Or the information could be presented with some sort of a "google maps" document to show where the SAR groups are working at the moment. RubbleViewer could also be useful in the staff tent to instruct the new SAR group that is coming to relieve the old SAR group.

Participant 1

This participant is not a USAR responder. The results of this participant leaded to usability issues, not thoroughly discussed in this thesis.

Participants 2 and 3 (pilot)

Participants 2 and 3 were two SAR commanders who were asked to do the pilot test. The difference of the pilot and actual test is described in section (5.1.4); the main scenario was similar to the actual test. They were discovering new ways to interact with RubbleViewer while trying to create an attack plan, since there was no RubbleViewer training in the pilot. The participants discovered the functionality of RubbleViewer in a goal based manner or after hints from the experimenter.

The first thing they did was trying to get an overview image, after which they rotated around the model, while discussing facts about the building like the number of floors. After that they viewed all the victim and hazmat locations and viewed the images used to create the model to discuss the structure around the building. After all the locations were viewed with the images the experimenter hinted that there was also information attached to the menus behind the victims. And they went on to inspect all this information for all elements on the map. While inspecting the detailed information they found out what the different INSARAG signs meant.

They missed a way to assign priority to victims, and a way to annotate who was going to inspect what. So they started to draw a sketch on their own to prioritize the different victims. They created an overview picture with RubbleViewer to discuss the attack plan.

The resulting attack plan was:

- Neglect $V_{deceased,}$ and $V_{rescued}$
- Provide medical attention to $V_{crushed}$
- Search specialist, needs to do a search effort for $V_{smiling}$, and later at V_{dog}.
- Safety Officer needs to inspect the Hazardous Material.

Participants 4 and 5

The first thing the participants did to gather information to create an attack plan was to get an overview position and they quickly assessed all the victims according the INSARAG guidelines. They decided to put effort in the $V_{smiling}$, $V_{crushed}$, V_{dog}, and HazMat locations. With the images they looked at the surroundings of the relevant victims. After that they looked at the images attached to the victims they were focusing on.

They said they had not enough information to decide who to rescue first. Basically they wanted to see both $V_{crushed}$ and $V_{smiling}$ in real live to make the decision about how to rescue these victims and who first.

Their preliminary attack plan was:

- Search specialist, needs to do a search effort for $V_{smiling}$, and $V_{crushed}$ to advice on who to rescue first.
- They neglected the HazMat, V_{dog}, $V_{deceased}$, and $V_{rescued}$

Participants 6 and 7

The participants first read the news paper about where they were going to and used that to infer some knowledge about the worksite they were going to work on. After that they got the INSARAG guidelines cheat sheet and started to give a summary of the victim types and Hazardous Materials that are on the worksite.

After the summary they discussed each victim that was relevant for them ($V_{crushed,}$ $V_{smiling}$, and V_{dog}), and the HAZMAT. With the information attached to the victim. They did not use the images that were used to create the model.

Normally the fact that Hazardous Materials was on the scene would mean that there would be no USAR activity. However the folk wisdom that the $V_{smiling}$, was still alive made it safe to assume that it was reasonably save around that victim. Thus it they decided to continue the USAR effort.

Their attack plan was:

- Search Specialist to V_{dog}
- Rest of the SAR group to $V_{crushed}$
- $V_{smiling}$ can wait
- Safety Officer needs to inspect the Hazardous Material.

6.1.1 Function 1: Capture data and convert into a Model

This function was not evaluated

6.1.2 Function 2: Show Model

The model combined with the images proofed to be effective for the responders in building situation awareness. However, it is possible to improve the efficiency a lot. The images proofed to be an eye opener for the responders, the responders started to grasp what the model was really about when the images used to create the model where shown. They could grasp what the model was about, so that is effective, but it took a while and they needed the images. That is not as efficient as it could be.

There were two remarks about the quality of the 3d model. The first was that noise points, or outliers sometimes were seen as parts of the construction. The other remark was that two different participants groups requested a way to know the measures of the 3d model. One group wanted to know how deep the collapsed building was at a certain position to determine an attack route. The other group wanted to estimate the distance from a hazardous materials source, which was described as dangerous in a range of 3 meters. The responders wanted the visualization of the inflicted area.

More remarks were about the texture of the model. Showing the original images relevant to the model was necessary to get any idea about what the model really is. All the three USAR participants groups were surprised when they saw the first image of the trainings set scenario, which was a heap of chopped wood. The texture did not provide any clue for them to expect that. Two of the three USAR participants groups requested a model with the images textured on the model.

The original images positioned relevant to the model was really helpful for understanding what the disaster area looked like and they are really necessary for their detail. At this moment the images are low resolution, but all the participants requested zoom capability to see more details. The participants used the images to estimate sizes on the disaster area.

Choosing the right image for the object they wanted to see was not efficient. They want to see objects from different sides. They rotated the camera to the site they wanted to see the object from, and hoped that the image that would be shown would also be from that side. They also requested to view all the camera positions that were relevant to an object so that they could choose the image they wanted themselves.

6.1.3 Function 3: Enable adding navigational aids

There was discussion about the use of the current navigational aids in RubbleViewer. These navigational aids are numbers on the sides of the worksite according the INSARAG guidelines. Unfortunately the usar.nl members did not know about the existence of these types of markings. One group used these markings on a sketch they made themselves, after the signs were explained to them. Another group requested for the quarters of the compass to be displayed instead of these numbers or some sort of underlying map where the model of the building was registered to in contrast of other buildings in the neighborhood.

6.1.4 Function 4: Enable annotating USAR information spatially ordered by points

The participants could use the INSARAG markings to decide which victim to assess first, after the markings were explained to them. Participants 2 and 3 did not know the Markings, so they did not narrow down on the relevant victims. Since they were the participants of the pilot, they did not have the INSARAG Guidelines cheat sheet. Participants 4, 5, 6, and 7 used the INSARAG Guidelines cheat sheet to narrow down the relevant victims and inspect these into more detail. Having the cheat sheet available made the use of the signs a lot more efficient.

It was possible for the participants to distinguish the different victims, but they missed a way to order them or refer to them in speech. While talking about specific victims they frequently turned the camera of RubbleViewer to the victim or they put the Pinprick at the location of the victim they were discussing. While using RubbleViewer they tried to find a way to distinguish the victims by speech. So they described the victim before talking about them. Four of the six participants requested some way to distinguish the victims in RubbleViewer. They said a number could do. RubbleViewer is effective, because the participants were able to distinguish the victims, but it could be more efficient.

6.1.5 Function 5: Describe the rubble pile internally

All the participants eventually used the “show scenario” button to get more information about the route to the victim. All the participants showed they understood the information attached to victim $V_{crushed}$ in the form of the pictures in the scenario. Especially the INSARAG Guidelines arrows drawn on the images were found useful and made the communication with RubbleViewer more efficient. These drawings were missing at the $V_{smiling}$ location and that caused some confusion about the actual entrance to the void the victim was hiding.

There were two things that could be improved for the description of the rubble pile internally. First the existence of these images was not clear to all participants. Some participants had to be guided by the experimenter to view these images. The second finding was that the responders requested zoom functionality. They wanted to see certain parts of the image in higher detail.

6.1.6 Function 6: Enable annotating USAR information spatially ordered by regions

Although this function was not a function that was supported by RubbleViewer and was thus not tested, the participants 6 and 7 missed the functionality to annotate region on the rubble pile. The participants wanted to know which part of the worksite was invested by the hazardous material and was thus deemed unsafe to work in.

6.2 Questionnaire SAR group members

The questionnaires were filled in by four SAR group members. This means that the results cannot be seen as scientifically proven, but only suggest an outcome. The section describes how the participants rate the current situation of communication (6.2.1), the future situation (6.2.2), and whether for which purpose they would RubbleViewer or sketches (6.2.3). The questions that correspond with these different parts are described in line and can be found in Attachment 3: Documents for expert review (in Dutch)**.**

6.2.1 Current situation

All the four participants can’t always understand sketches about collapsed buildings that they receive from someone else. This is supports the basis of our research question, that current shift changes are open for improvement.

The participants answer the question whether they are well prepared when traveling to a worksite (Attachment 4 Figure 2) slightly negative, two negative, one undecided, one positive. This at least means that there is some improvement possible in their preparations. Whether that means other equipment, more training or more detailed knowledge about the worksite cannot be said based on this result.

They are undecided about whether the relieve of SAR groups is well arranged (Attachment 4 Figure 3The relieve of SAR groups is well arranged.), two participants negative and two participants positive. This also means that there can be something improved. It is known that they don’t have a lot knowledge about a worksite when they are going to that worksite. So that can be an explanation, but it can for example also be through the fact that they want a better SAR group relieve timing.

As is describe in (Attachment 4 Figure 4 and Attachment 4 Figure 5) the responders are undecided whether they want to know what happened at a worksite where they were relieved. This was a functionality that was requested verbally by a responder, according the results they don’t think it is a must have.

6.2.2 Future situation with RubbleViewer

The result indicates that RubbleViewer is a suitable answer to the research question. This test did not include capturing the images, was not tested in the field, and was done with only four participants. In (Attachment 4 Figure 6) can be seen that all four participants thought that RubbleViewer can improve the effectiveness of their mission. In addition, in (Attachment 4 Figure 7) is described that they all think RubbleViewer is useful for communicating information to the SAR group that will relieve the current. They are also positive about issuing people to create

RubbleViewer (Attachment 4 Figure 10). Most of the participants would also be willing to add information to RubbleVIewer, two out of three who filled in that question (Attachment 4 Figure 9).

6.2.3 Use of RubbleViewer and Sketches compared

Sketches and 3d views with RubbleViewer are both to remember and communicate Situation Awareness, but they serve a different goal. This part of the questionnaire provides insight for whom both technologies can be used according personnel from usar.nl. Beforehand there were six groups of people identified to communicate Situation Awareness to: the person himself, other people in his SAR group, the USAR team commander (C1), the SAR group that will relieve the current SAR group, the structural specialist, and the safety officer.

With the questionnaires it is compared how often the person would sketch for one of these persons with whether they would create a 3d map for the same person. That is not strictly the same so it cannot be compared directly. However a result is that the person would never sketch for the safety officer, but would agree to create a 3d model with RubbleViewer for the Safety officer. This is at least a suggestion that RubbleViewer would be used for a goal where sketches are not used for.

For the person himself

As can be seen in (Attachment 4 Figure 11 and Attachment 4 Figure 12) the participants are likely to sketch for themselves, but four out of three people disagree to the fact that they would create a 3d model with RubbleViewer for themselves. This is not unexpected, because they will probably understand their own sketches. When that is the case it is not necessary to create a 3d map with RubbleViewer. The freedom and ease of sketching becomes more important.

The commander that filled in that he would use RubbleViewer for himself did that to make it easier for him to show information to others.

Apart from remembering information about the worksite for themselves and prioritize the victims the search specialists would use their sketch to document the search with the microphones.

For SAR group members

The participants would sketch for their SAR team members, and are indecisive about creating a RubbleViewer for their SAR group team members. This can be seen in (Attachment 4 Figure 14) where two ticked against and two are positive about creating a view on the rubble with RubbleViewer. There is a need to communicate, since they will very often sketch for their SAR group members (Attachment 4 Figure 13). So it is expected to be depending on the costs whether they would use RubbleViewer for the communication of information to their SAR group members.

The search specialist explained in the questionnaire that they would use sketches to document the search with listen and or seismic devices.

For Commandant USAR (C1)

The participants are slightly negative about using RubbleViewer for informing the USAR team commander (C1) (Attachment 4 Figure 16), and they would not (two participants) or rarely (two participants) sketch for the C1 (Attachment 4 Figure 15). It is expected that the USAR team commander does macro management of the disaster. Deciding which SAR group is send to which worksite to rescue people. For this cause it is irrelevant to know the exact location of the victim. It is more important to know how much victims can be saved at which worksite.

For other SAR group

SAR team members would sketch for another SAR group (Attachment 4 Figure 17), three would do that very often and one search specialist would never do that. All four participants would use RubbleViewer to inform a new SAR group that arrives at the worksite (Attachment 4 Figure 18). The fact that they sketch to transfer the knowledge indicates that the desire is there to transfer that knowledge using some kind of a map. The participants also indicated that they don't always understand the sketches they receive of others (Attachment 4 Figure 1).

One of the SAR group commanders wrote on the Questionnaire form that there was a clear transfer of knowledge with RubbleViewer. One of the search specialist indicated that he would never sketch for another SAR group, this might be because it is not the job of a search specialist to sketch transfer knowledge to people who are not in his SAR group.

For Structural Specialist

SAR teams will not sketch for a structural specialist (Attachment 4 Figure 19), and they are slightly negative whether they would use RubbleViewer to inform the structural specialist (Attachment 4 Figure 20). Two participants answered undecided and one answered negative. It is Important to notice that both SAR groups had negative experiences with structural specialists during a SAR mission, because the structural specialist was not able to provide useful advice.

One of the SAR team commanders indicated that it would be useful if the structural specialist would be able to annotate where the structure is stable and save and where it isn't. We have indications that a structural specialist might use RubbleViewer to advise the SAR group at a distance. If this could be done then their opinion might change radically. Because the structural engineer is not always available on the worksite and fast advice can improve the safety.

In the scenario there was no goal for the structural specialist.

For Safety Officer

The participants won't sketch for a safety officer (Attachment 4 Figure 21), but they are slightly positive about creating a RubbleViewer for the safety officer (Attachment 4 Figure 22). In the scenario (see section 5.1) there was a hazardous material that could be dangerous for the mission. One of the participants indicated that they would like the safety officer to annotate the danger area around the hazardous material, so they could continuo the mission around it.

In contrary to the structural specialist the safety officer will always be needed on the worksite when there are hazardous materials, because he would have to measure these materials and interpret the results.

6.3 Results informal Expert Review with structural specialist

This expert review suggested that RubbleViewer helped the structural specialist with sorting the images and thus helped in building situation awareness. The results must not be taken definitive, since the results are based on only one structural specialist. However the results provide a good hint on what the important information is for a structural specialist.

The core function that was analyzed was the Show Model function. Placing annotation and the other functions were found irrelevant for this stage of the research. Later these functions may become relevant when advising the SAR group on whether it is possible to rescue a victim or annotate regions that are for example found to dangerous to work in.

6.3.1 Function 2: Show Model

During the expert review there were two expected results and one unexpected result. The first expected result was that the structural specialist first needed overview image and detail images after that. The second and unexpected result was that the 3d structure in RubbleViewer was an important source of information, other than just pictures, on how the structure was collapsed. The third finding was that the images shown needed to be high resolution.

When the structural specialist is to analyze a collapsed structure the first thing he needs is an overview after that the specialist will want to look at specific details. The participant asked for a plan view containing the whole scene. That image was not available in the dataset. The model of RubbleViewer combined with the images served as this overview. Once the overview was clear the participant used the same images to look at details in the scene.

A new finding suggested that the 3d aspect of the model is important for the structural specialist in two ways. The first way is that the structural specialist is looking for the supporting elements in the collapsed building. These elements are said to be located at the locations where the collapsed structure is higher than its surroundings. The second reason that suggests that the 3d aspect is important for the structural specialist is that the participant is looking for height patterns in the model. This is information that could be used to determine the way the structure is collapsed, or through which pattern the structure is collapses see (Figure 2-6).

High resolution images are necessary , this finding is supported by (Murphy et al. 2008) and (Pratt et al. 2008). In this version of RubbleViewer the images are low resolution for computation purposes. The structural specialist frequently asked for the high resolution images or zoom functionality while using RubbleViewer. After the expert review the high resolution images could be shown. While analyzing these high resolution images the structural specialist corrected a mistake he made. The shoring equipment used for building the parking garage was in the low resolution mistaken for the steel bars of reinforced concrete.

Choosing the right images was found. The structural specialist wanted to see some objects from different angles in varying detail and found it difficult to select the right image.

Whether the context of an image that was used to create a model was understood depended on how the camera translation to that position was. The translation to the correct camera position where the image will be shown was found smoothly most of the times. Sometimes it involved a quick rotation. At these times the structural specialist had difficulties in understanding where he was looking at.

6.4 Conclusion

The main result of the expert review was that the participants could have a tactical discussion on the information stored in RubbleViewer. So the prototype of RubbleViewer was able to communicate information to participants who were not present on the scene. It has been found though that RubbleViewer is sometimes a too high tech solution for the task at hand. There is a balance between the need for clarity and the effort necessary to obtain this clarity, so sometimes sketches are a better solution than a view on the Rubble using RubbleViewer. The expert review did also show some factors where RubbleViewer can be improved.

The participants where positive about the use of RubbleViewer for their mission, said differently the satisfaction was high. They used RubbleViewer as an information source for their tactical discussion that resulted in an attack plan. This proves that it is possible to communicate information using RubbleViewer and construct at least level two situation awareness, comprehension of the current situation. The questionnaires also support this conclusion, since the participants thought RubbleViewer to be an asset that improves the effectiveness of the mission. However this is not proof that RubbleViewer is the best solution possible or even feasible for real USAR missions.

Clarity and effort necessary to obtain this clarity are factors that have to be weighted by the SAR group members when they decide how to communicate situation awareness. The questionnaires suggested that the knowledge about the worksite is a factor in deciding whether to sketch or create a view on the rubble with RubbleViewer. So for themselves they would create a sketch, because that is easy to do and they will understand the sketch. They are more likely to communicate Situation Awareness with RubbleViewer to a Safety Officer who does not know the worksite, than sketch.

The 3d model and images placed relevant to that model were effective but not efficient to describe the locations where the information like victim entrances was. This means that the participants are expected to be able to find the entrances to victims based on the information stored in RubbleViewer, but that RubbleViewer could be improved to make this faster. This also goes for the structural specialist who missed a good overview picture, which should be provided by the model.

The images were necessary to make this localization possible and the participants sometimes where surprised that the rubble pile looked that way when viewing the images. A textured model would make this localization easier and is expected to remove the surprise factor.

Choosing the right images was found difficult for the SAR group personnel and the structural specialist. Both wanted to see some objects from different angles in varying detail and found it difficult to select the right image.

7 Conclusion and further work

7.1 Conclusion and discussion

How many extra victims entombed in a collapsed building could be saved if SAR groups would have a better way to communicate their findings efficiently and effectively? RubbleViewer is a 3d mapping prototype made to support this communication and, as is described by the situated Cognitive Engineering methodology (Neerincx and Lindenberg 2008), to evaluate the requirements baseline for such a support tool. In other words RubbleViewer is the prototype created to answer the following research question:

"How to support a SAR group using 3d mapping techniques for the purpose of (1) communicating information from one SAR group to another SAR group during a change of shift and (2) the internal collaboration of a SAR group on a worksite?"

Six core functions are found necessary to solve this question after an extensive domain analysis. These core functions capture the whole spectrum necessary to create a RubbleViewer that can really be used by the end users. From capturing the image data with a sUAV to annotating mission critical information to the system all the elements are touched.

- Function 1: Capture data and convert into a Model
- Function 2: Show Model
- Function 3: Enable adding navigational aids
- Function 4: Enable annotating USAR information spatially ordered by points
- Function 5: Describe the rubble pile internally
- Function 6: Enable annotating USAR information spatially ordered by regions

The functions were evaluated during an expert review with responders from usar.nl. Constructing an attack plan on how to continue the rescue mission based on the information in RubbleViewer was the main part of the evaluation. This is to simulate the event that a SAR group comes to a worksite where another SAR group has already worked and needs to build situation awareness effectively and efficiently to continue working. Other elements in the expert review were two questionnaires one before and one after the main part.

The main finding was that all the pairs of responders were able to create an attack plan based on the information present in RubbleViewer. Such a plan cannot be created when the situation is not understood or the responders did not have at least situation awareness level two – comprehension of current situation. RubbleViewer was thus effective as a communication tool and thus it is suggested that RubbleViewer is an answer to the first part of the research question above. What the actual attack plan was is not of importance. Important was the fact that based on the information that was visualized by RubbleViewer the responders where able to have a tactical discussion.

RubbleViewer is still a prototype and the expert review also revealed a number of improvements that are possible to create a better prototype. This resulted in an update of the requirements that need to be satisfied in the core functions. For example the requirements of function two were updated with the requirement that the model on itself must provide an overview of the situation. Another example is the update of the requirements of functions 3, 4, 5, and 6 is that the signs used in RubbleViewer are not remembered by hearth by the responders, although these signs are copied from guidelines they use. The information these signs communicate must also be in writing.

For whom RubbleViewer can be useful is further analyzed in the questionnaires, the clarity of RubbleViewer comes with the cost of having to capture data. People will understand the sketches they make for themselves, meaning that the extra effort of capturing data for extra clarity has no added value. The participants are also reluctant to use RubbleViewer for the communication to their fellow SAR group members, two would use it and two won't. The fellow SAR group members are on the scene themselves and will probably understand a sketch that is made on the scene. This suggests that RubbleViewer is not an answer to the second part of the research question and will probably not be used as an internal collaboration tool at the worksite. This might change if the cost for creating a view on the rubble is reduced or there is already a view on the rubble available, so why not use it.

The value of RubbleViewer is in the communication to other people who have no situation awareness yet. The participants are more positive to use RubbleViewer to communicate to people who are new on the scene and have value for the Search and Rescue process. The questionnaires strongly suggest that another SAR group that is to relieve the current SAR group is such a group. The participants are also positive about RubbleViewer as a communication tool to the safety officer and are slightly negative as a communication tool for the structural specialist. In addition to the main research question the following research question lead also to interesting results:

> *"Additionally, can the same technology facilitate constructing situation awareness for other disciplines that are useful for the Search and Rescue process, when arriving at the worksite?"*

The question above is very broad so it was narrowed down to one discipline, the structural specialist, and an informal expert review was done with one such an expert. The core function "show model" was evaluated and lead to interesting results. RubbleViewer helped the structural specialist to understand the positions of the images relative to each other. The images need to be high resolution. A 3d model was also a valuable source of information for the structural specialist. This leaded to another update of the requirements baseline. Unfortunately there was no proof whatsoever that the structural specialist could build situation awareness level 3 and advice the SAR group based on the information in RubbleViewer.

7.2 Further work

Each of the core functions can be improved or extended. The two most important factors to show the value of RubbleViewer that can be extended are the ease of data capture and putting a good texture on the model. It is still a hit or miss situation whether RubbleViewer will be able to create a model from the images that were shot. Did the photographer comply with the rules to create a good dataset or not? The envisioned technology is a combination of laser scanning with photogrammetric technology. The other aspect that can be improved is the surprise when the first image is shown relative to the model. At that moment the participants understood where what kind of collapsed building they were looking at. A good informative texturing of the model could do the trick.

Currently the structural specialist has to visit the worksites where the SAR group is working when a structural inspection is necessary. These worksites are possibly located at a large distance from the base camp. This can result in a lot of travel time for the structural specialist and waiting time for the SAR group. Wouldn't it be great if the structural specialist and the SAR group could collaborate at a distance? A preliminary result of this research is that RubbleViewer is an improvement for the structural inspection mission compared to just a bunch of pictures. There is research necessary to make the structural inspection mission and RubbleViewer a perfect fit. This research must proof that the structural inspection with RubbleViewer provides the SAR groups with valid advice.

When we broaden our horizon and think of RubbleViewer in a bigger system that communicates information to build situation awareness for different people in an USAR team. Then there is a lot of careful thinking necessary to support each discipline the right way. Different disciplines at different times want information on different detail levels. For example an USAR commander needs to know where each SAR group is and the type of support each group needs. A search specialist needs to know exactly behind which concrete slab a living victim is. One must keep in mind though that there is a threshold where information that one needs to have becomes want to have and one must not pass this threshold for the sake of clarity.

This research can also be useful for whole different purposes each purpose has to be thoroughly investigated. Can archeologist use similar technology for documenting an excavation site? Can the police use similar technology to document crime scenes like a car crash site or a murder scene? Is a BuildingViewer interesting for the fire department to see heat images in perspective of the building that is burning?

8 Abbreviations

INSARAG	International Search and Rescue Advisory Group
C1	Commander usar.nl
COT	Country Operational Team
CRASAR	Center for Robot Assisted Search and Rescue
FEMA	Federal Emergency Management Agency
HRI	Human Robot Interaction
IMPACT	Intention Measures People Activities Context Technology
LEMA	Local Emergency Management Authorities
OCHA	Office for the Coordination of Humanitarian Affairs
OSOCC	On-Site Operational Coordination Centre
PACT	People Activities Context Technology
RAMR	Robot-Assisted Medical Reachback
SAR group	Search and Rescue group
SIFT	Scale Invariant Feature Transform
SA	Situation Awareness
SUAS	Small Unmanned Aerial System
SUAV	Small Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
UNDAC team	United Nations Disaster Assessment and Coordination team
USAR	Urban Search and Rescue
USAR.NL	Urban Search and Rescue – Netherlands
vOSOCC	Virtual On-Site Operational Coordination Centre

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Attachment 1: First design RubbleViewer

Why

USAR teams want to find (and rescue) victims of a structural collapse buried deeply inside the building. To be able to find the victim they need insight in the rubble. Currently they utilize different techniques to provide this insight: dogs, pole mounted cameras, microphones, and robots. *Rubble Viewer* combines these techniques to provide the USAR team with a "superman view" to see the parts inside the rubble necessary for their work. *Rubble Viewer* must do this without burdening the USAR team to much.

Apart from providing the USAR team with an overview of the search results *Rubble Viewer* also helps the user to solve existing problems. A problem with searching victims with robots is that it can get lost in the rubble. One might not know anymore where the robot is at that moment. This is a problem, because once a victim is found by the robot the victim's location is pretty important for the rescue process.

At this moment USAR teams write maps according to international guidelines with spray cans on the wall (if such a wall is present)(Attachment 1 Figure 1).It is very difficult to plan such a map in a way that discovering and adding new rooms to the map does not lead to visual clutter. The problem with this visual clutter is best shown when a team change take place after approximately 8 hours of Search and Rescue effort. The arriving team can have difficulties understanding the drawn map. These difficulties are larger in more difficult situations. Another difficulty with a 2 dimensional map is that it is difficult to notate the location of a victim in the 3d world.

Attachment 1 Figure 1 Current USAR map painted on the wall with a spray can.

It is also useful to be able to show the structure in the structural collapse, because this gives clues about possible voids, where victims can be located in.

Requirements

The proposed 3d map, *Rubble Viewer*, must be able to show the user the structure of the collapsed building and be really helpful in the task of searching and rescuing victims. The map must also be easy to create and the visual clutter should be minimized. Some facts annotated on the map will have a larger likely hood of being sound than other facts this must also be represented.

The map must aid the USAR team more than it burdens the team.

With such a map what are the functions *Rubble Viewer* should provide for USAR personnel:

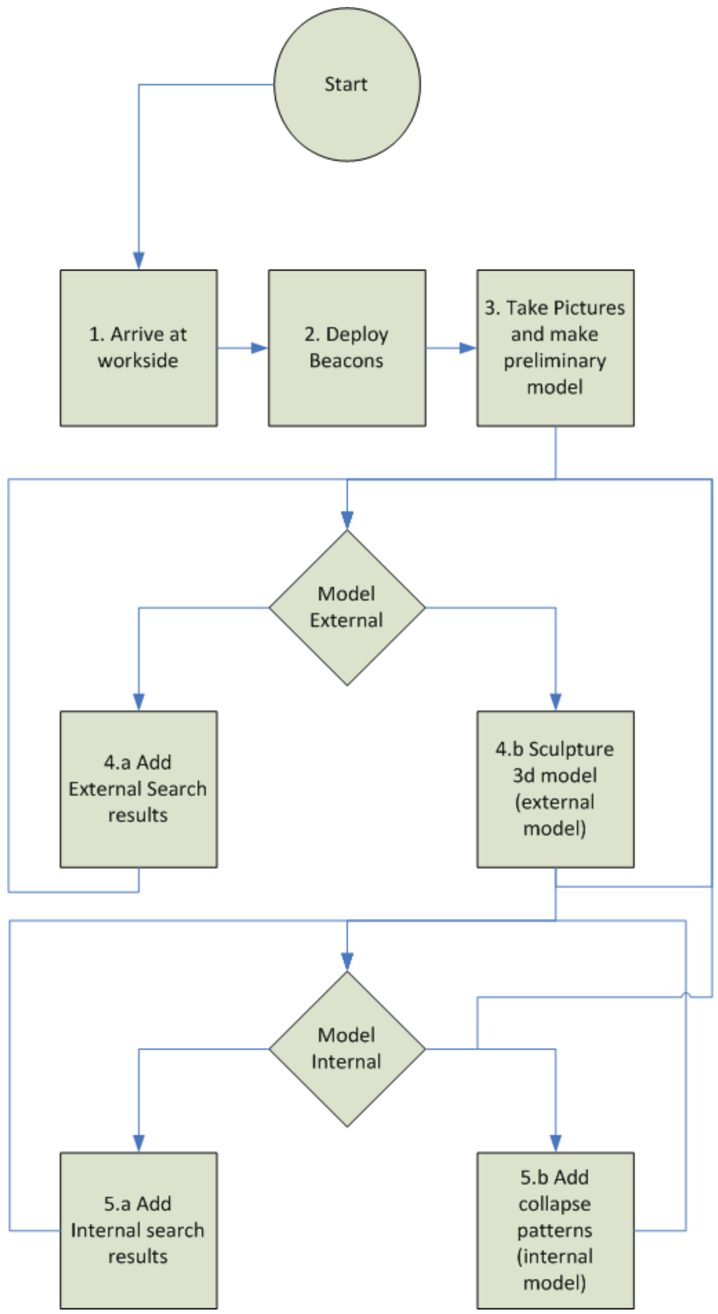
- Show search results
    - Search location + result
    - Estimated position of victim based on search results
    - Victim and status of victim
    - Estimated time to rescue a victim
    - Show path robot (Estimate path robot with inertia sensors (6 degrees of freedom), show drift)
- Rescue
    - Show possible routes to a victim
    - Show difficulties a route to a victim will contain
    - Information on building materials
- Provide void information
    - Show whether the void is already examined
- Provide danger information
    - Hazmat
    - Building stability

Rubble Viewer's possible functions:

- Advice where to search next
- Coordination of people.
    - Who is where
    - Doing what
- Connection to Incident Command.

Design

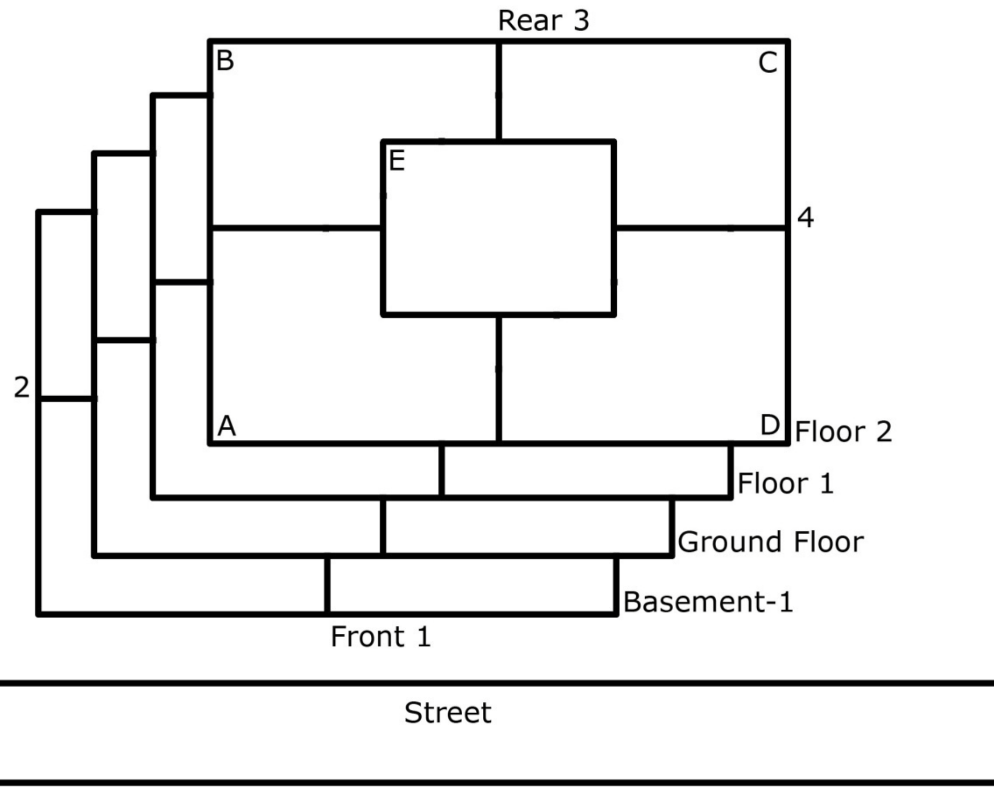
This is a procedure to create a 3d map of the collapsed building / rubble as efficient as possible (Attachment 1 Figure 2).



Attachment 1 Figure 2 Flow Chart 3d Map making

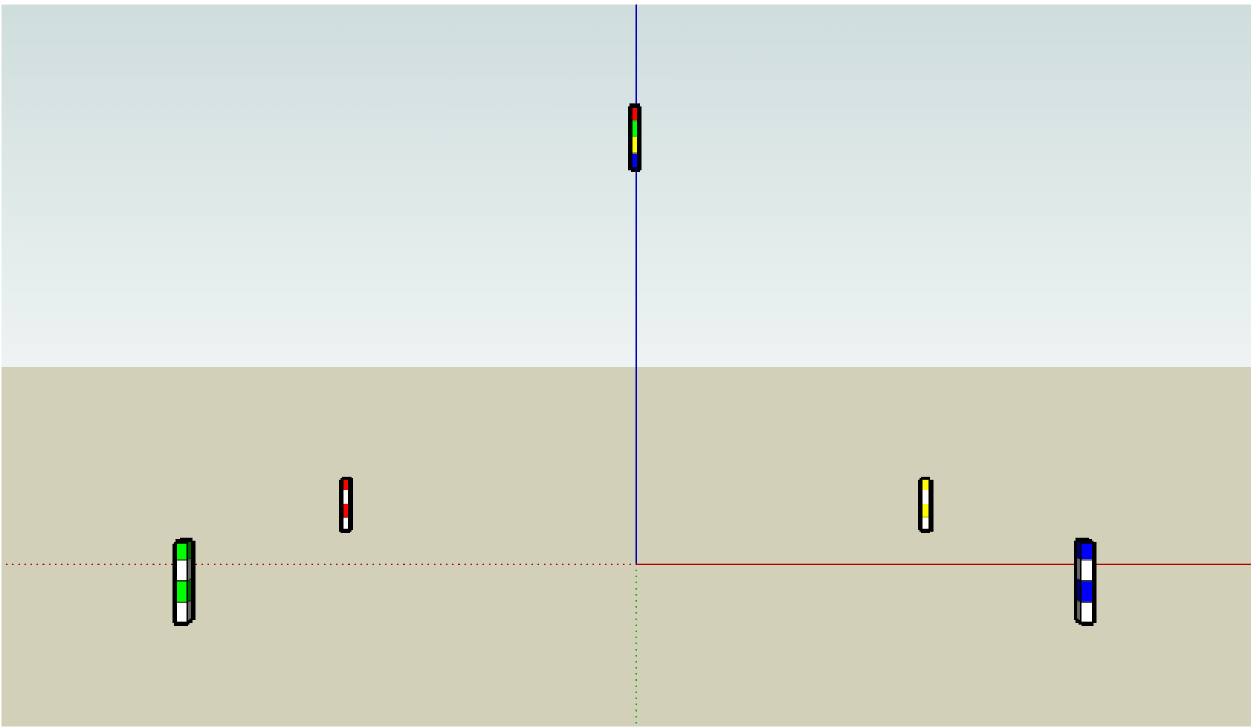
Step 1: Arrive at disaster side.
This is the phase in the plan where an USAR team arrives at the side and decides they are going to perform operation on this particular worksite.

Step 2: Deploy beacons
The goal of this phase is to define a coordinate system where actions can be described on. This coordinate system should be visible at all locations on the disaster area. For this application four beacons on the ground are chosen. These are located at the positions which are described in USAR jargon as A, B, C, and D (Attachment 1 Figure 3). The fifth beacon is deployed above the disaster area in the area called E.



Attachment 1 Figure 3 USAR location numbering

The beacons should have a color which catches the eye and all the beacons should have a different color so there is the possibility to easily discriminate between the beacons (Attachment 1 Figure 4). The beacons should contain a localization device. To localize the other beacons and calculate their relative position. The beacon at location E, should be some kind of a balloon.



Attachment 1 Figure 4 Example beacons, defining a coordinate system

Advantages of beacons

- The beacons provide a coordinate system.
- Precise localization is possible, because of triangulation.
- Precise localization is important, because it provides an entering robot with an initial fix. So it will be able to perform dead reckoning on his position with more precision.
- Other fixes are possible when the robot is near the surface of the rubble. (With the use of UWB radar a maximum of 60 cm for reinforced concrete is allowed)

Disadvantages of beacons

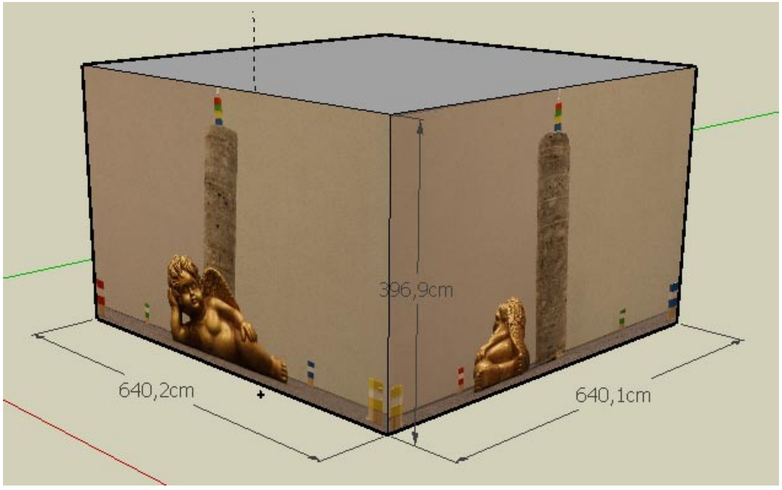
- The beacons have to be placed first.
- The beacons can break.
- The beacons have to be carried with them on the plane. Extra weight must provide enough functionality to leave something else at home.
- They may not move anymore. Otherwise the coordinate system will fail. Perhaps not true, when more than three beacons are used.

Step 3: Take pictures, and make preliminary model

In this phase pictures are taken from the outside of the rubble. These pictures are then loaded into the pc and used to provide the user with a preliminary model, which can be used to talk about the disaster site and possible attack plans.

Every picture must be located such that at least three beacons are visible. The beacon at position E should be visible at every image. The best images are created when the camera is on the ground at the same distance to the two beacons on the ground closest to it.

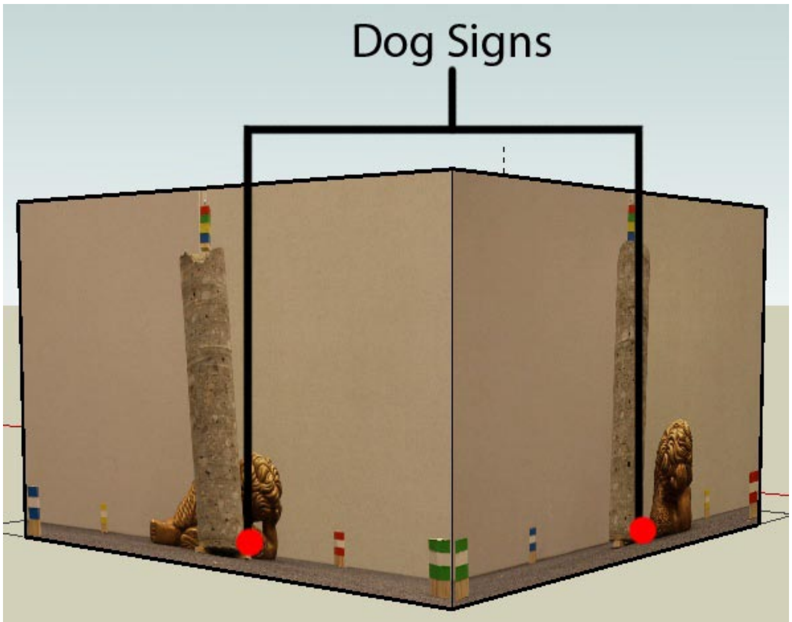
After computation a preliminary model (Attachment 1 Figure 5) will be presented to the user. The model will be made out of the pictures placed on sprites at the correct 3d position. It can be used by a USAR team member to talk about attack plans and possible victim location without having to be at the disaster site.



Attachment 1 Figure 5 Example Preliminary Model of perfect pictures

Step 4a: Add External results

Since step 4b is not yet finished, the only possibility is to add search results on the cube at two or more views. Results can be: “drilled at this location”, or “a dog signed at this location” (Attachment 1 Figure 6).



Attachment 1 Figure 6 Dog Signs at this location

Step 4b: Sculpture 3d model (external model)

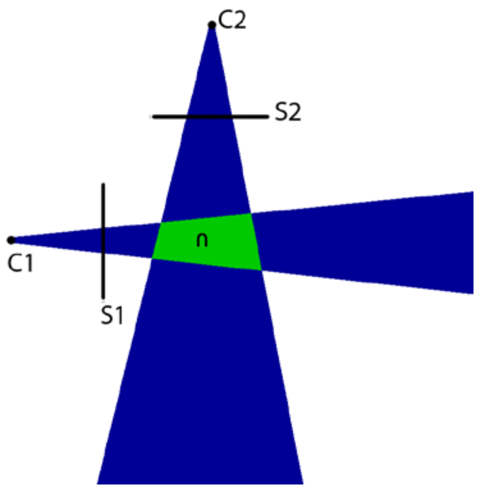
With the result of phase 3 is it still difficult to discuss the inside of a building. So a rough convex hull of the rubble is created during this step.

How is this done?

The user must draw the outline of the collapsed building on the images provided. Since the camera position is calculated and the sprites can be positioned at the correct location the computer can then perform perspective extrapolation to calculate what is expected to be in the rubble pile and what is out of the rubble pile. There are more sprites with corresponding camera positions that also have a perspective extrapolated model. The intersection of all these models provide a rough model of the rubble pile.

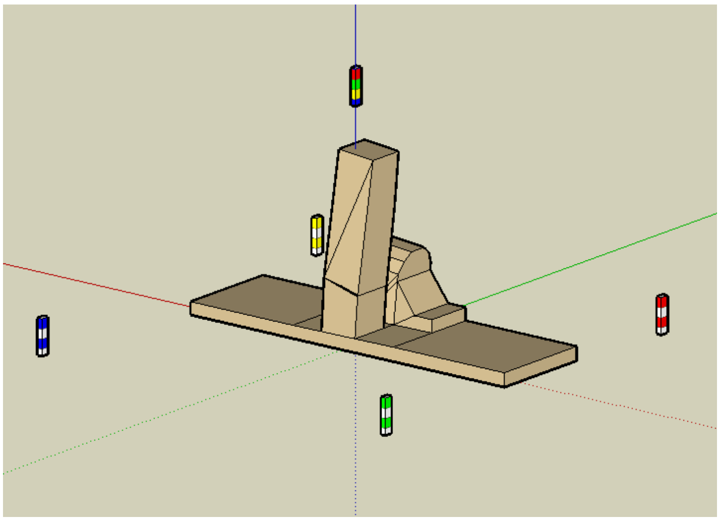
An example in two dimensions. First the camera 1 (C1) and the sprite 1 (S1) must be located at the correct position. Then the user should specify what is rubble and what not. This makes it possible for the computer to extrapolate the positions of the model (Attachment 1 Figure 7). It is possible to do the same for another camera (C2) and another sprite (S2). The intersection of both areas is a rough model of the object (Attachment 1 Figure 8).

Attachment 1 Figure 7 Result of one camera with extrapolated model.

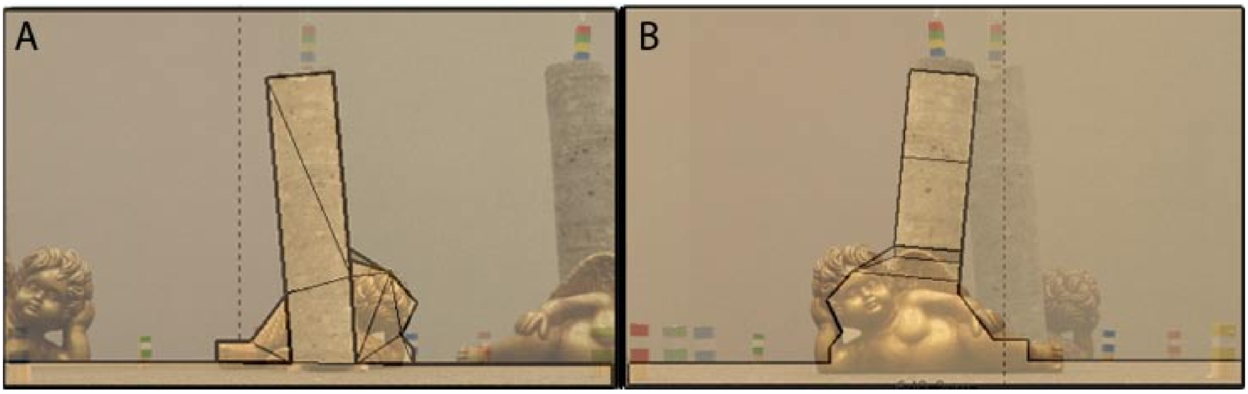


Attachment 1 Figure 8 Intersection of two cameras

The explained recipe is tested on a group of two simple objects. The technique was a little different. Parallel extrapolation was used instead of perspective extrapolation (Attachment 1 Figure 9). The technique was simulated in google SketchUP. Unfortunately the technique was found not sufficient, because of the problems best explained by (Attachment 1 Figure 10). In the B part of the image the head of the laying angel is outside the object. The other aspects of this design are explained with this example.



Attachment 1 Figure 9 External model with coordinate system



Attachment 1 Figure 10 parallel projections of opposite sides

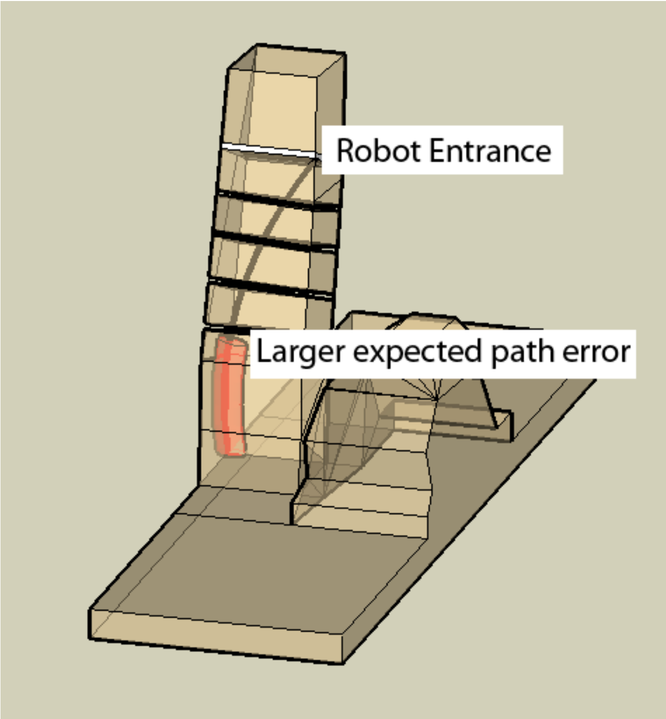
Step 5a: Add Internal Search results

Internal search results are for example:

- Robot paths.
- Images taken inside by a pole mounted camera.
- Possible sources of vibrations.
- Possible sent sources.
- Location of hazards
    - Fires inside the rubble
    - Hazardous Materials
- Possible victim locations.
- Possible routes to a victim.

It might be a good idea to show how certain a position is, since these positions are likely to have errors. In Attachment 1 Figure 11 a robot path is added to the model. The robot path is estimated by inertia sensors. The estimated path of the robots has errors. This is the result of sensor drift. The small path shows the expected path. The larger volume around it shows the location the robot can also be at.

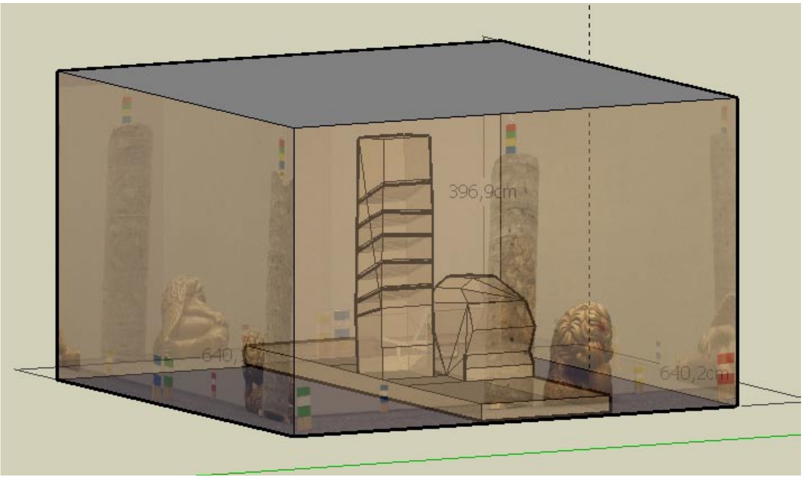
If collapse patterns are also added to the model, the structure in the model can be used to display possible voids. An option is to show whether there is already searched in a void.



Attachment 1 Figure 11 Robot Path in a model with a collapse pattern

Step 5b: Add collapse patterns (internal model)

In the database there should be a number of collapse patterns which give the opportunity to place them in the hull build in step four. This will give the internal model of the map more structure (Attachment 1 Figure 12). As example some floor slabs are added to the object as if they were collapsed in a pancake like collapse.



Attachment 1 Figure 12 Parallel projection of Inside model with collapse pattern

Discussion

The design of *Rubble Viewer,* was discussed In the former paragraphs. There are three technical difficulties expected in the creation of the 3d model.

1. Creating a coordinate system. (When the distances of the beacons is known, they must be positioned at the correct location in the 3d world.)
2. Position the images at the correct location in the 3d world

3. Calculating the intersection of the 3d models created by the perspective extrapolation of the images.

One of *Rubble Viewers* goals is to create the model without burdening the USAR team member too much. Yet provide enough precision for them to do their work and to let *Rubble Viewer* be useful. The domain expert can provide valuable input to optimize this.

Rubble Viewer is envisioned to be a collaboration tool for USAR team members to discuss the findings of their search together or with new teams (Attachment 1 Figure 13). It can also be used to show the Incident Commanders far away what the progress is of their teams. This gives them the situation awareness, necessary to make decisions.

Attachment 1 Figure 13 Rubble Viewer in action?

Attachment 2: RubbleViewer Manual

This manual explains the core functions of RubbleViewer. RubbleViewer comes with one dataset, the images taken in Jacksonville after the Berkman Plaza II Parking Garage collapse.

Load data:

- On init → press Load Rubble → Jax (and wait around 10 seconds on my machine) → esc closes the menu
- To remove noise press esc → Remove Noise → Gaussian Noise Remover → ok (This changes the position of the points and so how well the pictures and the points match.)

Navigation:

After closing the menu it is possible to view the model of the former Berkman Plaza II.

- The arrow keys rotate the object around the PinPrick (the red thingy).
- W and S move the object closer to the camera.
- The left mouse replaces the PinPrick to the position on the model where is clicked.
- “Enter” puts the user in the show image mode, the image that shows the position at the pinprick the best is shown. Pressing “enter” again will exit the show image mode.
  - “Space” toggles the camera or shows a new image, when the pinprick is moved.

Adding information to the model

This RubbleViewer prototype supports adding USAR relevant information to the model. Like victim information in diverse stadia, Side numbering (inSARag), and Hazmat. It is possible to attach a scenario to a victim.

Landmarks

- Right click on the model →Add Landmark → create new
  1. Moving the mouse over the model repositions the numbers. (left click go to 2, right click finishes positioning the landmarks)
  2. Moving the mouse rotates the numbers. (Left click go to 1, right click go to 1)
  3. Moving the mouse moves the numbers away from the center. (Left click finishes positioning the landmarks, right click go to 2)
- Right click on a number opens the landmark menu again.

Victim

- Right click on the model → Add Victim → Create New
- Right click on the victim model opens the menu again.
- In the menu it is possible to change the state of the victim.
- In the menu it is possible to add a scenario.

Hazmat

- Works similar to the Victim

Attachment 3: Documents for expert review (in Dutch)

RubbleViewer Expert Review

RubbleViewer is een programma om 3d kaarten te maken en te gebruiken voor USAR doeleinden. Het is gebleken dat de schetsen die nu gebruikt worden in ingewikkelde situaties lastig te interpreteren zijn. Het doel van RubbleViewer is om een uitkomst te zijn voor deze ingewikkeldere situaties. Enerzijds als kennis overdracht tussen twee shifts van SAR groepen en anderzijds voor het overleg aan de rand van de puinhoop over mogelijke aanvalsplannen.

Om het voor RubbleViewer mogelijk te maken om een 3d model te maken moeten er eerst foto's van de puinhoop gemaakt worden. Deze foto's moeten voldoende overlappen. Het beste kunnen deze foto's gemaakt worden met een Unmanned Aerial Vehicle. Deze robot kan over het ingestorte gebouw gevlogen worden. Na de vlucht moeten de foto's ingeladen worden in RubbleViewer. Na enige tijd is het model klaar om gebruikt te worden.

Het doel van dit expert review is om jullie, de USAR experts, te laten evalueren hoe RubbleViewer voor jullie in het veld nuttig kan zijn. Verder is het belangrijk dat RubbleViewer gemakkelijk in het gebruik is. Het expert review bestaat dan ook uit 2 delen. Allereerst krijgen jullie de opdracht om u de besturing te leren kennen. Vervolgens mogen jullie een aanvalsplan maken aan de hand van een scenario van een echt ingestort gebouw.

Het is de bedoeling dat jullie tijdens deze opdrachten zoveel mogelijk overleggen. Dit geeft ons inzicht in de gedachte achter de actie die uitgevoerd wordt. Het is nadrukkelijk niet zo dat jullie getest worden, RubbleViewer wordt door jullie getest. Uiteraard kunnen er altijd vragen aan ons gesteld worden. Als jullie ergens niet uit komen.

Aan de hand van deze expert reviews kan RubbleViewer verder ontwikkeld worden. Jullie input is dus ook zeer belangrijk en zal meegenomen worden in de volgende versies van RubbleViewer. De belofte kan niet gemaakt worden dat alle suggesties ook allemaal geïmplementeerd zullen worden. RubbleViewer is op dit moment nog een prototype en is dus nog niet compleet.

Expert Review Informed Consent Formulier

Naam onderzoeker: ________________________________

Naam participant: ________________________________

Participant nummer: ________________________________

Functie Participant: ________________________________

Dit onderzoek is bedoeld om de samenwerking van USAR personeel te bevorderen op de rampplaats met behulp van een 3d kaart. Ons doel is om USAR personeel daadwerkelijk te ondersteunen en niet te hinderen in hun werkzaamheden. Uw input als doelgroep is hierbij van vitaal belang!

In deze sessie gaat u samen met uw collega werken met het prototype RubbleViewer. U zult opdrachten krijgen om met uw collega uit te voeren, die geïnspireerd zijn uit het toekomstige gebruik van RubbleViewer. Twee onderzoekers zullen aanwezig zijn in dezelfde kamer als u. Zij kunnen vragen beantwoorden als dit nodig mocht zijn.

Alle informatie die in deze sessie verzameld wordt is van de TUDelft en zal gebruikt worden voor interne doeleinden. We zullen video en audio opnames maken van deze sessie. We mogen onze resultaten van deze en andere sessies publiceren in onze rapporten, maar in geen van deze rapporten zal uw naam genoemd worden.

Tijdens deze sessie wordt de software getest en niet u. Wij willen ervan leren zodat RubbleViewer verbeterd kan worden. Het is toegestaan om te pauzeren en u kunt uw medewerking aan dit onderzoek te allen tijde intrekken.

Verklaring van Informed Consent

Ik heb de beschrijving van deze studie gelezen en begrijp de rechten van mij als participant. Vrijwillig stem ik toe te participeren in dit onderzoek.

Naam: ________________________________

Handtekening: ________________________________

Datum: ________________________________

Vragenlijst vooraf

Participant nummer:

	Informatie voorziening vooraf	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
1	Als ik naar een rampplaats toe ga om een ander team af te lossen ben ik van te voren voldoende ingelicht over de situatie ter plaatse.					
2	De informatie overdracht tussen twee verschillende SAR groepen die elkaar aflossen is op dit moment goed geregeld.					
	Schetsen	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
3	Als ik een schets van een ingestort gebouw krijg van iemand anders, dan begrijp ik hem altijd?					
4	Wat zou een oorzaak kunnen zijn als ik een schets van een ingestort gebouw niet begrijp?					
	Voor wie maak ik schetsen?	Nooit	Zelden	Soms	Vaak	Zeer Vaak
5	Mezelf					
	Waarom?					
6	Mijn (SAR groep) team leden					
	Waarom?					
7	De commandant C1					

	Waarom?					
8	De SAR groep die mij komt aflossen					
	Waarom?					
	Voor wie maak ik schetsen?	Nooit	Zelden	Soms	Vaak	Zeer Vaak
9	De bouwkundige					
	Waarom?					
10	De veiligheidsofficier					
	Waarom?					
11	Anderen namelijk: _________________					
	Waarom?					
	Verwachtingen	Open				
12	Wat verwacht ik van een 3d kaart?					

Bedankt voor het invullen van deze vragenlijst.

Handleiding RubbleViewer

Navigatie:

Nadat de menus gesloten zijn kan de camera verplaatst worden.

- **De pijltjes toetsen** roteren het ingestorte gebouw om de naald heen. (De naald is het rode ding ongeveer in het midden van het ingestorte gebouw.)
- **W en S** verplaatsen de camera dichter naar de naald toe.
- **De linkermuis knop** verplaatst de naald naar de plek waarop geklikt is op het model.
- De **Enter** knop laat RubbleViewer wisselen tussen de modes waarin foto's kunnen worden getoond en de modes waarin dat niet kan.
    - Bij het indrukken van de **spatiebalk** in de juiste modes wordt de foto laten zien die de omgeving van de naald het beste laat zien.

Annoteren op de 3d kaart

Zijde numbering toevoegen:

- **Klik met de rechtermuis op het model → Add Landmark → create new**
    1. Om het middelpunt van de cijfers te verplaatsen beweeg dan de muis over het model. (**Klik met links** en ga naar 2, **klik met rechts** en je bent klaar met het plaatsen van de zijde nummering.)
    2. Het bewegen van de muis roteert de nummers van de zijde markering (**Klik met links** en ga naar 3, **klik met rechts** en ga naar 1.)
    3. Het bewegen van de muis beweegt de nummers verder van het middelpunt. (**Klik met links** en je bent klaar met het plaatsen van de zijde nummering, **klik met rechts** en ga naar 2.)
- Rechter muis klik op een nummer opent het landmark menu opnieuw.

Slachtoffer

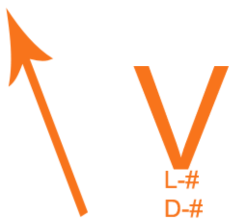
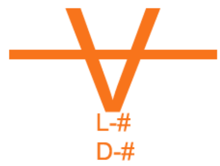
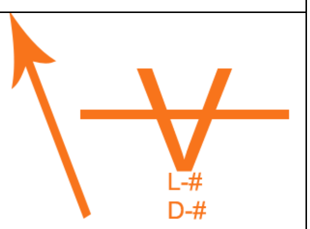
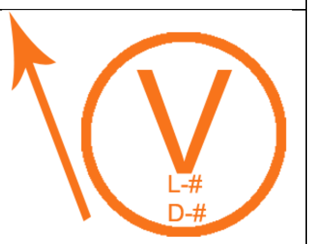
- Slachtoffers kunnen toegevoegd worden: **Rechter muis knop op het model → Add Victim → Create New**
- Het slachtoffer menu kan weer geopend worden: **Rechter muis knop op een slachtoffer model.**
- In dit menu is het mogelijk om de status van het slachtoffer te veranderen.
- In dit menu is het ook mogelijk om foto's en text toe te voegen aan het scenario: **Show Scenario → Add Picture →Add Image → vul de fotonaam (met extensie) in die staat in de map scenariopictures → ok → add →ok**

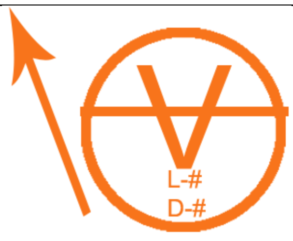
Gevaarlijke Stoffen

- Dit werkt gelijk aan slachtoffer
- Toevoegen: **Rechter muis knop op het model → Add Hazmat → Create New**

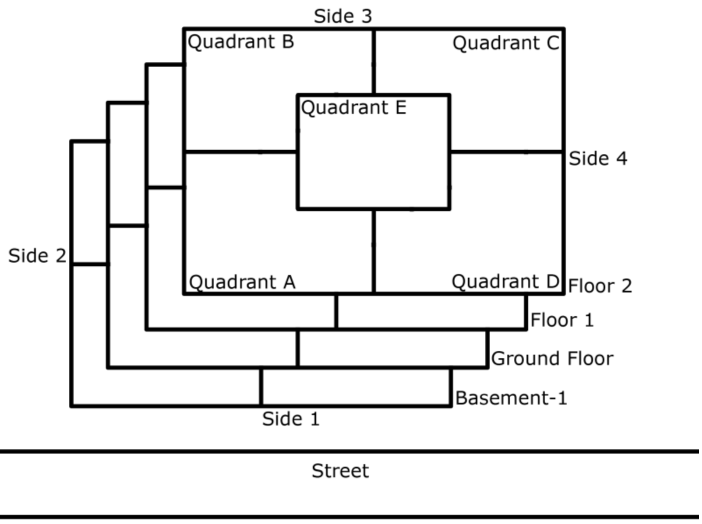
Spiekbrief INSARAG richtlijnen

Richtlijn voor slachtoffer annotaties:

Potentieel levend slachtoffer	
Vast gesteld Levend slachtoffer	
Nog niet vastgesteld overleden slachtoffer	
Vast gesteld overleden slachtoffer	
Gered levend slachtoffer	

Geborgen overleden slachtoffer	

Richtlijn voor locatie bepaling:

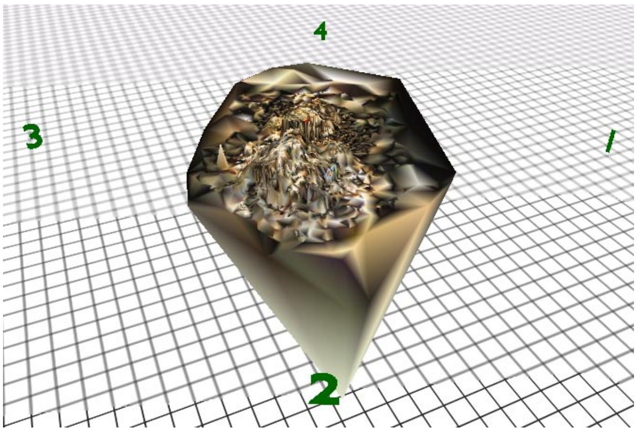


Takenset: Gebruiksgemak

Opdracht 1:
Inspecteer de puinhoop. Bespreek kort waar de puinhoop uit bestaat, zonder de fotos te gebruiken.

Opdracht 2:
Bekijk het pak sap en de grootste cilinder in detail van verschillende kanten. Doe dit met behulp van de originele foto's waar het model mee gemaakt is.

Opdracht 3:
Voeg de zijde nummering volgens het INSARAG protocol toe.



Opdracht4:
In kwadrant B is een hond aangeslagen, slachtoffer 1. Annoteer dit in RubbleViewer.

Opdracht5:
In kwadrant D is een kabel onder hoogspanning gevonden. Annoteer dit in Rubbleviewer.

Opdracht6:
Er is een slachtoffer (2) gevonden in de buurt van het grootste blokhout aan de 3^{e} zijde. Het slachtoffer is gevonden met behulp van een pole mounted camera. Het slachtoffer leeft nog. Annoteer dit in RubbleViewer. Hierbij horen de foto's: "Scen2_2a.jpg" en "Scen2_2b.jpg". Verplaats de slachtoffer annotatie, zodat deze juist is.

Opdracht7:
De tweede hond is niet aangeslagen in kwadrant B. Verdere zoek activiteiten hebben ook geen positief signaal opgeleverd. Verwijder daarom slachtoffer 1.

Opdracht8:
Verwerk het feit dat slachtoffer 2 gered is.

Casus: Inzet Plan

Krantenstuk:

Thursday, December 6, 2007

Downtown parking garage collapses

Jacksonville Business Journal - by Christian Conte and Stewart Verney

A parking garage under construction Downtown collapsed into a twisted pile of steel and concrete shortly before 6 a.m. Thursday.

The garage was part of the Berkman Plaza II project on the Northbank. The six-story garage collapsed as workers were pouring concrete.

Police and rescue personnel responded to the scene, transporting 14 people to local hospitals and treating nine others for minor injuries at the scene. Some workers are still unaccounted for. The garage collapsed during a shift change at the project, making it harder to account for all the workers.

…

Opdracht:

Kunt u gegeven het scenario in RubbleViewer een aanvalsplan ofwel inzetplan maken?

Vragenlijst achteraf

Participant nummer:

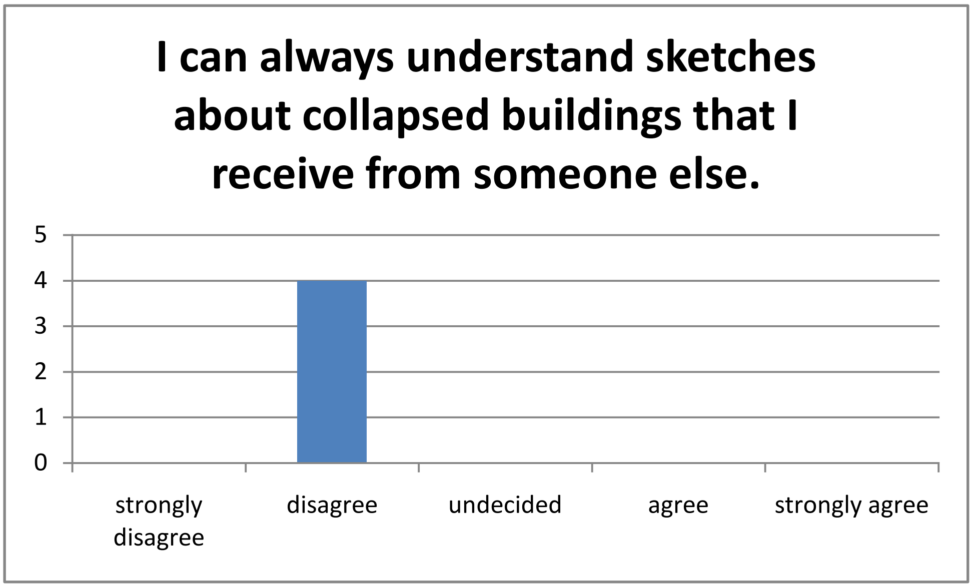
	Nut van RubbleViewer	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
1	RubbleViewer is nuttig om te gebruiken om informatie door te geven aan een nieuwe SAR groep die u komt aflossen **op de rampplaats**.					
2	RubbleViewer is nuttig om te gebruiken om informatie door te geven aan een nieuwe SAR groep die u komt aflossen, als briefing nog **op het kampterrein**.					
3	Ik **zou graag** na mijn inzet willen zien hoe een ander team door is gegaan met het object, waaraan ik gewerkt heb.					
4	Het is **zeer nuttig** als ik na mijn inzet kan zien hoe een ander team door is gegaan met het object waaraan ik gewerkt heb.					
5	RubbleViewer kan bijdragen aan de effectiviteit van een missie.					
	Hoe					
	Ik zou voor … een 3d kaart maken.	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
6	Mezelf					
	Waarom?					
7	Mijn (SAR groep) team leden					
	Waarom?					

	Ik zou voor … een 3d kaart maken.	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
8	De commandant C1					
	Waarom?					
9	De SAR groep die mij komt aflossen					
	Waarom?					
10	De bouwkundige					
	Waarom?					
11	De veiligheidsofficier					
	Waarom?					
12	Anderen namelijk: ___________________					
	Waarom?					
	Kosten	Zeer mee oneens	Mee oneens	Geen mening	Mee eens	Zeer mee eens
13	Ik zou informatie aan RubbleViewer toevoegen, zodat mijn team leden dat op een ander tijdstip kunnen zien.					
14	Ik zou twee USAR leden het eerste half uur van de missie kunnen missen om met een robot foto's van het puin te maken.					

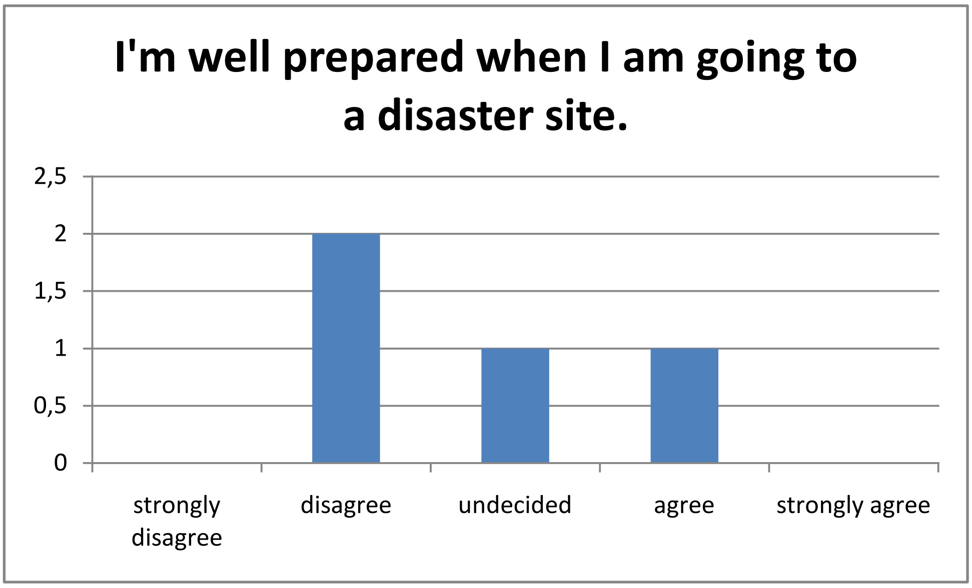
Bedankt voor het invullen van deze vragenlijst.

Attachment 4 Questionnaire results

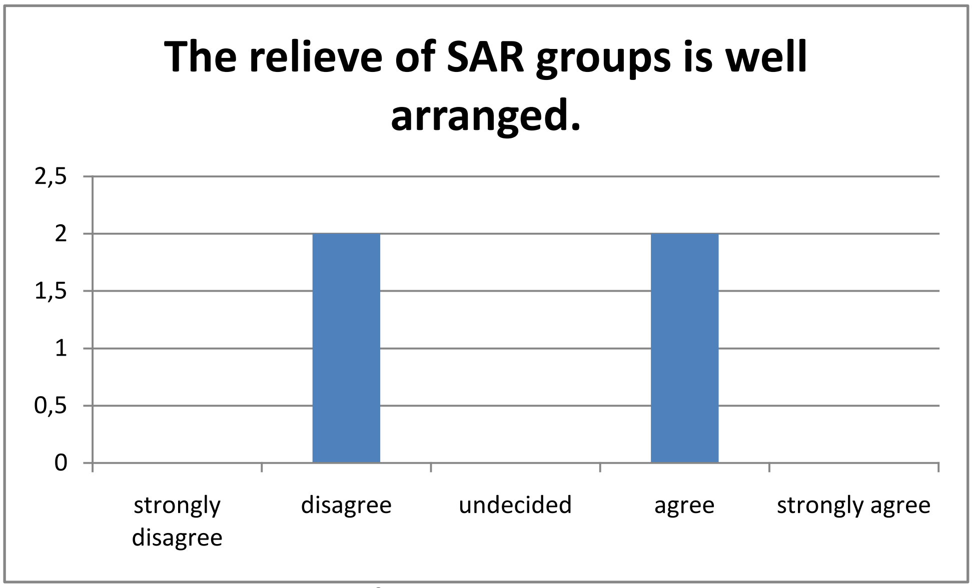
Situation before RubbleViewer



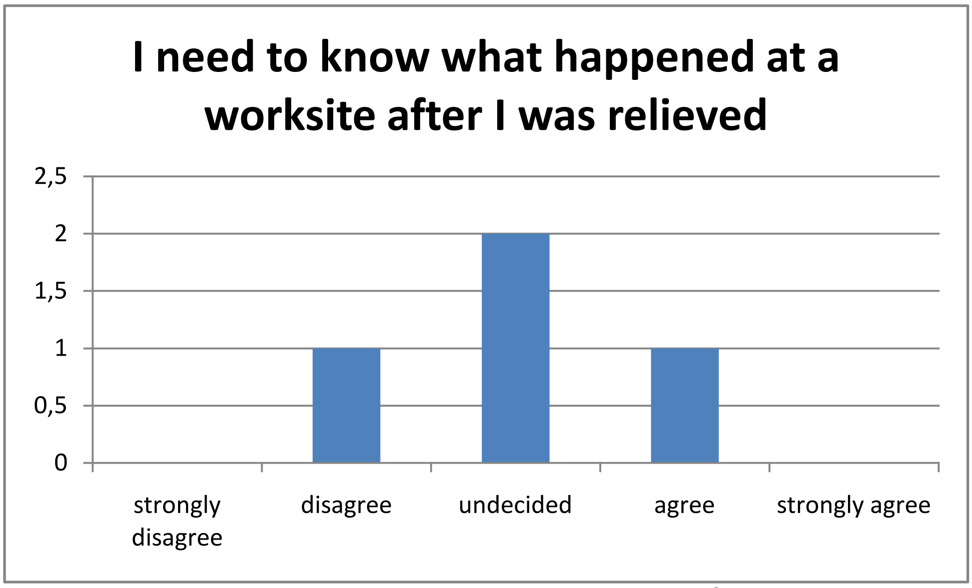
Attachment 4 Figure 1 I can always understand sketches about collapsed buildings that I receive from someone else.



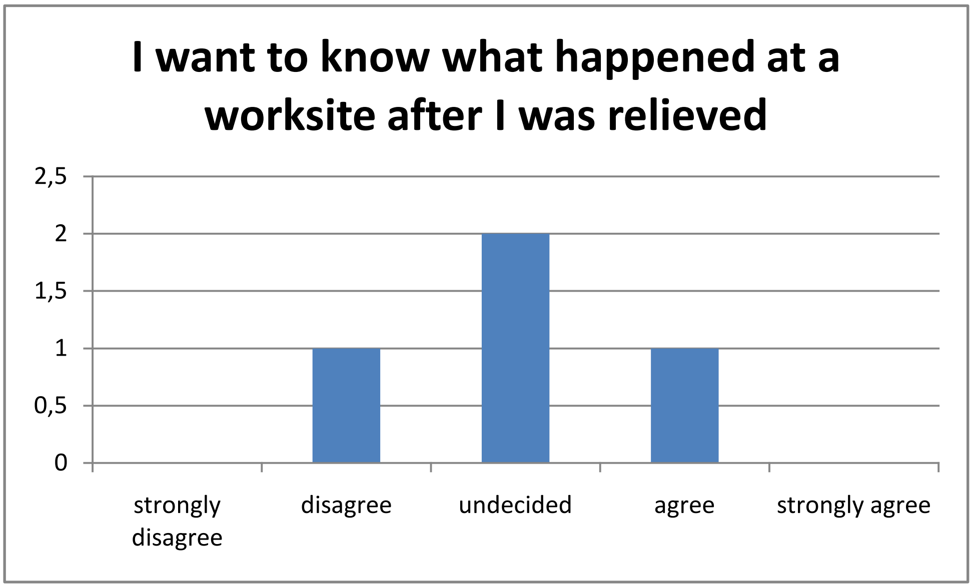
Attachment 4 Figure 2 I'm well prepared when I am going to a disaster site.



Attachment 4 Figure 3 The relieve of SAR groups is well arranged.

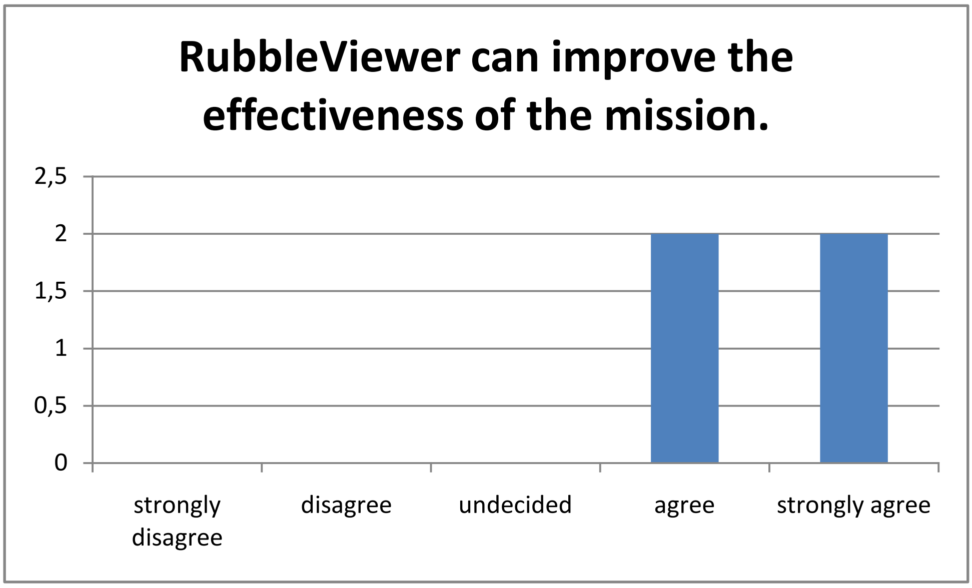


Attachment 4 Figure 4 I need to know what happened at a worksite after I was relieved

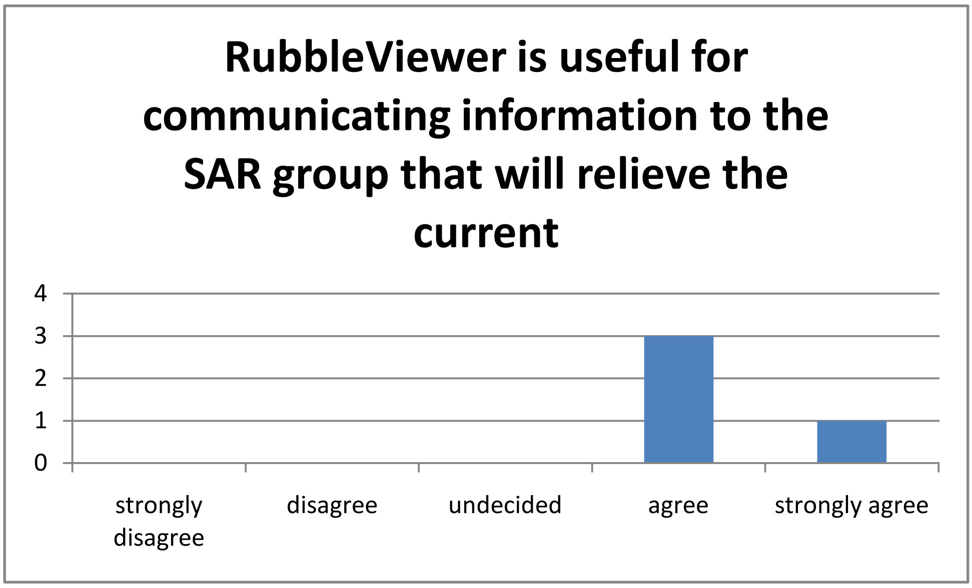


Attachment 4 Figure 5 I want to know what happened at a worksite after I was relieved

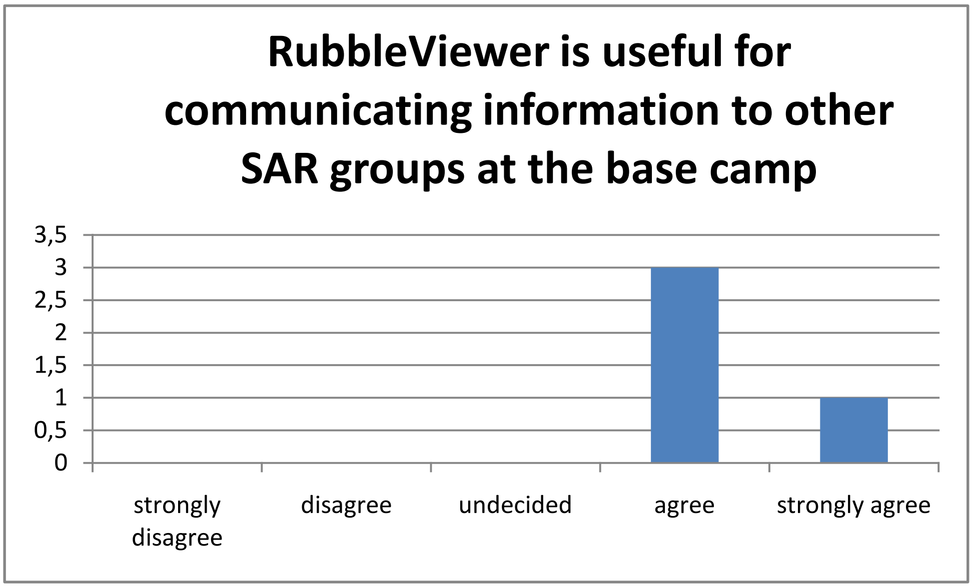
Future situation with RubbleViewer



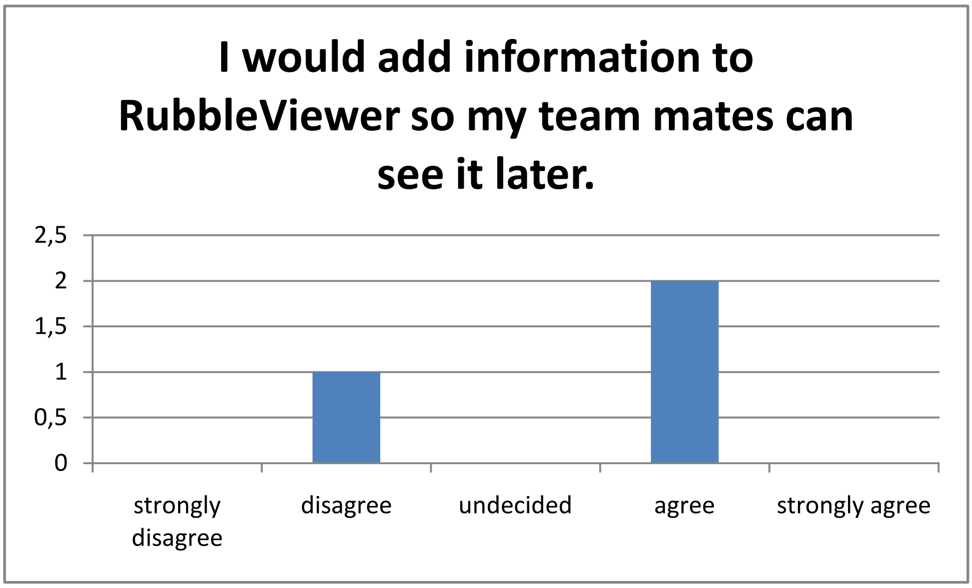
Attachment 4 Figure 6 RubbleViewer can improve the effectiveness of the mission.



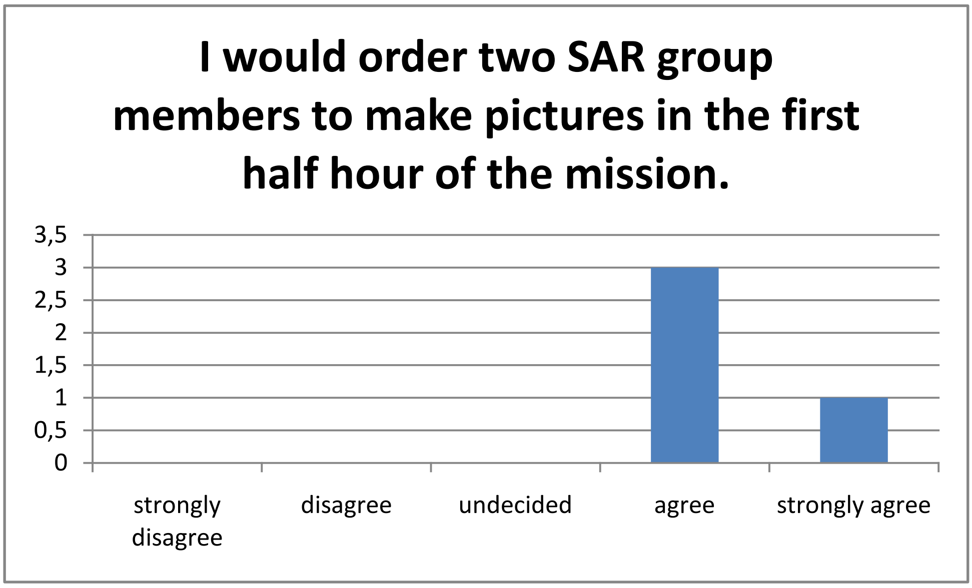
Attachment 4 Figure 7 RubbleViewer is useful for communicating information to the SAR group that will relieve the current



Attachment 4 Figure 8 RubbleViewer is useful for communicating information to other SAR groups at the base camp

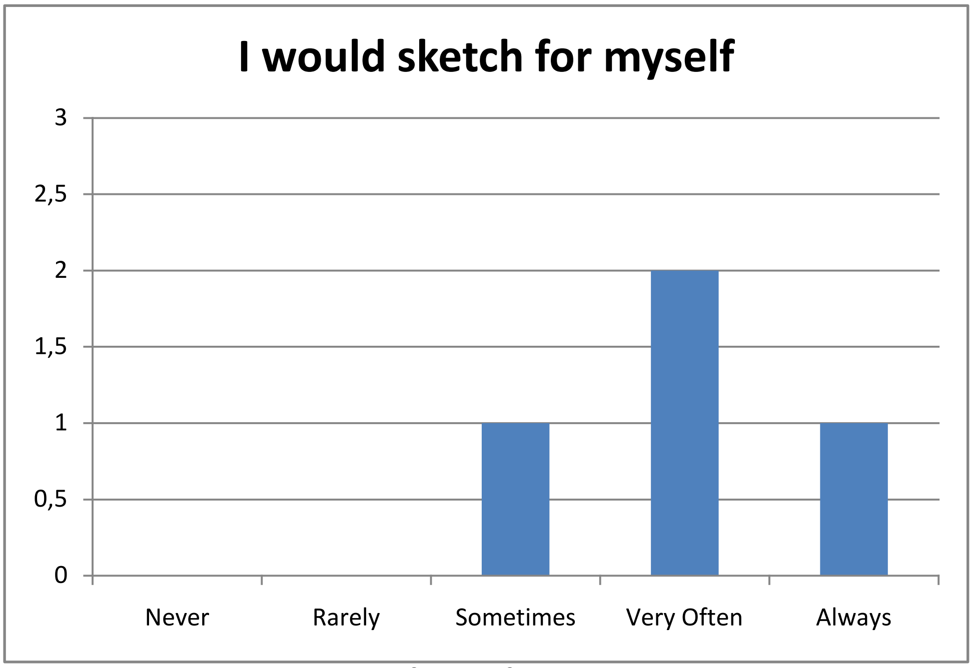


Attachment 4 Figure 9 I would add information to RubbleViewer so my team mates can see it later.

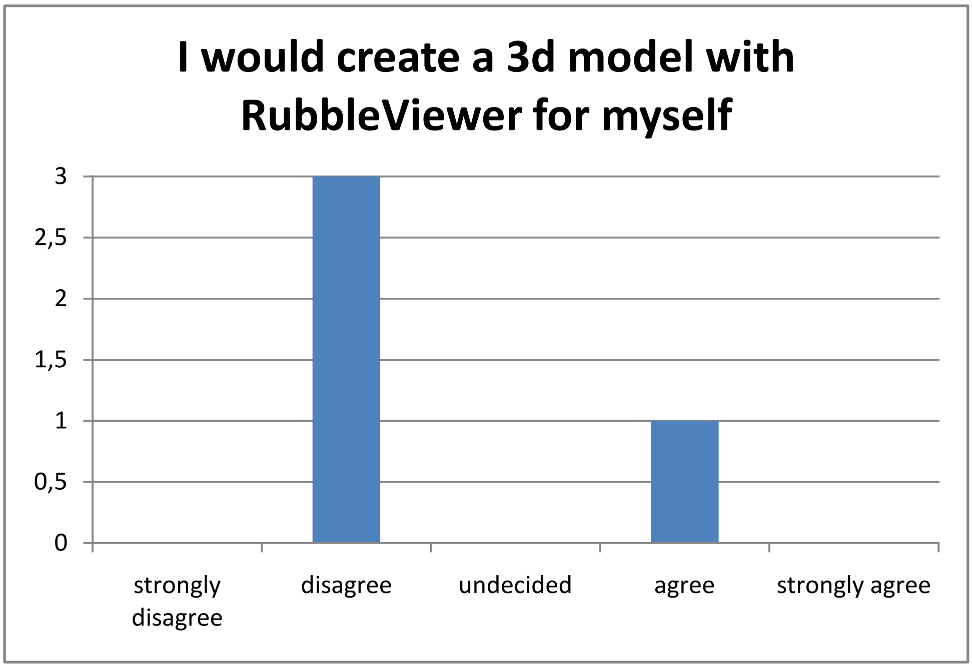


Attachment 4 Figure 10 I would order two SAR group members to make pictures in the first half hour of the mission.

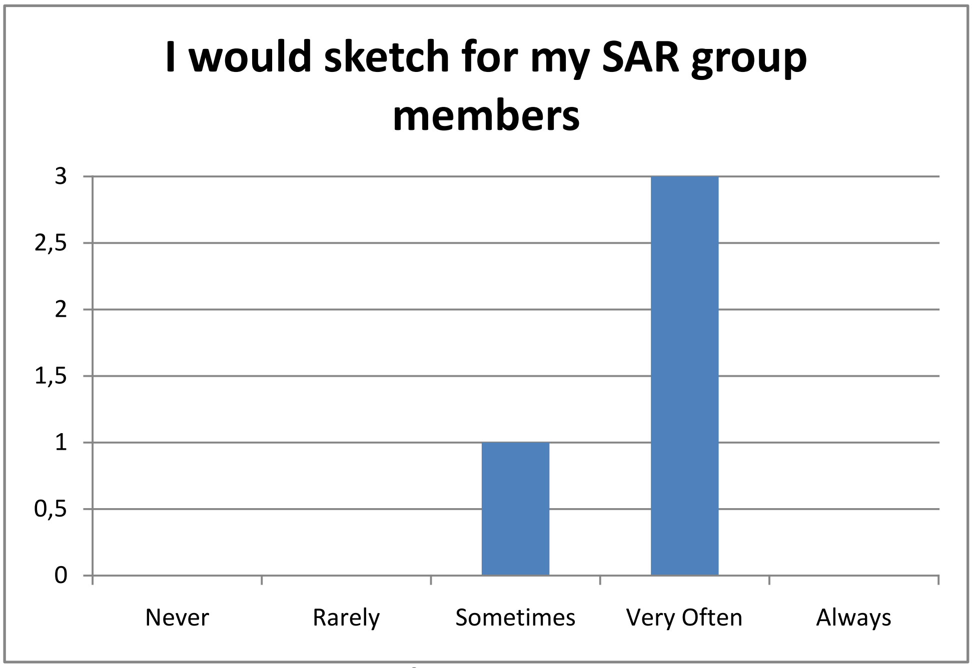
Use of RubbleViewer and Sketches compared



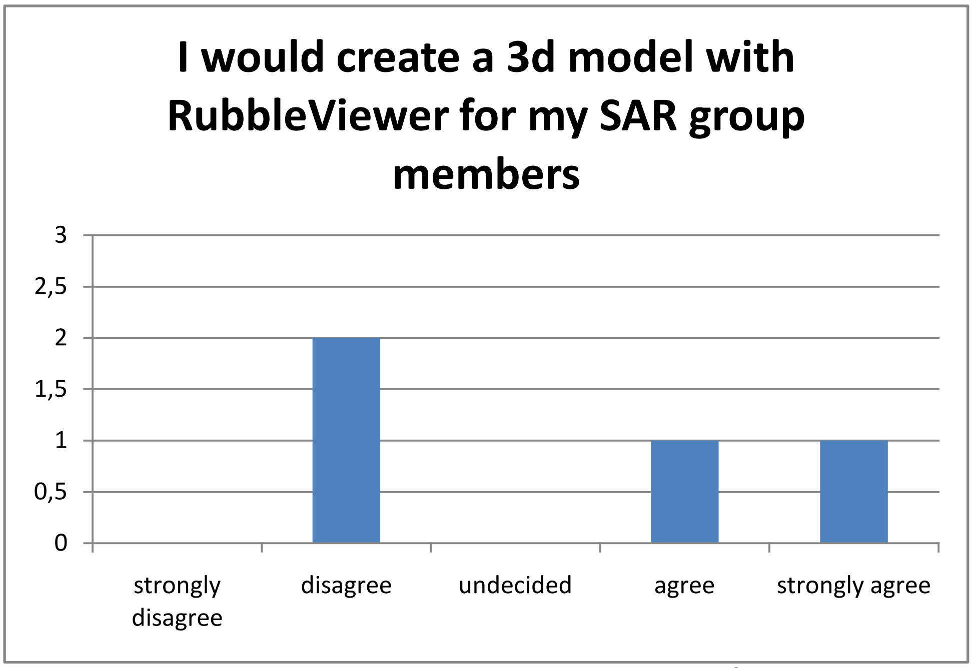
Attachment 4 Figure 11 I would sketch for myself



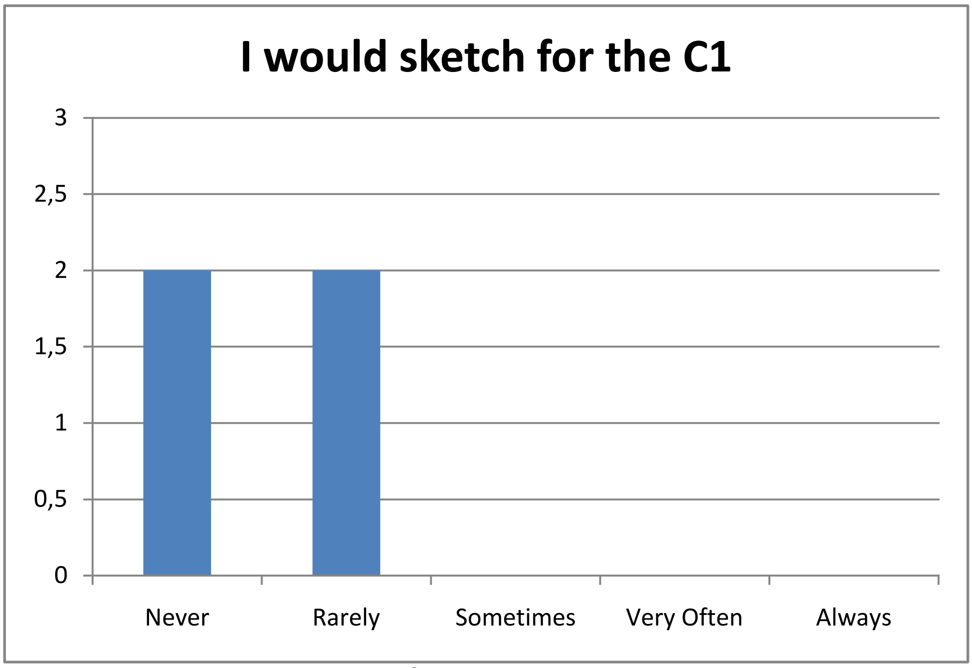
Attachment 4 Figure 12 I would create a 3d model with RubbleViewer for myself



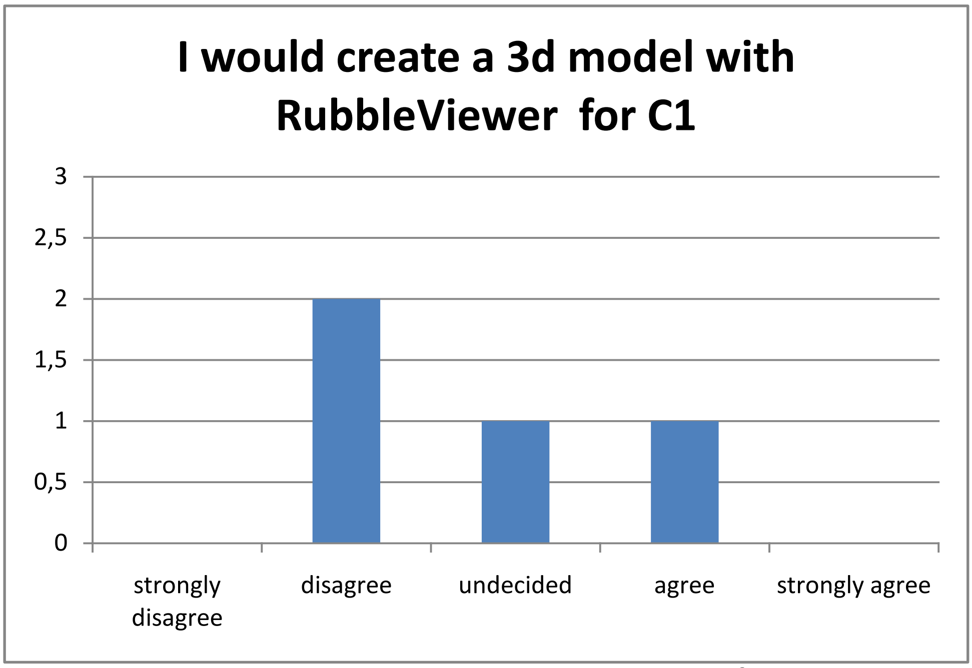
Attachment 4 Figure 13 I would sketch for my SAR group members



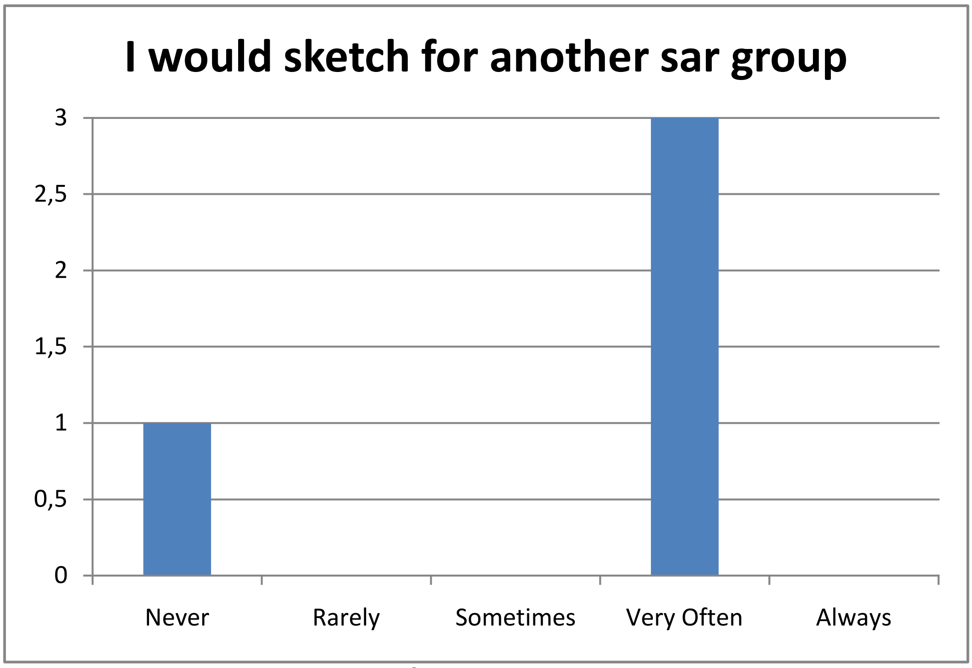
Attachment 4 Figure 14 I would create a 3d model with RubbleViewer for my SAR group members



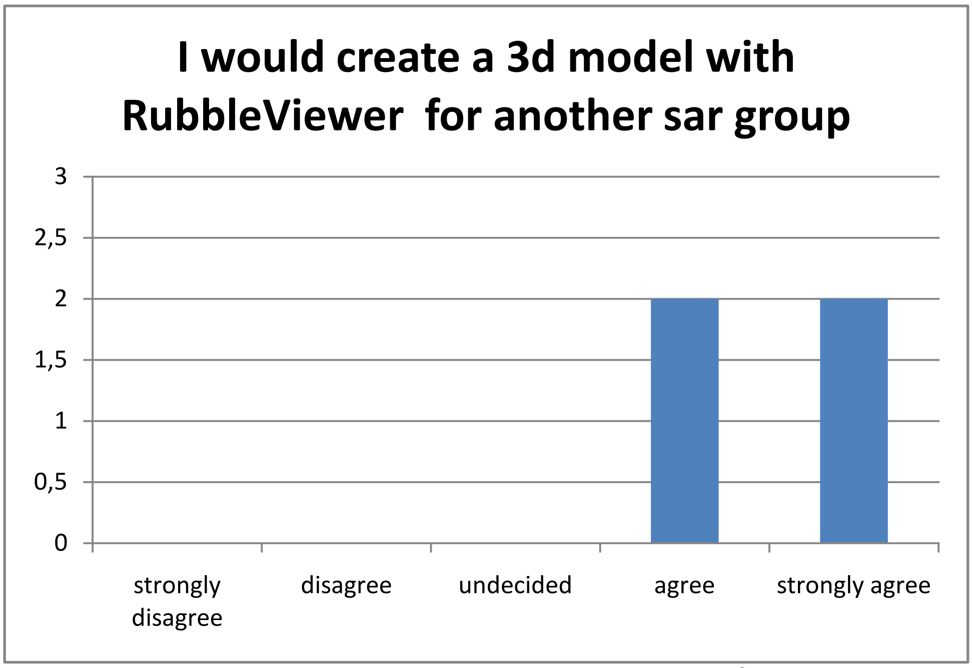
Attachment 4 Figure 15 I would sketch for the C1



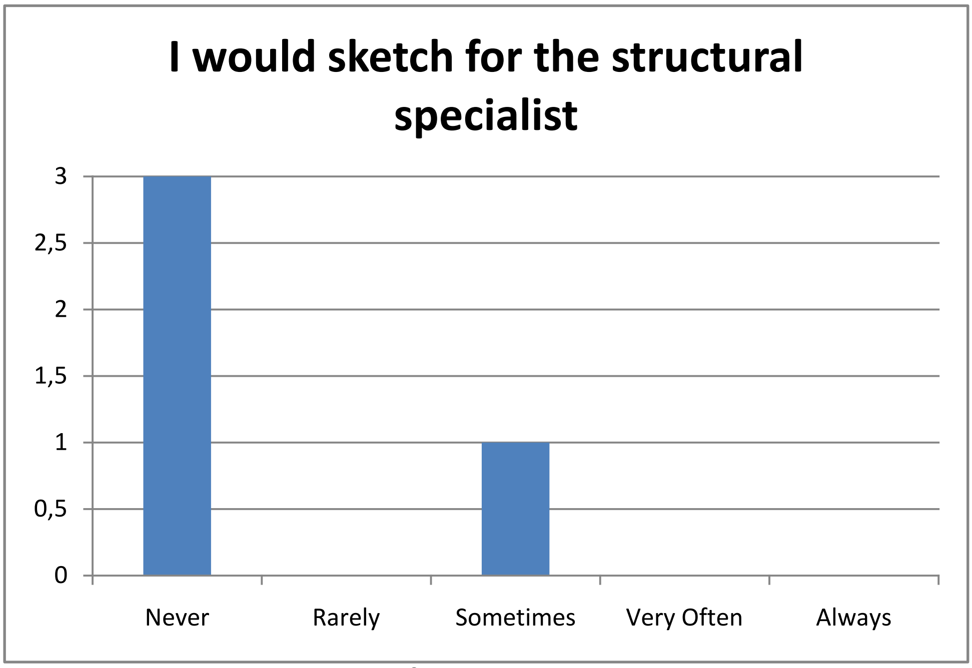
Attachment 4 Figure 16 I would create a 3d model with RubbleViewer for C1



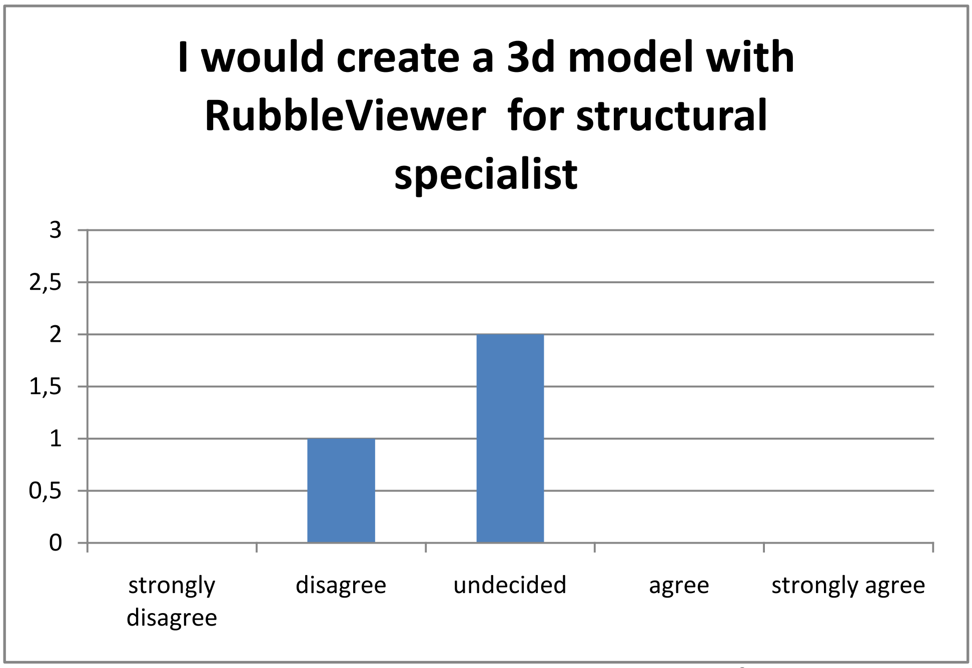
Attachment 4 Figure 17 I would sketch for another sar group



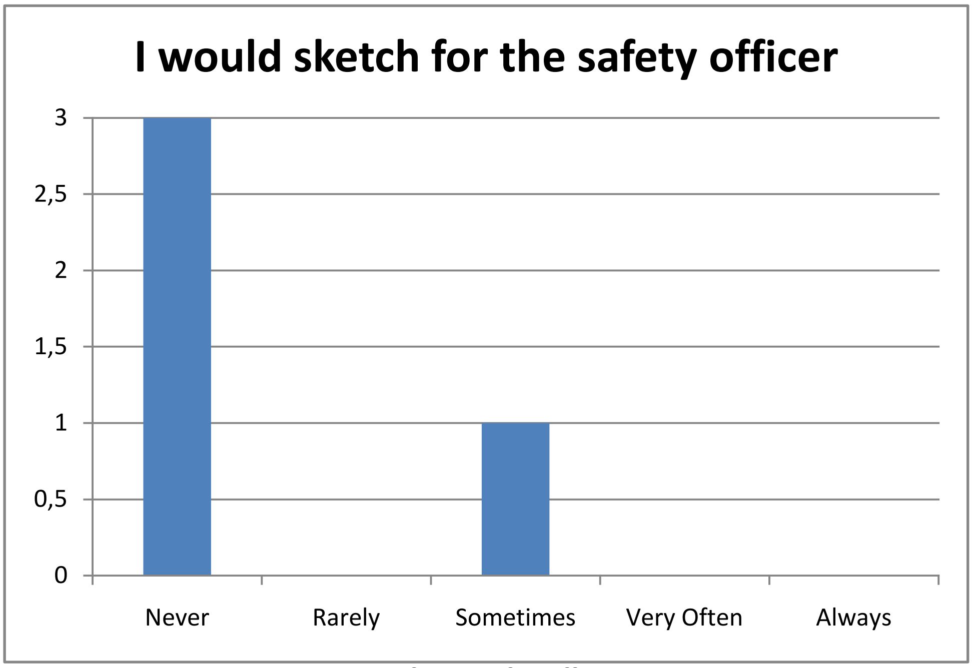
Attachment 4 Figure 18 I would create a 3d model with RubbleViewer for another sar group



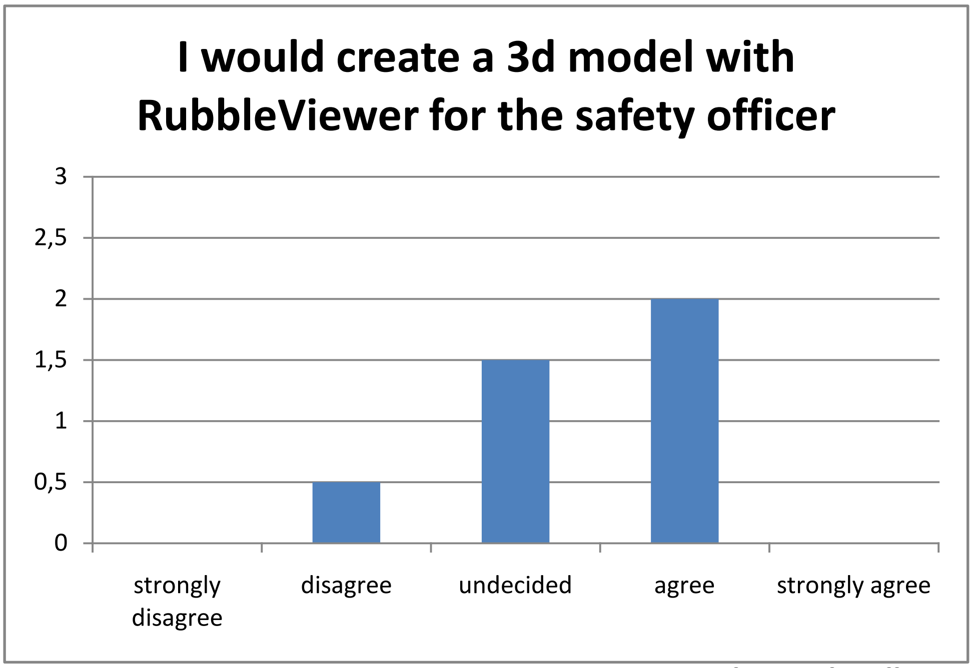
Attachment 4 Figure 19 I would sketch for the structural specialist



Attachment 4 Figure 20 I would create a 3d model with RubbleViewer for structural specialist



Attachment 4 Figure 21 I would sketch for the safety officer



Attachment 4 Figure 22 I would create a 3d model with RubbleViewer for the safety officer