Considering end user needs when developing new technologies – a new plug and play sensor technology for locating trapped victims

Lennart Landsberg
TH Köln
lennart_walter.landsberg@th-koeln.de

Alexandra Braun
THW
alexandra.braun@thw.de

Ompe Aimé Mudimu
TH Köln
ompe_aime.mudimu@th-koeln.de

Klaus-Dieter Büttgen
THW
klaus-dieter.buettgen@thw.de

ABSTRACT

Building collapses often happen unexpectedly and suddenly. Consequently, people are often buried under the debris. What follows is a complicated search by first responders, which is characterized by time pressure and danger. In the research project SORTIE, a modular and UAV-based technical system is being developed to support the first responders in their search efforts. During the first phase of this project, an extensive requirements analysis was conducted with the involvement of end users. This ensures that the developed technology meets the requirements for later use under realistic circumstance. The project consortium has good experience with this operational approach and is in close cooperation with end users who are part of the consortium. In addition to a comprehensive understanding of building collapses and prevailing conditions, the technical partners were also able to identify requirements that they might not have discovered without the involvement of end users and the appropriate methods.

Keywords

Search and rescue, UAV, multi sensors, requirement analysis, building collapse.

INTRODUCTION

According to a study by the United Nations Office for Disaster Risk Reduction, 1.7 billion people were affected by natural disasters between 2005 and 2014, including approximately 700,000 fatalities (United Nations International Strategy Disaster Reduction [UN ISDR], 2015). In particular, collapsing buildings present risks to the local population during natural disasters. Due to their impact on structures, especially earthquakes pose high risks to buildings. While incidents such as the severe earthquakes in central Italy in 2016 and gas explosions are also recorded in western European countries, the frequency and consequences are much more pronounced in Asian countries with a high poverty rate. According to a document of the German Federal Ministry for Economic Cooperation and Development, 90% of the people affected are residents of such regions (Federal Ministry of Economic Cooperation and Development, 2015). In the past 50 years alone, 838 earthquakes have been recorded that were above the value of 6 on the Richter scale. More than 1.2 million people have been killed in these earthquakes (Université catholique de Louvain, Last verified: 2021). It is likely that more people will be affected by earthquakes in the future. Not because the number of earthquakes is increasing, but because the world's population is growing steadily. Earthquakes, and other reasons for strong mechanical impact such as gas explosions, often cause the collapse of buildings, potentially with a high number of victims. Depending on the impact, emergency services then face challenges such as an unclear and dangerous situation, difficult circumstances and time pressure in order to rescue the victims alive.

Urban search and rescue (USAR) teams working onsite still use common recourses such as physical search (listening, shouting, knocking), canine search and technical search. Most processes of finding trapped victims rely on the manual application of the various technical equipment directly on top of the debris. Therefore, the rescuers have to step onto the debris and find themselves in a dangerous situation. The cone of debris could be unstable and any movement could lead to another person being trapped. In addition, there are limitations affecting all recourses: For instance, the performance of the acoustic device and the bioradar is strongly dependent on the composition of the debris cone and ambient noise reduces the usability of the acoustic devices (Jöckel and Döll, 2012). Depending on the prevailing operating conditions, search dogs only have a standby time of 15 to 20 minutes.

As a result, and with view to new technologies and more common use of unmanned aerial vehicles (UAVs), there are many opportunities to make USAR operations faster, more effective, safer and more efficient. The research project Sensor-Systeme zur Lokalisierung von verschütteten Personen in eingestürzten Gebäuden (SORTIE: in English Sensor Systems for Localization of Trapped Victims in Collapsed Infrastructure) therefore aims to develop a modular sensor system that can be attached to a UAV. This sensor system under development consists of a bioradar, a cell phone location module, a long-range gas detection and a debris field analysis (Federal Ministry of Education and Research, 2020). The main idea behind the new system SORTIE is to investigate, develop and evaluate a technical solution that can augment the process of urban search and rescue, not only with regard to improved localization and rescue activities but also concerning fact-finding and the localization of leakages of gas supply and service pipes. To ensure that the new system is developed for practical use in search and rescue missions, the Federal Agency for Technical Relief (THW) and the Institute of Rescue Engineering and Civil Protection (IRG) have worked together to identify the most relevant end user needs.

RELEVANCE

The early involvement of end users in the project is particularly important and crucial to its success as the end users can provide their experiences to the technical partners. Researchers and technicians often have no operational knowledge, low imagination regarding the situation on site and the circumstances the USAR members and rescuers have to face. A system that is developed without the expertise of end users may not be as practical in use as intended. Late adaptions to improve the system for a better operational use can cause further costs and may reduce the acceptance of the system. As the THW with its voluntary experts is an important player in civil protection and takes on USAR tasks worldwide, it has accompanied the project from the very beginning. THW USAR experts work according to International Search and Rescue Advisory Group (INSARAG) guidelines as well as national standards and they bring vast experience in dealing with building collapses to use for development purposes of SORTIE. In summary, the early involvement of end users can be seen as very important in order to be able to develop technologies for first responders in a purposeful manner. Early attention to end user needs ensures that the technology will meet the real-world challenges.

METHOD

The aim of THW and IRG in this research project is to ensure the end user relevance as well as to evaluate the SORTIE system. This essentially includes the elaboration of relevant and realistic scenarios, including exemplarily conceivable operational action, the development of the requirements for the system and the individual components as well as testing the new technology and continuously supporting and advising the technology partners. All results build on each other and will be used until the end of the project. The findings from scenario development are used to define end user needs and to verify the final SORTIE system. With the scenarios created in mind, the end users described what requirements they have for the particular system during the first phase of the project. At the end of the project, field testing and a large-scale exercise will be conducted based on the scenarios in order to validate the scope of application of the SORTIE system and to verify that the identified end user needs have been met.

Scenario Development

The development and detailed description of realistic and representative scenarios were carried out at the very beginning of the project. For scenario development, past incidents with collapsed buildings irrespective of their cause were brought together and discussed. As a basis for this, information of past collapse events was collected and analyzed. Important data sources were past research projects as well as databases of THW (Fleig et al., 2015). Information on the cause of collapse, building use and type, as well as building materials and environmental conditions could be identified. In addition, a survey (n = 61) was conducted among emergency personnel with specialization and expertise in collapse events, which also targeted the same information as well as parts of the specification of end user requirements. 75 % of survey respondents were deployed in 1-5 collapse events during their careers, the others had more experience. First responders were asked to answer what characteristics are most common in a building collapse. This approach allowed the validation of information from the research projects and databases.

Furthermore, all the personal experiences and impressions not only regarding past incidents but also regarding the emergency procedures were provided by THW voluntary experts and first responders within an end users workshop. Reliable and fact-based information was provided on the following issues:

- What are typical scenarios and operational options for USAR activities?
- What does a typical scenario with collapsed buildings look like?
- How do USAR units usually proceed?
- What are the problems and challenges relief teams have to face?
- Are there any gaps regarding the technical equipment, processes?

Specification of End User Requirements

The second step allowed the actual definition of technical requirements for the system. For this purpose, the voluntary experts and emergency personnel were questioned individually or in small groups using a previously developed catalog of criteria based on the previously developed collapse scenarios.

The whole SORTIE system and the single parts were discussed in detail with respect to the overriding issues such as

- Under which conditions should SORTIE work?
- Are there any standards, regulations, legal issues concerning the SORTIE sensor system?
- Are there any aspects of reliability, conformability, security, robustness, easy handling, unambiguity, maintenance, etc.?
- What information should be given by the overall system and the subsystems/single components?

In addition to the surveys, national and international standard operating procedures were analyzed to identify further requirements for the system or to validate the requirements from the previously mentioned surveys. In a national context, the German vfdb Guideline 03/01 (Vereinigung zur Förderung des Deutschen Brandschutzes e.V. [vfdb], 2005) was analyzed; the INSARAG Guidelines (International Search and Rescue Advisory Group [INSARAG] and United Nations Office for the Coordination of Humanitarian Affairs [OCHA], 2020) were used for the international area. All standards were examined according to the scheme shown in Figure 1. First, the guidelines were searched for standards. In this context, the word standard was defined as anything that describes an exemplary action of the emergency services or an exemplary use of equipment. In some cases, backgrounds for the standards had to be derived so that requirements for the technology could be defined. For example, the standard may be that search dogs are not allowed to be on the debris field during acoustic locating. The derived background is that no sounds must be generated during this technical search. As a background, the present method defines all explanations that give a reason for the existence of a standard.

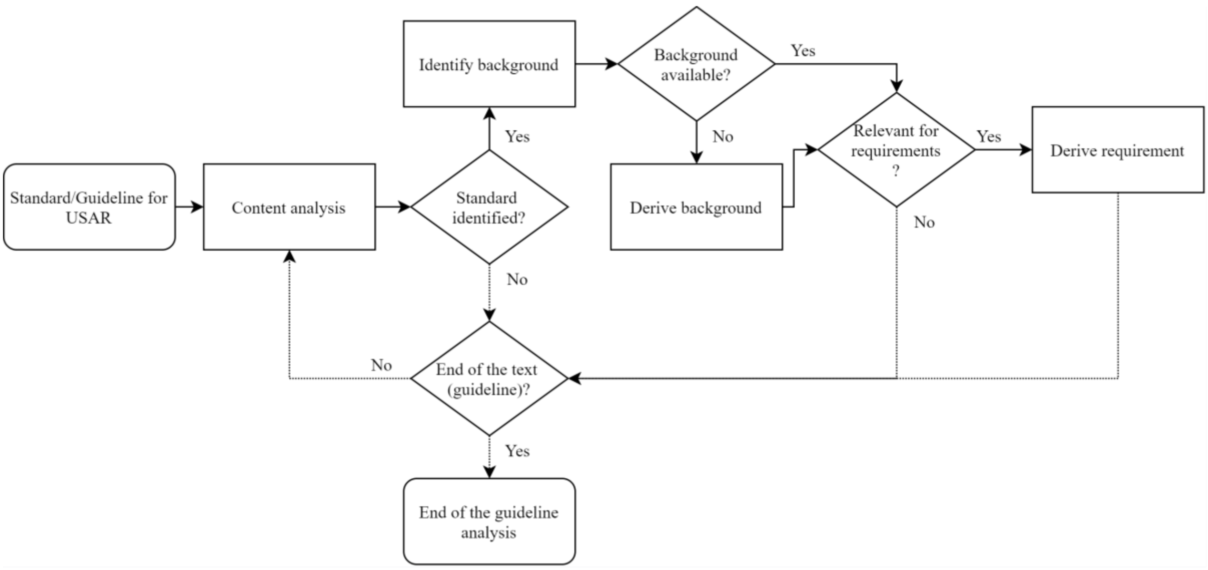

Figure 1. Analysis of Standard Operating Procedures

The requirements from the surveys and the standard operating procedures were collated and compared in a table. IRG and THW listed all requirements in a specification sheet and assigned them to the individual technical partners. Furthermore, the technical partners consolidated and discussed the results in a joint video conference together with the end users. Figure 2 summarized the sources used and how they were combined.

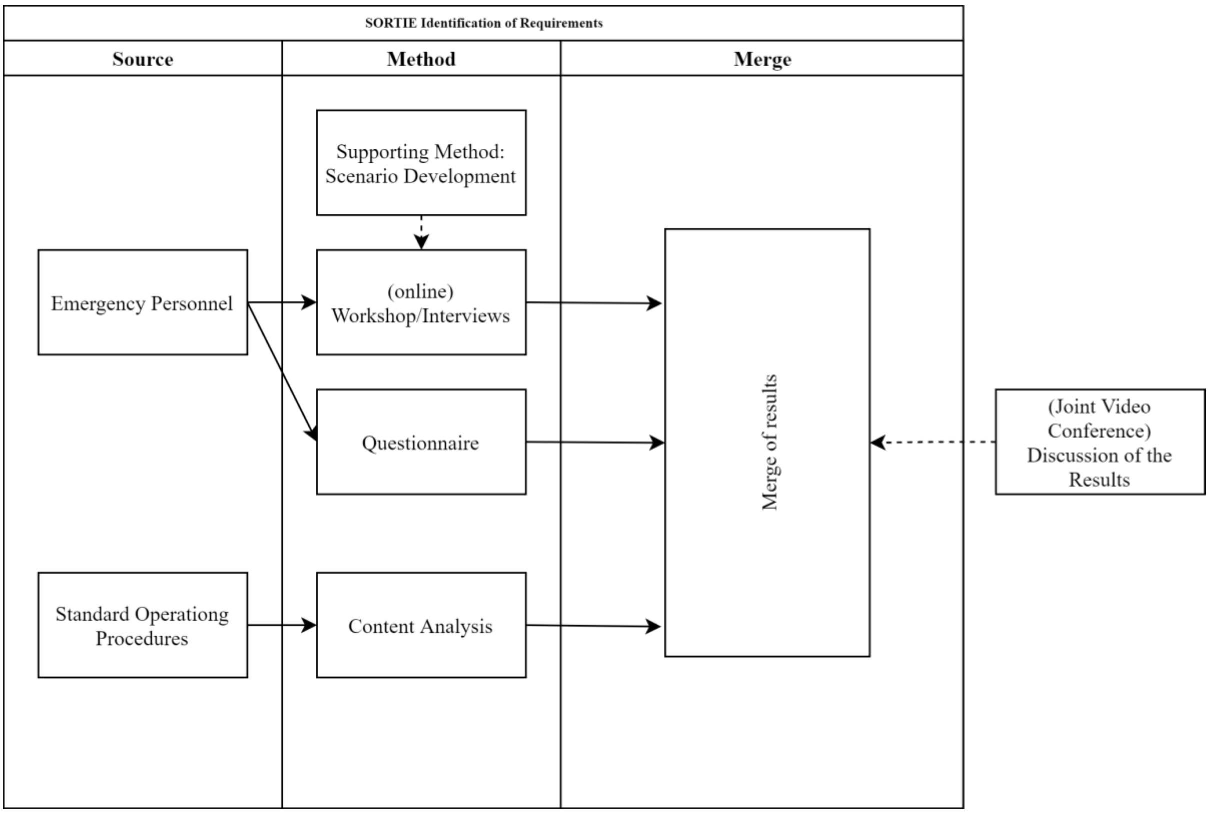

Figure 2. Identification of End User Requirements

RESULTS

Further results were achieved on the way to the requirements analysis. For example, collapse events were analyzed to create the scenarios. The results of the sub-processes are therefore listed separately.

Results from Scenario Development

Experiences of the voluntary experts as well as first responders and the analysis from the past incidents show that gas explosions nationally (in Germany) and earthquakes internationally are the most frequent causes of building collapses. Figure 3 shows the evaluation of collapse events in Germany. "Explosions" can clearly be seen as the main cause of collapse in Germany. For these statistics, a total of 280 collapse events were evaluated. Furthermore, it could be determined that most of the affected buildings were residential and had three floors. Very common damage elements are edge debris, debris cones, damaged/filled rooms, and layering. All analyzed debris elements are presented in figure 4.

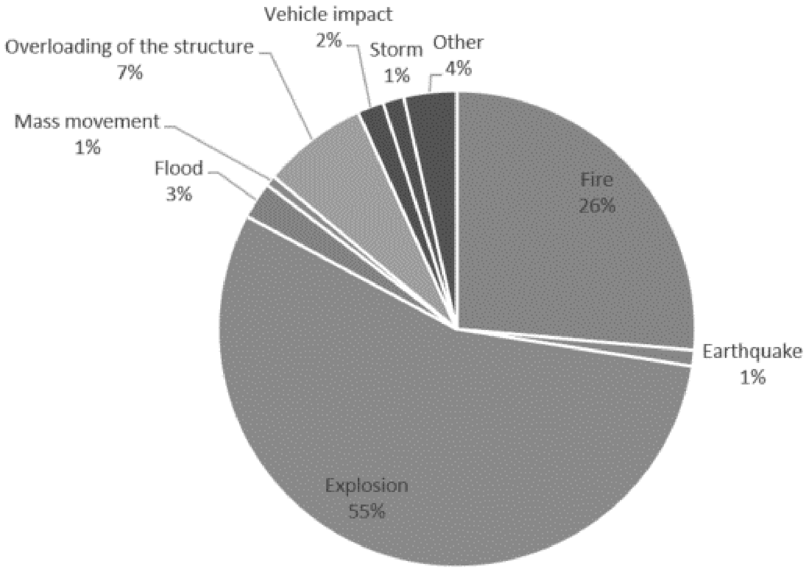

Figure 3. Proportional distribution of the causes of collapse in Germany; n = 280

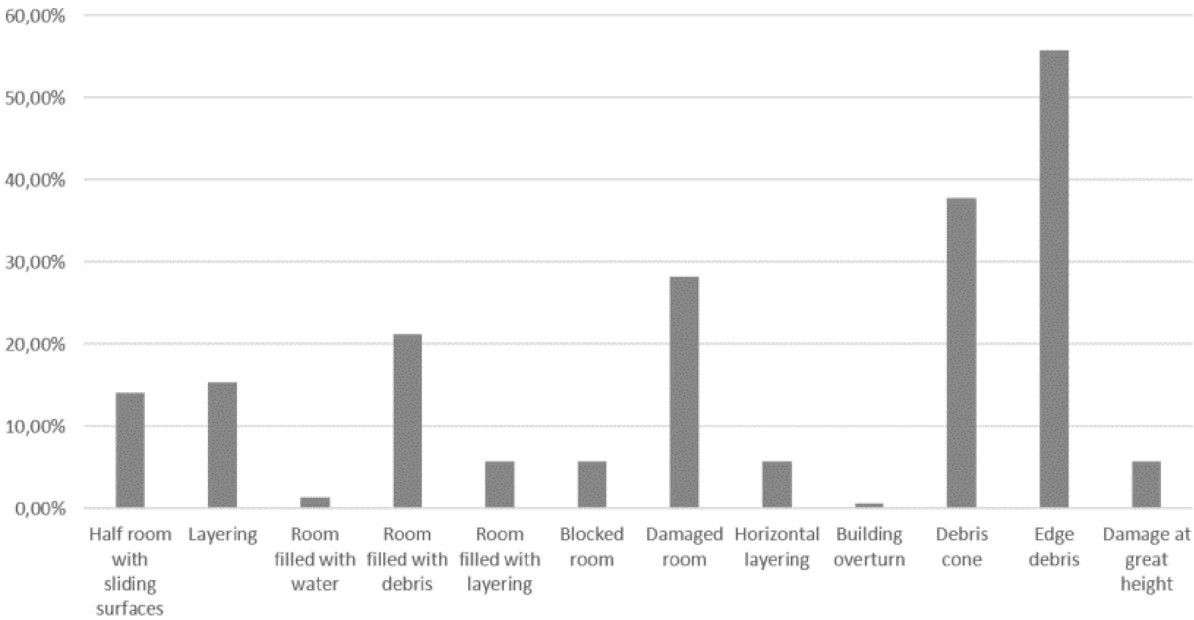

Figure 4. Occurrence of damage elements in percent; n = 156

In a direct comparison of national and international scenarios, there are some specific characteristics that were developed for the scenario description: Gas explosions often show a punctual situation with a low number of victims. The houses affected are solid, build of reinforced concrete skeleton and masonry, with the ceilings often made of wood. Thus, rooms are filled with debris layering. Half rooms with sliding surfaces, edge debris also exist. On the other hand, an earthquake caused scenario affects a large area with many victims in multistoried buildings of reinforced concrete structures. These result in pancake layers and in case of old buildings of brick masonry, in rubble piles.

The hypothetical relief processes were also described for these two typical scenarios and some important issues to be considered with regard to requirements and the potential implementation of the SORTIE system into USAR processes were determined.

Results from Requirement Analysis

In discussing and working out the requirements, a closer look at the typical scenarios showed that the circumstances call for robustness of the technology. For example, the technology must be usable under nearly all weather conditions, such as wind and rain, and be able to withstand heat as well as cold, dust and dirt. Intuitive operability, easy handling and low training effort are also important. Data/results provided by the technology should be reliable and unambiguous. Data transfer, communication, control and analysis tools have to be safe, fast and consistent. The table below shows examples of some of the requirements that were developed. The requirements have been specified for the overall system as well as for the individual subsystems.

Table 1. Examples of specified requirements for the SORTIE system

Subsystem	Requirement	Description
Overall System	Transportability	For easy transport, the overall system should be small in size and light in weight
	Decontamination	Easy decontamination by wiping with a wet cloth
	Operating time/flight duration	45 minutes without battery change; even at low or high temperatures
	Setup time	5 min set-up time; 5 min module change
	Battery	Continuous flying (3 - 4 batteries are required); Explosion/overload protection, fire protection must be provided, redundant
Mapping and autonomous UAV operation	Visual output for assessment	Photos or videos; Live streaming; Camera stabilization through gimbal
	Traceability of UAV movements	Tracking and comprehensible display of the routes flown
	Duration of data acquisition	30 minutes for 625 m²
Bioradar	Interpretation of the results	Communicate and clarify system boundaries to end users
	Information about signs of life	Automatic marking of respiratory movements in a special way
	Presentation of the locating results	Traffic light (red-yellow-green) and curve (raw measurement results)
Debris field analysis	Warning when the debris structure changes	Meaningful warning (optical and acoustic)
	Information on cavities and accesses	Information on cavities meaningful optical/acoustic (including opportunities for access)
	Static analysis and evaluation	Visual assessment of the debris; Visual representation of support measures and erosion in the 3D model; Visual registration of no-go areas

CONCLUSION AND FUTURE WORK

The SORTIE project has been very focused on involving end users in the development of this new technology from the very beginning. In order not to overlook any requirements for the system, different methods were used and merged. In this way, the requirements for the overall system and the system components could be transparently presented to the technical project partners.

More information regarding the technical feasibility will be given at a later time, as currently the overall system and the subsystem are still being developed. The environmental influences (e.g., water, dust) on the sensors will be evaluated in individual tests.

If the new technical solution offers a significant advantage over current technologies such as taking over new technologies and methods, consolidating and simplifying existing technologies and processes, improving information collection, increasing the reliability of the technology or reducing the resources needed (material, personnel) SORTIE may be a conceivable complement to existing equipment.

Model setting and continuous field testing will be carried out to check the relevance of the new technology in the future of the project. Due to the fact that responsibility for the tests is given to end users, the identification of operational limitations of the system as well as possible interactions with other search method will be observed early.

ACKNOWLEDGEMENTS

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REFERENCES

Federal Ministry of Economic Cooperation and Development (2015). Katastrophenrisikomanagement: Ansatz und Beiträge der deutschen Entwicklungszusammenarbeit.

Federal Ministry of Education and Research (2020). Sensor-Systeme zur Lokalisierung von verschütteten Personen in eingestürzten Gebäuden (SORTIE).

Fleig, A., Markus, M. and Bosse, K. (2015). AURIS - Autonomes Risiko- und Informationssystem zur Strukturanalyse und Überwachung sicherheitsrelevanter Bauwerke: Teilprojekt des THW - Beratung und Syzenario-Entwicklung. Schlussbericht THW Teil I + II. Bonn.

International Search and Rescue Advisory Group; United Nations Office for the Coordination of Humanitarian Affairs (2020). INSARAG Guidelines: Volume III: Operational Field Guide (2nd ed.). *INSARAG Guidelines.*

Jöckel, U. and Döll, D. (2012). Schlussbericht: I-LOV - Intelligentes sicherndes Lokalisierungssystem für die Rettungs und Bergung von Verschütteten. Teilvorhaben: Ortungssonde.

United Nations International Strategy Disaster Reduction (2015). Infographic on Economic and Human Impacts of Disasters 2005-2014.

Université catholique de Louvain (Last verified: 1/2021). The International Disaster Database: Centre for Research on the Epidemiology of Disasters. Database used: https://public.emdat.be/. Retrieved from https://www.emdat.be/

Vereinigung zur Förderung des Deutschen Brandschutzes e.V. (2005). Hinweise für Maßnahmen der Feuerwehr und anderer Hilfskräfte nach Gebäudeeinstürzen. *vfdb Richtlinie: 03/01*. Köln: VdS Schadenverhütung Verlag.