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Jun, 2017

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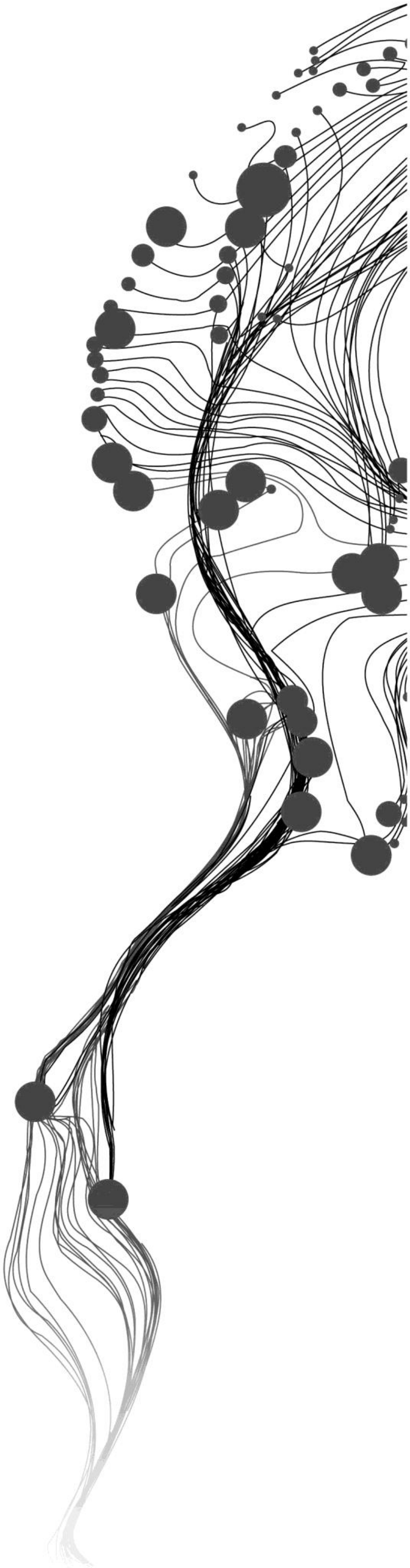

THE VALUE OF RAPID DISASTER RESPONSE WITH UAVS

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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ABSTRACT

In recent years there has been a big change in acquisition of geospatial data by introduction of Unmanned Aerial Vehicle (UAV) technology. For disaster management, the ability to deploy and take images in any given moment is crucial which is enabled by UAV technology. UAV's have many application in humanitarian and rapid disaster response such as: gathering information and increasing situational awareness, rapid disaster mapping, logistics, search and rescue operations, light-weight delivery of essential items to hard-to-reach areas, etc. They are also used to produce 3D images which can be integrated into existing maps. Drones can be used to continuously monitor changes during the response phase and then later during recovery phase. Major advantage of UAV is their flexibility and ability to be flown even after immediate response stops and there is no longer support from agencies that would provide free Earth observation data.

UAV technology introduced new ways for addressing the critical issues in rapid response situations. This study summarizes main findings from literature and explores the value of UAV technology in rapid disaster response situations by looking into the application of this technology in practice, specifically in earthquake response. This study is focused on the 'value of information' that UAVs allow by looking at two case studies in Nepal and Italy after the earthquakes in 2015 and 2016 respectively. The study is predominantly focused in the Nepal case study as it is one of the first instances when UAVs were used before other remote sensing approaches such as satellite images and aerial photos. Additionally, expert interviews are conducted to analyze the value of UAV's in the immediate disaster response.

This research found that Nepal case did demonstrate that there is a significant value of having drones in rapid response, especially in early stages. The fact that drones now can provide images before any other remote sensing platforms does change disaster management by speeding it up and allowing quicker and more targeted response. However, Nepal was not a good case to showcase the full capability of UAV technology in rapid response as a remote sensing tool because of many obstacles that were present. Lack of coordination between the users of drones, incidental coverage in patches, insufficient sharing of data, flying restrictions. The conditions for gaining full benefits from the use of UAVs are: developing appropriate capacities before the disaster, introduction of standard operational procedures on how obtain and process data, and streamlining all aspects in order to serve its purpose while fully taking account all the societal consequences of utilisation of this kind of technology.

Keywords: Unmanned Aerial Vehicle (UAV); drone; remote sensing; value of UAV data; disaster response, value of information.

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1. INTRODUCTION

1.1. Natural Disasters and Disaster management cycle

A hazard is a potentially damaging event, phenomenon or destructive human activity, that may cause loss of life or injury, damages of property, social and economical disruption or environmental degradation (UNISDR, 2009). Hazards could be divided into natural hazards (floods, earthquakes, landslides, tsunamis, etc.) and human caused hazards (terrorist attacks, fire, industrial accidents etc.). Hazard becomes a disaster only if human life, property or livelihood is impacted by the event (Zlatanova & Fabbri, 2009). Disasters have become a global concern due to the increased frequency of their occurrence in the last few decades. The United Nations Office for Disaster Risk Reduction (UNISDR, 2009) defines disaster as: "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources".

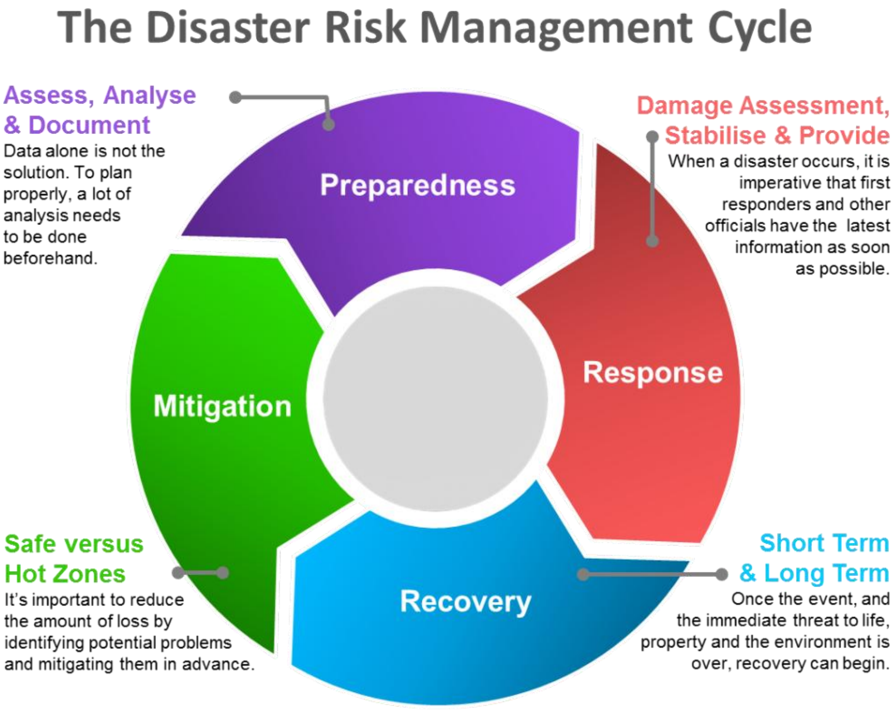


Figure 1 Image of Disaster Management Cycle. In this study focus is on response phase of the cycle.

Disaster management refers to managing the consequences of hazardous events (Zlatanova & Fabbri, 2009). Volcano eruptions, storms, floods, and earthquakes are some of the hazards that cause thousands of deaths and enormous harm to property around the world. They displace millions of people and affect the livelihoods of people. Disaster management cycle (Figure 1) has four phases; preparedness, mitigation, response and recovery. First two refers to pre-disaster activities and second two are referring to post-disaster activities. The response phase is a period of time immediately after a disaster and it usually lasts from several days to a few weeks (Lemmens, 2011). This is the most challenging phase because it requires special set of skills and coordination of disaster responders and it is highly time-constrained (Voigt et al., 2016). During response phase rapid assessment of critical information such as impact area, affected population, damage distribution, potential areas where search and rescue teams are needed have the highest priority (Barrington et al., 2011). Recovery phase comes right after the response and includes arrangements of removing damages, restoration and improvement of facilities, livelihoods and living conditions (Zlatanova & Fabbri, 2009).

1.2. Remote sensing

First aerial photograph was created in 1858 from a balloon by Gaspard Felix Tournachhon (nicknamed "Nadir"). In 1906 George R. Lawrence created oblique aerial photos (Figure 2) of damages caused by earthquake and fire in San Francisco (Baumann, 2014) using large kites. Since then remote sensing (RS) has become an intricate part of disaster management as it is one of the fastest ways of data acquisition of pre and post disaster situations (Bello & Aina, 2014). In post disaster assessment remote sensing is used for gathering information about the damage extent, impact to the critical infrastructure (electrical grid, transportation network, public facilities etc.), providing situational awareness, mapping damages etc. (Lippitt, Stow, & Coulter, 2015). Even though RS techniques are less accurate and reliable than ground survey, they are still the most popular approach for rapid damage assessment (Lemoine, Corbane, Louvrier, & Kauffmann, 2013). To be able to optimally use remote sensing as a tool in disaster management it is necessary to select the appropriate type of RS data. This is carried out by taking in concern the disaster type and then accordingly choosing necessary spatial, spectral, temporal and radiometric resolution of needed data (Joyce, Wright, Samsonov, & Ambrosia, 2009). Satellites, airplanes, helicopters and drones are different alternatives for acquiring remote sensing data. These are not opposing data sources, they are complementary tools with different advantages and disadvantages.

Figure 2 San Francisco after the earthquake and fire. One of the images created by George Lawrence in 1906.

1.2.1. Satellite remote sensing

Satellite remote sensing has a long tradition in monitoring and mapping disaster-struck areas (Van Westen, 2000). Satellite imagery can capture wide area in one take and can be updated. Remote sensing imagery sources from different satellite sensors could be used depending upon the spatial and temporal resolution and sensor type and the required data (Liu & Hodgson, 2016). For example, during large flood disasters, active radar sensors that operate in the microwave section of the electromagnetic spectrum are often used because they can penetrate heavy clouds that are often present in flood hazard situations (Joyce et al., 2009). The imagery from METEOSAT[1] and NOAA AVHRR[2] on one hand have high temporal resolution but on the other hand have coarse spatial resolution. Polar orbiting Indian Remote Sensing (IRS) satellites have low temporal and spectral resolution and high spatial resolution (Lemmens, 2011). Satellites have the ability to provide images with high spectral, special and temporal resolution, radar images, stereo-mapping. However it is not possible to obtain all of this data from one satellite (Bhanumurthy & Behera, 2008).

[1] Series of geostationary meteorological satellites, Meteosat-7, -8, -9 and -10 are operating over Europe and Africa.
[2] The National Oceanic and Atmospheric Administration, The Advanced Very High Resolution Radiometer.

Rapid collection of damage information and its distribution during the disaster emergency response stage is vital. Images can be taken by satellites only on certain dates at certain time, depending on their orbits, swath width and off nadir viewing capabilities. This means that satellites are not always available to respond to a disaster and they only have coverage if the satellite is orbiting close by the area of interest. Besides the problem of timeliness there are additional issues of data processing speed and spatial resolution (ground sampling distance- GSD) (Lemmens, 2011). Coarser spatial resolution is acceptable when damage assessment is done in scarcely populated rural area with small building numbers. In densely populated urban zones more detailed images with higher spatial resolution are much needed. Satellites can obtain very high resolution (VHR) imagery with the ground sample distance up to 0.3m (World View 3) for optical sensors (Boccardo & Tonolo, 2015) that could be used for overlooking the extend of disaster struck area as well as for visual interpretation of the damages caused by earthquake (Joyce et al., 2009).
One satellite cannot cover all disaster management needs and that is why Earth observation collaboration on global level is needed by a constellation of satellites operating together, combining different sensors, temporal, special and spectral resolutions. As such more than 100 governments, including European Commission, and over 90 organizations worldwide have joined forces and crated a Global Earth Observation System of Systems (GEOSS). This system of systems connects planned and existing observing system around the globe. Major support in gathering and processing satellite data in disaster response is provided through the assistance of the International Charter "Space and Major Disasters", global response mechanism based on civilian Earth Observation (EO) satellites (Kerle, 2010). During the activation period all RS products produced by the Carter are cost-free. Charter was created in 2000 by the European, French and Canadian Space Agencies. In 2015 alone it had forty activations, including activation from Nepal which suffered devastating earthquake on 25th of April 2015. The Disaster Charter is active only during immediate disaster response phase. Space agencies help by priority satellite tasking, collecting the images and organising production of maps (Disasters Charter, 2016). The image processing is done by a number of experts at the Center for Satellite-based Crisis Information of the German Aerospace Center (DLR-ZKI), the Operational Satellite Applications Programme (UNOSAT) of the United Nations Institute for Training and Research (UNITAR) or the ServiceR´egional de Traitement d'Image et de T´el´ed´etection (SERTIT;based at the University of Strasbourg, France) (Kerle & Hoffman, 2013). In this way, large amounts of satellite images are being processed to suit the emergency response. Additionally, "Copernicus, Emergency Management Service" provides free of charge, Reference and Delineation maps (for assessing the event extent) and Grading maps (for damage assessment) (Copernicus, 2015).
Many international, national and local agencies and institutions use satellite based emergency maps as a part of emergency response plan to reduce the impact of disasters (Voigt et al., 2016). Unfortunately, regardless of the organized efforts of programs such as these, there is still a issues of temporal resolution (data availability), because we are not always be able to acquire wanted images in a timely manner (Bello & Aina, 2014).

1.2.2. Traditional airborne remote sensing platforms

By using airborne platform it is possible to overcome issues of spatial and temporal resolution that satellites have, as well as the problem of cloud coverage when the optical data is needed. For a long time dominant airborne platform were airplanes. They can carry large payloads and sensors. Most common airborne sensors are optical and LIDAR which has been found useful for generating Digital Surface Models (DSM) of costal zones and urban settlements (Lemmens, 2011). Sensors such as laser scanners acquire height information by design, optical sensors can obtain overlapping (stereo) images from which

3D information can be extracted by using photogrammetric techniques (Kerle, Heuel, & Pfeifer, 2008). LIDAR data is a good choice for capturing geometry of structures, unfortunately it is not able to capture the texture as well, and that is limiting its applicability in damage assessment. Texture information is highly important in determining more fine damage levels (Jorge Fernandez Galarreta, 2014).

Many maps still used today were created through photogrammetry. . They are effective because airborne sensors often have higher spatial resolution. However, it should be noted that modern optical satellites are capable of producing high resolution images of up to 0.3m. The difference in resolution might be a key component in assessing the images depending upon the total area covered by a disaster. Floods which cover larger area might be analyzed at 100-500m resolution whereas localized urban disasters may require greater detail for analysis (Kerle et al., 2008). In a high magnitude earthquake event, however, the area covered might be very large and it is when using airborne sensors with limited coverage becomes costly and ineffective. One of the ways to overcome this challenge can be through Unmanned Aerial Vehicles (UAV) which are cheaper to fly and can be operated instantly after the disaster. They are also able to produce 3D images which can be integrated into existing maps, although, there are many pre-processing steps required before the actual integration as to account for perspective distortions (Kerle et al., 2008).

1.2.3. Unmanned Aerial Vehicle (UAV) technology

In recent years there has been a big change in acquisition of geospatial data by introduction of Unmanned Aerial Vehicle (UAV) technology. Unmanned Aerial Vehicles are known under different names and acronyms, "UAV" and "drone" are the most popular terms but there are also, "Unmanned Aircraft Systems" or "UAS" or "Areal robots" . The term UAS was received by the US Department of Defence (DOD) and the Civil Aviation Authority (CAA) of the UK (Colomina & Molina, 2014). The International Civil Aviation Organization (ICAO) has presented a more formal term of "Remotely-Piloted Aerial System" (RPAS)(ICAO, 2011). In this study terms "UAV" and "drone" will be used. This technology was created by military, but in recent years it has found civilian application for scientific, recreational, commercial and other purposes (Dalamagkidis, 2015). UAV platform is a fairly cheap and very useful tool in rapid response situations because they have possibility of taking oblique images, they posses recording sensors for fast digital data production, they are flexible and they deliver quickly high temporal and spatial resolution information (Lewis, 2007).

For immediate emergency response, the ability to deploy and take images in any given moment is perhaps the most important characteristic of UAV technology. Drones have high flexibility that gives them an advantage over satellites. They are able to monitor multiple places simultaneously, observe areas of interest in greater detail than satellites (higher spatial resolution), they can fly under the clouds and cover satellites' blind spots (Valavanis & Vachtsevanos, 2015). Moreover, they can fly into areas that are unsafe or inaccessible to humans allowing first responders in emergency situations to assess the situation quickly and safely (Klauser & Pedrozo, 2015). Some drones do not even need takeoff or landing space, which is ideal in disaster situations. Possibility of vertical takeoff and landing is well suited for dense urban space where there is not that much room for manoeuvring (Clarke, 2014). Because of the high starting prices of the satellite and airplane imagery, for covering smaller areas they are definitely the most cost effective solution (Matese et al., 2015). Cheap and small models can perform quick scene assessments while larger and more stabile UAV platforms could perform detailed surveys (Kerle et al., 2008).

Major advantage of UAV in respect to their flexibility is that they can be flown even after immediate response stops and there is no longer support from agencies that would provide free Earth observation data. Drones can be used to continuously monitor changes during the response phase and then later during recovery phase. They can be used for monitoring derby removal and repair and reconstruction works, thus providing important continuous, updated information. Furthermore, the autonomy of function of drones allows them to be highly efficient and easy to use. All the data required for flights such as location in space, altitude and relative locations of obstacles can be processed thorough onboard equipment. It is even possible to take-off, fly pre-determined flight paths and make automatic landings (Clarke, 2014)

Drone flight can be performed in manual, assisted, or autonomous mode, depending on the mission specifications, platform's type (fixed wing of rotor), and environmental conditions (Nex & Remondino, 2014). Drones can be categorized based on their sizes: 1) Large drones are usually 150 kg for aircraft and 100 kg for rotorcrafts. 2) Mini drones are between 20-150 kg for aircrafts. 3) Micro drones are any drones which are smaller in size than the mini drones. They are usually from 7kg -0.1 kg (Emery, 2016).
There are still other methods of classifying drones based on their design, functionality etc. For example, fixed wing drones are design based drones which have, as the name suggests, fixed wings often used to carry longer distances and heavier loads. One of the more popular models is eBee fixed wing drone. This type of aircraft can stay airborne from 30 minutes to many hours and often use autopilot systems. However, they require clear open space for takeoff and landing which might not be always available. Rotor drones, have four, six, eight propellers and have been widely used. Most popular ones are quad copters, drones with four propellers, DJI Phantom is one of an example of this type of aircraft. The primary advantage of this drone is the limited space requirement for takeoff and landings but can only be used for shorter periods at a time (cheaper ones). Hybrid drone consists of both rotors and wings which allows it the ability of vertical takeoffs and landings as well as to fly horizontally. They are new and promising development for drones which can be used for long flight cargo delivery even in smaller spaces (FSD, 2016a). Rotary-wing UAVs have possess the ability to hover and take oblique images (Meier, 2014a). Small and cheap fixed-wing hand-launched UAVs can land on various surfaces with only couple of meters of landing space, they fly autonomously along pre-programmed routes and they land automatically as well (Valavanis & Vachtsevanos, 2015). These systems might have problems with stability due to strong wind conditions while bigger and more stabile systems have longer endurance, because they use internal combustion engine and have higher payload and can carry medium camera or LiDAR or SAR instruments (Nex & Remondino, 2014). Drones can use video cameras as sensors to obtain more clear and detailed characteristics of ground features and to provide real time view of situation, areal video is as well additional source of imagery (Li, Yang, Wu, & Wang, 2012).

UAV technology has several advantages for gaining significant information and several other purposes in disaster management. Drones can be easily transported and they can take off at moment's notice, this is what gives them an upper hand in the situations where a quick respond is needed (Measure, 2015). UAV data collection and processing in rapid response situations is done in similar manners as satellite data processing, but an important advantage is that UAV go beyond offering just a vertical view (Baiocchi, Dominici, & Mormile, 2013a). Multiple images can be taken which are then processed to form a mosaic, to create an ortho photo and even provide 3D representation (Kerle et al., 2008). UAV photogrammetry is the reinvention of photogrammetry that was done with conventional airborne platforms, with it presenting a more efficient and affordable option (Eisenbeiß, 2009). There is a wide range of UAV application in humanitarian and rapid disaster response such as: gathering information and increasing situational awareness, rapid disaster mapping, logistics, search and rescue operations, light-weight delivery of essential items to hart-to-reach areas and so on (Boccardo, Chiabrando, Dutto, Tonolo, & Lingua, 2015).

1.3. Justification

Selecting the appropriate type of RS data is key in disaster management when using remote sensing. This includes understanding the disaster type and accordingly choosing the tools based on the specific needs. Alternatives that can be used for acquiring these data are satellites, airplanes, helicopters and drones. In rapid disaster response, the advantages and disadvantages of using one over the other can differentiate based on different factors, thus it is of importance to consider the attributes of each and evaluate their benefits.
Satellite imagery has an ability to obtain updated information and capture wide area in one take. Depending on the satellite, they can provide high temporal resolution but have a coarse spatial resolution, or vice versa. They can deliver a broad range of products, however, it is not possible to get them all from one satellite. Images can be taken by satellites only on certain dates at certain time, depending on their orbits, swath width and off nadir viewing capabilities. This limits their usefulness and availability in rapid disaster response.

On the other hand, when compared to satellites, drones can monitor multiple places simultaneously, observe areas of interest and capture under cloud and blind spots. They can fly into unsafe areas and inaccessible to humans allowing first responders to asses quickly and safely to situations. They offer more than just a vertical view, providing different products. But more importantly, their ability to deploy and take images at any given moment is what adds to their value in rapid disaster response.

UAV technology introduced new ways for addressing the critical issues in rapid response situations. So far, many studies reviewed the potential applicability of this technology in disaster management and usability of data produced with UAV's (Adams & Friedland, 2011; Boccardo et al., 2015; Tanzi et al., 2016). On the other hand, there are studies focused on practical aspects with analysing specific areas that used UAV's in disastrous situation (FSD, 2016; Giordan et al., 2015; Pajares, 2015). Nevertheless, there is a lack of summarized analysis that explores the value of using UVA's in rapid disaster response, and considers their advantages and disadvantages when compared to other RS platforms.

This study attempts to address this gap and explore the value of UAV technology in rapid disaster response situations by looking into the application of this technology in practice. In order to do so, it will use the experiences and testimonies of experts who work with this technology in the field and compare the remote sensing products created by more traditional platforms such as satellites and airplanes with UAV derived products. The study is predominantly focusing on the case of 7.8 magnitude earthquake in Nepal on April 25th 2015 as this is considered to be the first case in which UAVs' generated images were available before any other areal or satellite imagery making it significant for the analysis both from practical and theoretical perspective.

1.4. General objective

To understand the value of UAV technology in rapid disaster response scenarios.

1.5. Specific objectives

1. To investigate the dimensions of 'value' in relation to UAVs in rapid disaster response;
2. To compare UAVs with satellites to highlight the advantages and disadvantages of UAV technology for rapid disaster response.

Research questions:

1. To investigate the value in relation to UAVs in rapid disaster response;
    - What are the functions of UAVs that could be considered of value?
    - How can the value of information be conceptualized?
    - What are the indicators to assess value of information in rapid disaster response?

2. To compare UAVs with satellites to highlight the added value during rapid disaster response;
    - What are the advantages/disadvantages in using UAV's in rapid disaster response?
    - What are the added values of UAV in rapid disaster response?

1.6. Thesis outline

This research is divided into 6 chapters. Outline of each chapter is given below.

Chapter 1 Introduction

Context of research and research justification are presented in this chapter together with the research objectives and questions.

Chapter 2 Literature review

Literature review presents the newest information about different concepts and covers as well the conceptual framework.

Chapter 3 Study case

This part of thesis provides basic info on two sites of disaster (earthquake) that were used as cases studies for the master thesis.

Chapter 4 Methodology

In this study, the methodology is divided into two parts. First part is the research on all the different stakeholders that were present during the response phase in primary case study of Nepal**.** The second part of the methodology is the analysis of gathered information and data.

Chapter 5 Results

In this chapter results of previously described methodology will be presented and discussed.

Chapter 6 Discussion

Here the results will be discussed and connected wit the research questions

Chapter 7 Conclusion

Conclusions of the discussions and results

2. LITERATURE REVIEW

2.1. Understanding value

Oxford Living Dictionary defines value as " The regard that something is held to deserve; the importance, worth, or usefulness of something" and Merriam-Wbster Dictionary defines it as "a relative worth, utility, or importance" as well as "a numerical quantity that is assigned or is determined by calculation or measurement ".

When new technologies emerge, or when a technology is trying to reinvent its purpose like in the case of drones, it is important to understand their value. This could be done ether by demonstrating it or, if it is possible, by measuring it. On one side there are technology producers who have the difficulty of proving the value and demonstrating the impact of new technology. On the other side there is the potential technology and information users who have low awareness of available technologies and their possibilities or they may have preconceived negative perspective on this technology (Kooistra, Van der Wal, & Poppe, 2015). Transferring the UAV derived data into the actionable knowledge is still not developed enough, however it is essential for creating the added value. Some of the biggest adoption barriers of this technology are difficulties in proving value and showcasing its impact (Kooistra et al., 2015). For these reasons the problem of demonstrating the value of drones is even more difficult and even more important. In this research, the value of UAV is primarily discussed in relation to the information it allows, particularly in case of rapid disaster response

2.2. Value of Information

Eaton & Bawden make a point that value of information strongly depends on its context and how it is used. It is not possible to determine its value unless its use is known as well as the context or occasion in which the information is being used (Eaton & Bawden, 1991). Information possesses the hidden property good feature because its value is sometimes fully appreciated only after it is used, and it does not need to be immediately obvious (Engelsman, 2007).

In response phase of disaster circle the most valuable commodity is quickly acquired information that will help officials to establish situational awareness. In these early stages of response information that they receive has the largest impact because officials operate in high level of uncertainty. Any delay in acquiring the information will reduce its value. When obtained in real-time, video footage and areal images of disaster struck area, are a commodity of high value because they give the knowledge to the responders about who needs help and where do they need it (Griffin, 2014).

The value of UAV's can be observed through the value of information produced by the UAV technology. So far, because of the substantial devastating effect disasters have on the functioning of economic system of affected area in general, value of information (VOI) in disaster management was mostly expressed through monetary value and through cost benefit analysis (Bernknopf & Shapiro, 2015). For this reason, the most common way of measuring value is by using the equation *Value = Benefits / Cost.* Study conducted by Macauley (2005) found that information value depends on number of different factors, such as: 1) how uncertain decision makers are; 2) what is at stake as an outcome of their decisions; 3) how much will it cost to use the information to make decisions; and 4) what is the price of the next best substitute for the information. All these factors have monetary nature and are directly connected to the price of the information and effect of that price on the decision making. Information gathered using satellites and UAV's have different value for various stakeholders in disaster management. Macauley (2005) as well stresses on the important aspect of values based on the necessity. Geospatial information has an essential role in reducing uncertainty in decision making process, which makes it highly necessary and valuable. Oppenheim *et al* states that it is general mistake to only quantify value of information based on cost because information that cost little (or is even free) can be of great value (Oppenheim, Stenson, & Wilson, 2002). As mentioned previously, information value depends on its context and use.

To better comprehend the value of information it is possible to observe information as an asset (Engelsman, 2007). According to (Moody and Walsh (1999) information does qualify as an asset when it possesses characteristics like: service potential or future economic benefits, when it is a result of past transactions and it is controlled by an organisation. Poor finds in his study that it is possible to value information both qualitatively and quantitatively. According to him, in quantitative valuation of information assets, when information is timely, useful, reliable, accurate, rare and permitted then it has positive value. It has negative value when the opposite is truth. He makes also a statement that it is not possible to value all information quantitatively and that some aspects are better valued qualitatively. For qualitative valuation he made an example with three topics: political sensitivity, criminality and life safety (Poore, 2000). Poore, Moody, Walsh and Oppenheim are all in agreement that timelines has the greatest importance in valuing information as an asset. Additional important information feature is its use, value of information increases the more its used (Moody & Walsh, 1999; Oppenheim et al., 2002; Poore, 2000).

Information valuing could be performed after determining the valuation context and then assigning different levels, or positive and negative, value to relevant information indicators. Another possibility is to concentrate on its cost of generating and the income that creates. It is also possible to regard the value of information trough the benefits that are created as a consequence of its use. Information sharing, timeliness, usage and reliability are some of the recognized value increasing properties of information (Engelsman, 2007).

Based on the literature, the value of information can be classified into 4 logical and sequential steps which is termed as information chain in this research. It encompasses 1)information need 2) data acquisition 3)data processing and 4)results.

2.3. Information needs

Information about who is affected, where, how and when in disaster rapid response situation is of upmost importance to the first responders. It provides them the situational awareness that they need in order to react rapidly, which is especially important in search and rescue operations. For this reason remote sensing has a important role in disaster response and satellite imagery has had a long tradition in providing the needed information (Al-Khudhairy, 2010). Even though large number of studies point out the benefits of disaster prevention and preparedness, the biggest need for disaster related geo information is based in the support of disaster response (Backhaus, 2013).

Different stakeholders in the disaster emergency response have different information needs. Stakeholders in response situations that are recognised in the literature are: decision-makers and consultants (they coordinate and advise the teams on the field), emergency responders in the field (fire department, police, ambulance etc), victims, journalists and the public (Diehl, Neuvel, Zlatanova, & Scholten, 2006).

Timeliness is depicting the measure of time required to create, deliver, and ingest information produced by remote sensing. In time-sensitive remote sensing it is fundamental to consider the user's information needs, in the event that the information comes too late, its value reduces or is eliminated (Lippitt, Stow, &

Coulter, 2015). In the first 72 hours after a disastrous event, damage of critical infrastructure, disaster extent, damages on transportation features and building damage (for the purposes of search and rescue)have the highest priority level of information needs. The threshold of 72h has been mentioned in a number of researched books and articles (Andrienko, Andrienko, Schumann, & Tominski, 2014; Bizimana & Schilling, 2010; C. Lippitt et al., 2015). In emergency response it is necessary to select adequate information source. For instance, medium resolution images are more appropriate for monitoring large scale natural disasters such as flooded area or coast line destroyed by tsunami, or forest fire. High resolution images are more convenient for detailed inspection of more localized areas damaged by natural hazard. In urban areas for detailed inspection of infrastructure and buildings, as well for people locating (Zhang & Kerle, 2008). Emergency response are dynamic situations that requires frequent monitoring of relevant development so that the response actions are effective and efficient (Zlatanova & Fabbri, 2009). Because of that it is imperative that a geospatial data which shows impacts on critical infrastructures is made available as soon as possible (Bizimana & Schilling, 2010). To achieve this through use of traditional airborne/satellite images within 24 hour is challenging. In 2013, typhoon Haiyan devastated Philippines, where the first satellite imagery analysis was available to responders 64 hours after the incident (Spruyt & Lemoine, 2013). This information is too late for the responders on the ground, especially for the purposes of search and rescue.

One of the challenges is to successfully co-ordinate the use of resources throughout the incident command structure (Hodgson & Davis, 1998). This is because the use of the obtained maps may be determined by the knowledge of the technology and the ability to understand the output maps. Although this scenario has been improving with higher impact of remote sensed images for decision making, communication about and access to it can be enhanced (Bizimana & Schilling, 2010).

That being said, UAVs can capture high resolution aerial imagery within hours and commercially available UAVs are considerably cheaper than satellites, also they are fairly easy to use (Ezequiel et al., 2014). For these reasons experts are expecting more and more humanitarian UAV missions in coming years (Ofli et al., 2016).

2.4. Data aquisition

First time-sensitive step in information production chain is data acquisition. It is crucial to collect critical data as quickly as possible (Lippitt et al., 2015). Presented here are latest trends in data acquisitioning by satellites and UAVs.

2.4.1. Satellite data acquisitioning

The data obtained over the last few decades have mainly focused on response phase of disasters (Gaetani, Petiteville, Pisano, Rudari, & St. Pierre, 2015). This has further advanced due to increased no. of EO satellite systems which are equipped with various sensors such as for electromagnetic spectrum, radar frequencies and near to mid-infrared, they have become more useful to map extent of disasters. These sensors often have a ground sampling distance (GSD) of range of 0.3 m – more than 300m (Voigt et al., 2016). There are many organizations which use this to support disaster response. There are 5 major satellite emergency mapping (SEM) mechanisms: the International CHARTER Space and Major Disasters, the European COPERNICUS program (including the phase when it was still called GMES), United Nations (UNOSAT-UNITAR and ReliefWeb), SENTINEL ASIA, and the NDRCC (Voigt et al., 2016). Among them the COPERNICUS program has been continuously increasing the no. of disasters analyzed per year The COPERNICUS is expected to grow further due to strong support from the European Commission policy and funding. Its SEM activation has increased from 2-5 products per SEM activation between 2000 and 2014(Voigt et al., 2016). UNOSAT has provided satellite imagery analysis and GIS support in over 300 major disasters as of now. They support UN agencies as well as member states from disaster management to training for capacity building. International Disaster Charter a collaboration of international partners which aims to provide user organizations with swift access to satellite data when requested. This data is then used to assist in disaster management. The access to Charter data is universal, i.e. it is accessible to all who may require the data to support in disaster management activities. Sentinel Asia is a collaborative initiative of space agencies and disaster management agencies to assist disaster management in the Asia-Pacific region through applying remote sensing and Web-GIS technologies.. (Gaetani et al., 2015)

2.4.2. Trends in satellite use

Due to increased number of satellite emergency mapping products which has improved quantity, complexity as well as timeliness, their use are now applicable in various phases of a disaster event. For example, during Gorkha earthquake in Nepal in 2015, ad hoc satellite image were used for surveying geo-hazards such as landslides and destabilized glacier lakes (Kargel et al., 2016).

This trend is ever growing due to increased capacity of satellite systems and increasing partnerships between public, private and government sectors. Higher spatial resolutions, automated image data mining and emergence of mass data processing systems will have considerable impacts on global satellite emergency mapping landscape. This will allow for frequent satellite imagery, multi-scale and multi-temporal nested monitoring approaches which can assist in near real time observations of dynamic state of the disasters. In terms of accessibility of data, Landsat paved the way for open access and even commercial platforms such as Planet Labs and SkyBox want to make their data available free of cost to academics and non-government organizations (Voigt et al., 2016). This means that in near future more data will be available for more people with varied backgrounds than ever before.

2.4.3. Use of drones in emergency situations

Use of UAV technology for gathering data (images) is offering several advantages in comparison to other image acquisition options. In comparison to satellite images important advantages are the flexible time of image acquisition and independence of cloud cover, which UAV provides besides offering very high resolution of images. Even though the single flight range covers less ground, multiple drones could be flown at the same time for more coverage. Besides providing base maps, important assets of UAV technology in the domain of disaster management is the opportunity to create elevation models and 3D models of buildings (FSD, 2016a). The costs can vary significantly but still the technology and processing software are becoming more available every day. Examples of successful drone use in mapping efforts can be find in different disaster situations, from hurricane damage analysis (Medair, IOM), Flood mapping (FSD, World Bank and Humanitarian Open Street Map Team), to earthquake damage analysis (UAViators) and building damage assessment ("Drones in Humanitarian Action," n.d.). Drones can also be used following the International Charter actions, post immediate response and find use in monitoring of the affected sites, clearing etc.

UAV technology is well suited for acquiring the data in dangerous scenarios, for example, in post earthquake areas (Baiocchi, Dominici, & Mormile, 2013b). In case of the earthquake in L'Aquila, UAVs were equipped with photo cameras and used for building damage assessment, demonstrating their advantage over satellites by producing detailed VHR images from different angles (Baiocchi et al., 2013a). They can also be sent inside the buildings for more detailed inspection of structural damages. Such an example is the inspection of the New Zealand's Christchurch Cathedral, which suffered damage in the

2011 earthquake and following aftershocks, which had made it very unsafe to enter so a drone was used update information on the interior (Rhodes, 2016).

In many dangerous situations, use of drones is demonstrating its value by preventing potential human causalities in terrain examination. For example in Bosnia and Hercegovina, after the floods of 2014, drones were utilized to search for landmines and other unexploded material that were being displaced with the flooding and mudslides (Meier, 2014b).

2.4.4. Humanitarian drones and UAViators

Along with data and technology becoming more available rises the opportunity for volunteer work in disaster situations, even by using drones. International initiatives such as the Humanitarian UAV Network (UAViators) are trying to connect humanitarian and professional UAV communities with purpose to facilitate information sharing, coordination and operational safety (Ajmar, Boccardo, Disabato, & Giulio Tonolo, 2015). This initiative now already includes about 2,700 members in over 120 countries, which are mobilized by competent authorities in disaster situations (Meier, 2016) They also promote safe and responsible use of drones, help establish guidelines for practice and develop the scientific base for this new technology. For example, after the earthquake in Nepal in 2015, UAViators, in collaboration with Kathmandu University's Department of Civil and Geomatics Engineering, Kathmandu Living Labs, DJI, Pix4D and Smartisan, have initiated a large training program for UAV operators, offering also the program for the use of Pix4D software and creating of 3D models and maps. Focus area of this training was a heavily affected village Panga so a complete map of that area came as a result, demonstrating the effectiveness of drone use for damage mapping (Pix4d, n.d.). Drones were also in use in 2010 during the Haiti earthquake, and provided important maps for reactions in the Yolanda Typhoon in the Philippines in 2013 (Belliveau, 2016; Tanzi et al., 2016).

The European Commission is assessing the potential role of UAVs by examining collected imagery "as an alternative and/or complementary source of post-event imagery in emergency situations and in a rapid response and mapping context" (Copernicus, 2015).

2.5. Data processing

Data processing is perhaps one of the most time-consuming steps. It could take couple of hours to couple of days, depending on the size of observed area, complexity of the observed scene, number of the people performing the analysis, experts' skills, available tool sets etc (Lippitt et al., 2015).

2.5.1. Satellite damage mapping

Assessing the damage on site is the most basic method and it suits the needs for a detailed review of a smaller scope. However once the scope of the damages is too large to be covered effectively, this way of assessing the damages shows its shortcomings concerning the time spent, as well as the needed resources (human and equipment). At times, the affected site might also be inaccessible which further complicates the assessment in the field. In such instances, and especially when time of data acquisition is of great concern, various remote sensing alternatives are showing great results and are increasingly being utilized for damage mapping (Baumann, 2014; Zhang & Kerle, 2008). Visual interpretation of aerial photos is one of the first remote sensing methods used in damage assessment, and today modern techniques that enable automatisation of data analysis are providing a way to eliminate subjectivity and increase efficiency for fast obtaining of needed data. For example, object oriented analysis is giving very good results in this domain, as well as many others (Blaschke, 2010). However, even with increasingly better technology, mapping structural damages with the use remote sensing data still has limitations (Kerle, 2010).

European macroseismic scale EMS-98 scale for grading structural damage levels of buildings was designed for use in ground surveys, and it offers 5 categories to grade the level of damage (Grünthal, 1998). In Figure 3 damage scale is presented and different damage levels (D1 to D5) are described in more detail. Today, EMS-98 scale is also the most commonly used scale in damage mapping via remote sensing as well, however in this application it has some shortcomings (Dekker, 2011). Without a better view of the façade it is impossible to asses negligible or slight damages e.g. hair-line cracks in the wall, which is the D1 level of the scale. It also would not detect D2 level which is moderate damage. With sufficient spatial resolution total or near total collapse (D5) is easily recognizable from the nadir view, and very heavy damage (D4) can somewhat be recognized from the damages visible on the roof, while substantial damages (D3) cannot be properly detected without a side view so oblique images would be needed (Corbane et al., 2011).

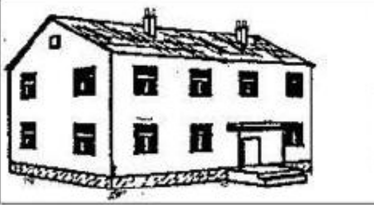
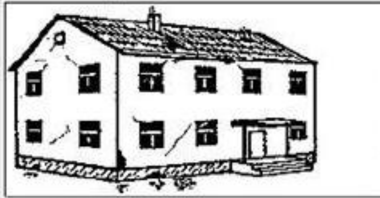
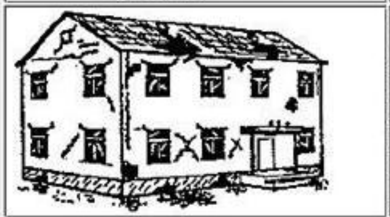
Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction (very heavy structural damage) Total or near total collapse.

Figure 3 EMS-98 scale for grading the structural damage levels of buildings (image source: Grünthal, 1998)

So, while proven to be useful, remote sensing application in structure damage assessment still has a problem of underestimation of damages (Huynh, Eguchi, Lin, & Eguchi, 2014; Kerle, 2010).

When analysing images for damage assessment, visual interpretation is still the method that provides the highest accuracy (Disasters Charter, 2016; Voigt et al., 2007), but the problem is that this is a complicated task which requires a lot of man power and time. This is particularly challenging in mapping of structural damages because determining the ground truth is very difficult due to the situational conditions. Adding time pressure that is typical for these situations means that many created maps go unevaluated for accuracy (Kerle, 2010). Even when data from the ground assessment are available, there are many problems with comparison with image derived assessments, due to the different perspectives. As mentioned, the full EMS-98 scale can be used in observations from the ground, and classes 1-5 can be made in the description of the level of damage. However, since lesser damages and wall defects cannot be seen from a vertical perspective provided by the image, results are often being reduced to binary maps with the damaged and undamaged categories. (Miura, Yamazaki, & Matsuoka, 2007). The fact that outputs from image analysis have different classification of damage levels is additionally standing in the way of accuracy evaluation, which is why it would be very useful to introduce an universally accepted nomenclature for damage levels in mapping from images (Kerle, 2010).

2.5.2. Crowdsourcing

Crowdsourcing is a voluntary participative online activity in which group of people tackles a specific task (Arolas & De-Guevara, 2012). In the context of disaster response, crowdsourcing aims to quickly and accurately create, disseminate and analyze large data sets by using a distributed network of human analysts. For example, after a disaster, large aerial and satellite image datasets can be split into small sections and sent to an online crowd of annotators to identify, classify, and prioritize damaged regions. This crowd can be composed of a small group of experts, the public at large, or a combination of the two (Barrington et al., 2011).

Particularly useful crowdsourced data in the context of disaster-response is volunteered geographic information (VGI) (Goodchild & Glennon, 2010). With the advancement in the location accuracy of mobile phones, and with many different web sites that encourage and facilitate crowdsourcing activities, volunteered geographic information has became useful tool for disaster-response. Popular sites that might contain useful geographic information are Flickr with geo-referenced pictures, Wikimapia and OpenStreetMap, and there is also an increasing use of Twitter and Facebook in the VGI aspect (Goodchild & Glennon, 2010). One phenomenon that has been used in disaster response situations is mass-sourced data in the cloud, also referred to as peer production, cloud collaboration, or cloud sourcing, where people from around the world are collaborating on projects that are often highly ambitious in both their scale and scope (Graham, 2011).

One prime example of cloud sourced mapping is the OpenStreetMap (OSM) project mentioned above, which leverages Global Positioning System (GPS) trails and digitized street patterns from aerial imagery to create a free street map for the entire world. Although developed countries enjoy better coverage than poor countries, the OSM project proved to be important source information even in developing countries. After the use of crowdsourced mapping efforts was proven useful in Haiti earthquake response (Zook, Graham, Shelton, & Gorman, 2010), a platform to contribute to humanitarian aid was developed on top of OpenStreetMap – Humanitarian OpenStreetMap Team (HOT). The HOT platform was used successfully for emergency response after disasters such as earthquakes, floods and hurricanes. Its usage was particularly useful after the earthquake in Haiti in 2010 (Soden & Palen, 2014; Zook et al., 2010), and after the earthquake in Nepal in 2015 (Poiani, Rocha, Degrossi, & Albuquerque, 2016).

With the development of new technologies and web platforms, the ability of volunteers to assist in disaster response situations via mapping and other spatial analysis has grown significantly (Goodchild & Glennon, 2010; Poiani et al., 2016; Soden & Palen, 2014; Zook et al., 2010). Thanks to this kind of distributed mapping it is possible to create large number of maps in short time period which then allows scarce technical resources to be diverted on other tasks. There is a concern about the validity, quality and accuracy of croudsourced products. Some situations demand high accuracy and quality that can be only assured by expert's skills and correct tool sets. However, in disaster rapid response situation geo-

information needs to be only good enough to assist the responders, which means that croursourced information is equally good as perhaps the information produced by more centralised means (Zook et al., 2010). Furthermore, there are some indications that in some circumstances, crowdsourced data has as high accuracy, if not higher than datasets from authoritative sources (Goodchild & Glennon, 2010).
In the future crowdsourcing might become even more useful tool for disaster response. Recently, UAVs have been used in a crowdsourced effort to contribute to disaster response efforts. Humanitarian UAV network – UAViators is a coordinated network with more than 2700 members that are mobilized at the request of established aid for services of data collection and cargo delivery. The UAV humanitarian network volunteers were mobilized in Nepal 2015 earthquake after 4 hours, and their efforts contributed to the disaster response after the earthquake (Deogawanka, 2015; McFarland, 2015). UAViators is actively promoting work of Humanitarian OpenStreetMap and MicroMappers that use crowdsourcing for fast analysis of areal imagery, like in case of Typhoon Haiyan. Hundreds of volunteers, so called "digital humanitarians", used the OpenStreetMap's crowdsourcing platform to create most detailed and updated map of downtown Tacloban, which was one of the most devastated areas. Many of those volunteers were Filipinos who wanted to help their country (Meier, 2015b).

2.5.3. 3D point cloud

Due to their flexibility in capturing images and their ability to capture images of occluded areas, UAVs are an ideal platform for generating high quality 3D point clouds, particularly in emergency response situations (Nex & Remondino, 2014; Vetrivel, Gerke, Kerle, & Vosselman, 2015). Typical workflow of generating 3D point clouds with UAVs includes several stages, which can be roughly divided into mission planning, image acquisition and image processing and feature extraction (Nex & Remondino, 2014). Mission planning includes deciding on parameters such as the ground sample distance, area of interest, and also camera calibration and set-up of ground control points. Identifying ground control points in the images is an important step in the photogrammetric workflow when working with UAVs, since on-board GPS sensors usually do not have high accuracy (Barazzetti, Remondino, Scaioni, & Brumana, 2010). Therefore it is necessary to manually identify ground control points when accuracy needs to be high.
3D point clouds can be generated by using Structure from Motion approach (SfM). This approach allows to reconstruct sparse and dense 3D point clouds from sequence of 2D images using three-dimensional structures and the position of the camera (Nex & Remondino, 2014; Yamazaki, Matsuda, Denda, & Liu, 2015). This technique is particularly useful when assessing the damage of buildings after earthquakes and other events that cause building damage (J. Fernandez Galarreta, Kerle, & Gerke, 2014; Sui, Tu, Song, Chen, & Li, 2014; Yamazaki et al., 2015). Information about captured objects such as their size and shape, distances to other objects or object features, angles or volumes of object features can be obtained by using 3D point clouds.

2.6. Products and results of data processing

Here are described the products and results derived from processed data as well as their possible applications and uses.

2.6.1. Satellite damage maps

Many countries use satellite emergency mapping (SEM) mechanisms to support their disaster response. Copernicus, for example, offers different map types. Reference maps are based on pre-event images that were obtained as close as possible prior to the disaster. They contain topographic features of affected area, particularly exposed assets other information that could be useful in crisis management (Copernicus, 2015). Damage extent overview maps are created from post-event images and they show estimation of disaster extent. In case of earthquake disasters they show the impact areas. Damage grading maps are created from post-event images and they include extent and damage grades of affected assets such as critical infrastructure, transport networks, settlements, utilities etc. Disaster Charter offers a landslide inventory and landslide damage maps that provide an assessment of landslides occurred after the event, and also shows potential damages caused (interruptions of traffic network, river blocks, damaged settlements etc.) (Copernicus, 2015).

As with any application of remote sensing data, there are compromises to be made regarding the quality of data, their accessibility, and cost, spatial, spectral and temporal resolution. Lidar data which provide a 3D perspective can be very useful in assessing structural damages are often difficult to obtain, as well as very high resolution images which can offer much detail but only from a vertical perspective(Dinand, Wietske, Ali, Zoltan, & Wouter, 2013). The use of an UAV can offer more perspectives, it is much cheaper than other methods of acquiring quality images and images can be taken at any time, which is why its use is gaining popularity in damage mapping, especially for the building level assessments (Baiocchi et al., 2013a; J. Fernandez Galarreta et al., 2014).

2.6.2. Point clouds

Point clouds generated from UAV derived images usually have multi-perspective oblique characteristics which enables detection of higher range of damage in emergency situations, especially compared to airborne oblique images (Vetrivel et al., 2015). It was also shown that 3D point clouds can be used to detect geometric irregularities, which can be particularly useful to detect building damage that otherwise might not be detected using typical image data (Galarreta et al., 2014). Furthermore, 3D point clouds can be used to detect change in damaged infrastructure by comparing point clouds taken at multiple time steps (Sui et al., 2014). This can be especially useful in situations when pre-disaster and post-disaster 3D point cloud data is available. Swiss nonprofit organisation Drone Adventures used eBees to help the Philippines with post disaster needs assessment after the Typhoon Haiyan. They were able to create detailed maps and damage assessments using the orthomosaics and detailed point clouds, thus providing efficient and quick help to emergency teams (Emery, 2016).

However, there are still issues with using 3D point clouds for precise detection of damage caused by disasters. In the situations where data is needed quickly, often the quality and the precision of data can be an issue, which in turn can cause errors in interpreting data. Gaps in 3D clouds that can be attributed to damage can be in fact caused by occlusion or image matching problems (Vetrivel et al., 2015). Furthermore, often sparse point clouds with lower resolution and lower accuracy are produced in rapid response and disaster assessment situations due to time constrains (Nex & Remondino, 2014), which again may cause flawed conclusions about the damage.

2.6.3. Drones in action on the field

During the initial emergency response, especially within first 72 hours, search and rescue of afected people is a key priority for response workers. Ability to rapidly locate the injured people increases their chances to survive (Bizimana & Schilling, 2010; Griffin, 2014). UAVs provide a solution for rapid search missions, especially in hard-to-reach and dangerous areas. One of the first recorded cases of using drone for search and rescue was reported in Canada where police force used Dragonflyer drone with an infrared camera to locate a car crash victim in wooded area in near-freezing temperatures (Franzen, 2013).

There is growing interest of developing and using thermal sensors together with UAVs. They shown large potential in detecting and monitoring wildfire with their ability to get close to the danger zone, even inside the smoke. UAV technology is providing the fire fighters an extra safety measure and it is expanding their fire monitoring capabilities (Aden, Bialas, Champion, Levin, & McCarty, 2014). In cases of fire, the smoke can hamper manned extraction as the visibility is decreased, so that unmanned extraction is the preferred

option. In this case, a real-time video transmission in enabling control of the situation, and an extra infra-red option can assess the temperatures of the area to track the fire (Measure, 2015).
These options are also invaluable in search and rescue operations in night conditions (FSD, 2016a). In a simulation of a refugee crisis spot being hit by a hurricane, created to evaluate drone use in search and rescue operations, it was concluded by users that a big advantage is the possibility to assess the sites with live video, and detect survivors with thermal cameras (FSD, 2016b)
UAVs can even be used for cargo transfer, of a reasonable small load, which is extremely important in situations where access in made difficult or even impossible in adequate time, and the affected people are in need of urgent supplies, such as medicine. Many organization are now starting to use this tool in their humanitarian efforts (Belliveau, 2016). Another interesting option is to use UAVs as temporary mobile access points to compensate for cell towers in situations of collapsed networks, or in non-covered remote areas (Tanzi et al., 2016), similarly it is possible to bring the internet connection to the affected areas. In that way they can enable communication and exchange of valuable information, which is extremely important in situations of disaster management.

2.7. Challenges of drone use in rapid response

One of the bigger problems with flying UAVs is that there are no common, internationally accepted certifications, standards and specifications for UAV platforms. Every country has their own system through which national security and wellbeing of their population are secured (The Human Environment and Transport Inspectorate, 2015). This often means that the use of UAVs needs to be negotiated, which can hamper humanitarian work. Among the disadvantages of using drones are the issue of privacy, safety and security, that is the risk of potential malfunctions that can cause collapse and unintentional damage, as well as issues of causing intentional damage (Tanzi et al., 2016). Relevant legislation regulating UAVs started to emerge in early 2000es with development of technology and its use. According to available data, many countries enacted relevant national laws from 2014 onwards and there are now laws in around one third of countries globally. However, there are no (clear) data on around half of all countries and in many jurisdictions new legislation is expected. As results of comparative analysis show there are now three countries (Uzbekistan, Egypt and Cuba) that are known to have banned the use of UAVs (Stöcker, Bennett, Nex, Gerke, & Zevenbergen, 2017). Same authors also point that search and rescue operations performed by fire fighters or governments services are usually exempted from the authorisation procedures. When examining relevant UAVs regulations Stöcker et al. point to six main criteria and variables which are: Applicability, Technical prerequisites, Operational limitations, Administrative procedure, Human resource requirements and Implementation of ethical constraints (2017).
In order to achieve maximum benefit from UAV use in humanitarian efforts, as well as in many other valuable use opportunities, legal and ethical issues need to be properly resolved. Some international guidelines that have been set can serve as foundation to achieve this. A good example is the Humantiatian UAV Code of Conduct and Guidelines, created by UAViators (Belliveau, 2016).
There is also general distrust of residents, even in cases where drones helped in critical situation, like in the case of 2015 earthquake in Nepal (Hern & Guardian, 2015). People think that drones kill people and destroy property, because they associate word drone with the military, this adds to the negative perception of the public. Lucien Miller in his lecture about benefits and risks of drone technology lists 6 stages of technological acceptance: ignorance, denial, fear & anger, acceptance, understanding and enthusiasm. He points out that we are now at the point of fear & anger where people are aware that UAV technology exists and is being used but they do not understand for what purposes is and can be used, and for those reasons people often over-react in a negative way (Miller, 2013). Based on the survey conducted in

Australia it seems that their society has a neutral opinion on drones and that people are not aware what this technology does in civil use (Reece, Dominique, Duncan, & Amisha, 2015). I some less developed countries in minds of people drones are strongly connected with military, especially because of its high level of autonomy, they perceived them as a weapon or a spying tool (Valavanis & Vachtsevanos, 2015). For a successful humanitarian mission perceptions are very important, and seeing UAVs in a neutral light or as just a tool in response and relief missions is essential (Emery, 2016).

Exchange of information between different stakeholders in emergency situations is crucial. Because of time sensitivity rapid data input and transfer is needed (Diehl, Neuvel, Zlatanova, & Scholten, 2006). UAV imagery could be shared as individual photos or orthomosaics. They are usually shared in an ad hoc manner on line, many times without any metadata. Information is shared from hand to hand without clear overview of who has what information and its quality. Geospatial information is created in different software, in different coordinate systems and different accuracies. This all is creates technical challenges for creating an open user-generated image repository (Johnson, Ricker, & Harrison, 2017).

There is also a large number of amateur drone pilots who think that they are helping and end up unintentionally in the way of relief and rescue efforts. Since they are not trained, they do not know what to look for and they produce a lot unnecessary data, also often duplicating the data (Love, 2016).

2.8. Conceptual framework

When the context is given in which the information will be used it is possible to observe and determine its value. Figure 4 shows the graphical representation of proposed conceptual framework. The value of UAV (drones) in post disaster rapid response situation can be assessed in terms of two broad functionalities it allows. The first is its use as carriers of goods and services to remote and difficult locations where traditional transport systems cannot be used, are either expensive or time consuming. Transporting medical goods and food rations or mobile and internet connections for communications are some of the functionalities that drones can be used for. Secondly, it can be used as tools for acquiring valuable information in the form of remote sensing data. This data can be used for search and rescue purposes, damage detection and mapping of critical infrastructure and damage assessment. The type of data required and the sensors to use would be defined by the purpose of its use. This research is focused on assessing value of UAV's in relation to the value of information they can provide. There are 5 distinct sequential phases of information chain during post disaster scenarios. They are identified as 1) Information need, 2) Data acquisition, 3) Data processing and 4) Results/products. There is a fifth aspect to this information chain which is 'data sharing' but due to its intrinsic nature it is considered as a value indicator.

The first step in information chain is **information need** which is dependent on the needs of different stakeholders in rapid response situation. They dictate the information type that is needed, accuracy of the information and the coverage. The need gives the purpose for the use of the information thus enabling te possibility to observe and determine its value. After establishing the need it is possible to proceed to the **data acquisitioning**, where key segments are equipment that will be used and the experts who will conduct the acquisition. Next in line is **data processing** which relays on the quality of acquired data, processing software and expert's skills. Finally, there are the **results** or products that carry the needed information. They could be in a form of a map, orthomosaic, digital surface model, 3D point could etc.

Each component of information chain carries certain level or intensity of value, depending on the value indicator that refers to them. Their value could be observed through value indicators which are divided into internal and external indicators. **Internal indicators** are dependent on the UAV technology itself and they are usefulness, timeliness, reliability and economic cost, data sharing. **External indicators** are outside influences on the value and they are legislation issues and social perceptions. Between internal and external indicators there is data sharing, which is a bridge between the two because it could fall in both categories.

2.8.1. Internal indicators

Timelines carries the strongest influence on the value because of the sensitivity of rapid response situation, where all the information needs to be available as soon as possible. In that sense all parts of information chain are affected by time and the value could be expressed with it, the less time is needed to complete the step in the chain the higher the value is. **Usefulness** has strong value in the data acquisition and results/products parts of information chain. By looking at drone technology as a tool that can be used, the same like with the results/products, if they exist but they are not used properly or at all then their value does not exist. On the other hand if they are used, what are the outcomes of their use? **Reliability** demonstrates its value influence in data acquisition and processing steps. The more the reliable the source is and the experts working in these steps the value is higher. **Economic cost** is present in first three steps, but it is mostly influential in the data acquisitioning and processing parts.

Bridge indicator

Data sharing is essential because it is necessary to provide needed information to the right stakeholder. It is strongly connected to the results, because results need to be used and in many cases in order to be valuable.

2.8.2. External indicators

Legislation, for now, has been usually perceived as indicator of negative value. It influences the value of drones mostly negatively because of the many restrictions and rules that are not enabling this technology to reach its full potential in rapid response. It has the strongest influence in data acquisitioning phase and results because of the way the information will be used and what is information carrying. It considers issues of privacy, security and safety. **Perception**, of general public, people who are affected by a disaster (victims) and in some cases even government officials, has its influence in the same parts of information chain as legislation. For now, it is as well considered as indicator of negative value in the most cases. This is because UAV technology is still strongly connected with the military use in the people's minds.

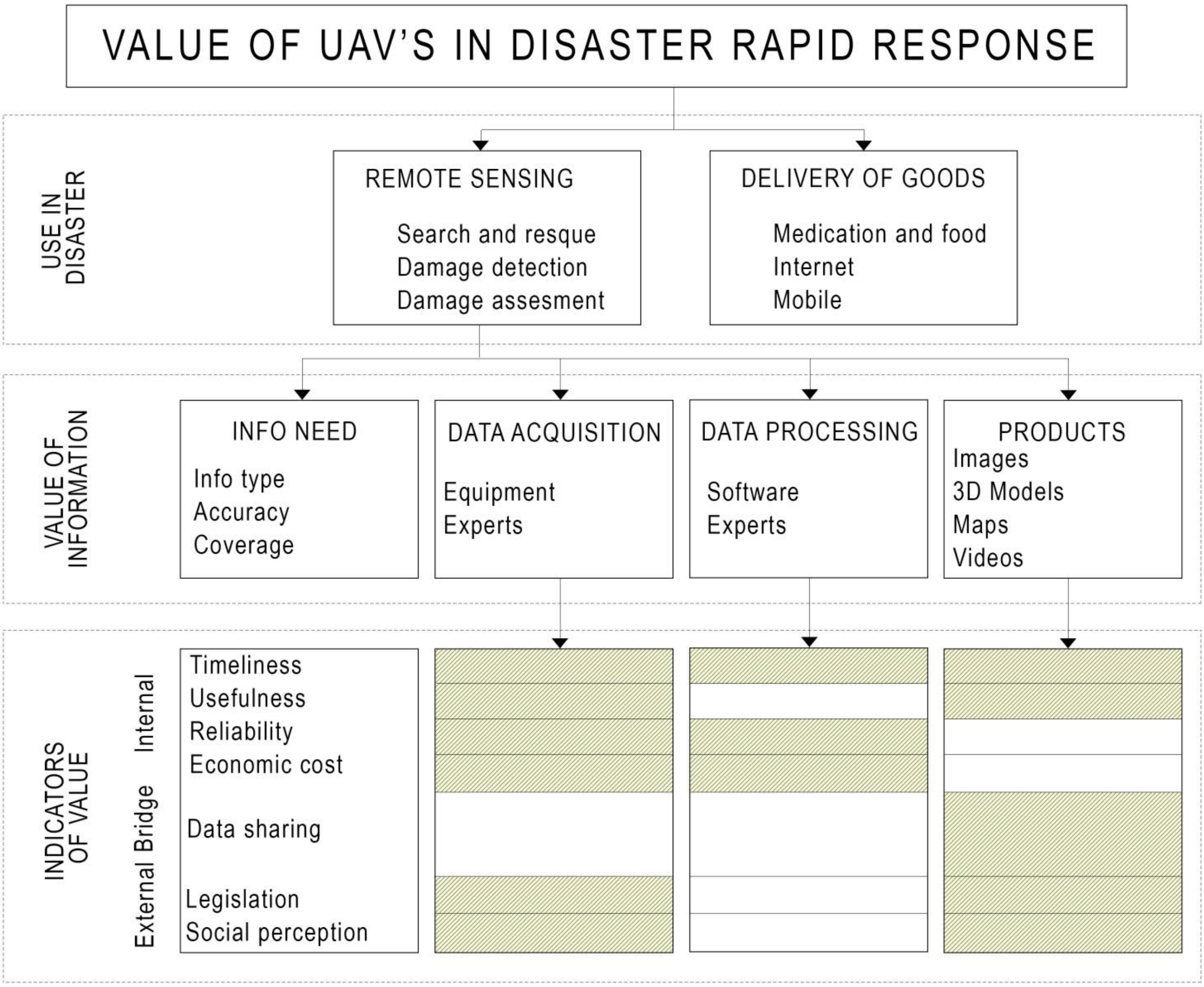


Figure 4 Graphical representation of proposed conceptual framework. In the part "indicators of value", areas that are coloured are indicating that the corresponding phase of information chain is being influenced by coloured value indicator.

3. CASE STUDY

3.1. Earthquake in Nepal on 25 April 2015

Nepal is a spatially relatively small country sandwiched between its larger neighbours India and China. It is world-renowned for its highest mountain range which emerged due collision of the Indian tectonic plate with the Eurasian tectonic plate. Two major fault lines Himalayan Frontal Thrust and Main Boundary Thrust run through the boundary of the country (Benfield, 2015) which has made it one of the most earthquake prone regions in the world. Nepal is spread over an area of 147,181 sq km with a population of 28.5 million people. On April 25th 2015, it was struck by a devastating 7.8 magnitude earthquake with subsequent aftershocks. The tremor adversely affected 14 of the 75 districts resulting in 8891 deaths and destruction of 605,000 homes. An estimated 189,000 people were displaced. Although the destruction to lives and properties is immense, it was relatively low compared to the previous projections for potential earthquake with estimated death of 40000 people, 90000 injured and up to 900000 displaced (JICA, 2002).

There are numerous factors that contributed to the lower than anticipated devastation. The basin like structure of Kathmandu valley modifies the ground motions considerably such that the dominant period of seismic activity ranges between 1-2 seconds. This means, buildings which are taller than 10 storeys high will resonate with it causing more destruction (Benfield, 2015). But Kathmandu valley has relatively few buildings which are taller than this limiting the extent of overall damage. The event occurred on midday of Saturday which meant many people were outside and not inside schools, offices etc. which minimized the death toll (Milton, 2015). Furthermore, limited damage to major infrastructure such as highways, connecting bridges, the international airport and major hospitals supported to subdue the effects of the earthquake. However, it should be noted that the energy loss of earthquake was directed primarily in eastward directions of the country and a possibility of 8.5 magnitude earthquake still remains in the near future (Benfield, 2015).

The National Disaster Response Framework (NDRF) gives a clear outline of the roles and responsibilities of different stakeholders during an event of the disaster (Government of Nepal, 2013). It states that disaster response is primarily undertaken by the Ministry of Home Affairs (MoHA) in accordance to Nepal Government's roles for division 2007. Disaster Relief Act 1982 and Local Self Governance Act 1999 are the basic legal provisions for disaster response of which, the local self-governance act allows municipalities to undertake necessary actions for disaster preparedness and response (Dangal, 2011). Central Disaster Relief Committee (CDRC) Regional Disaster Relief Committee (RDRC), District Disaster Relief Committee (DDRC) and Local Disaster Relief Committee (LDRC) were created under the Natural Calamity Relief Act 1982 which operate at different organizational level for disaster response.

Immediately after the earthquake, there was considerable response from the local people, communities, I/NGO's as well as from the international partners to help the people in need. Emergency response teams, supplies, monetary aids poured into the country in the aftermath of the disaster. This immediate response is also considered one of the factors that reduced the impact of earthquake on people (Floerchinger, Andreas, Kit, & Gfz, 2015). There were two local organizations which were involved in disaster response activities - Kathmandu Living Labs (KLL) and ICIMOD. KLL is a civic technology company which has worked in partnership with the UAViators. This is international humanitarian initiative/organization for utilisation of UAV generated data in humanitarian missions (Meier, 2015a). KLL was also working with Humanitarian Open street maps team – which is an initiative to create free and up to date maps for relief organisations. International Centre for Integrated Mountain Development (ICIMOD) is a regional intergovernmental organization based in Nepal working on economic and environmental mountain development and was involved in producing disaster maps after the earthquake. Specifically, ICIMOD was working with the Nepalese Government and providing its expertise in GIS and remote sensing to support the relief. Furthermore, it was also reported that ICIMOD was working with other stakeholders and space agencies to monitor other hazards triggered by the earthquake such as landslides and bursting of glacial lakes (Shakya, 2015). Two other international mechanisms – Charter and Copernicus were also activated and were producing maps during first two weeks of rapid response.

One of the most unique features of the disaster response was the use of drones. This was the first case where images and videos of destruction, created using drones, emerged in public before any other images. At least 15 different UAV teams operated within this period in co-ordination with the UAViators who are asked to oversee all the UAV teams by UN office for Co-ordination of Humanitarian Affairs (OCHA) (Meier, 2015a). Drones were used mainly for mapping damages, in some cases for search and rescue and one of the relief teams from Canadian used the drones as eye in the sky to see possible road block in front of their vehicles. These immediate acquisitions of images were helpful to understand the extent of damage in communities as well as collaborate with local people to assist in disaster response.
For the purpose of this research, Sankhu town, an old Newari settlement east to the capital city of Kathmandu has been chosen. Map presenting the location of the town can be seen in Figure 5.

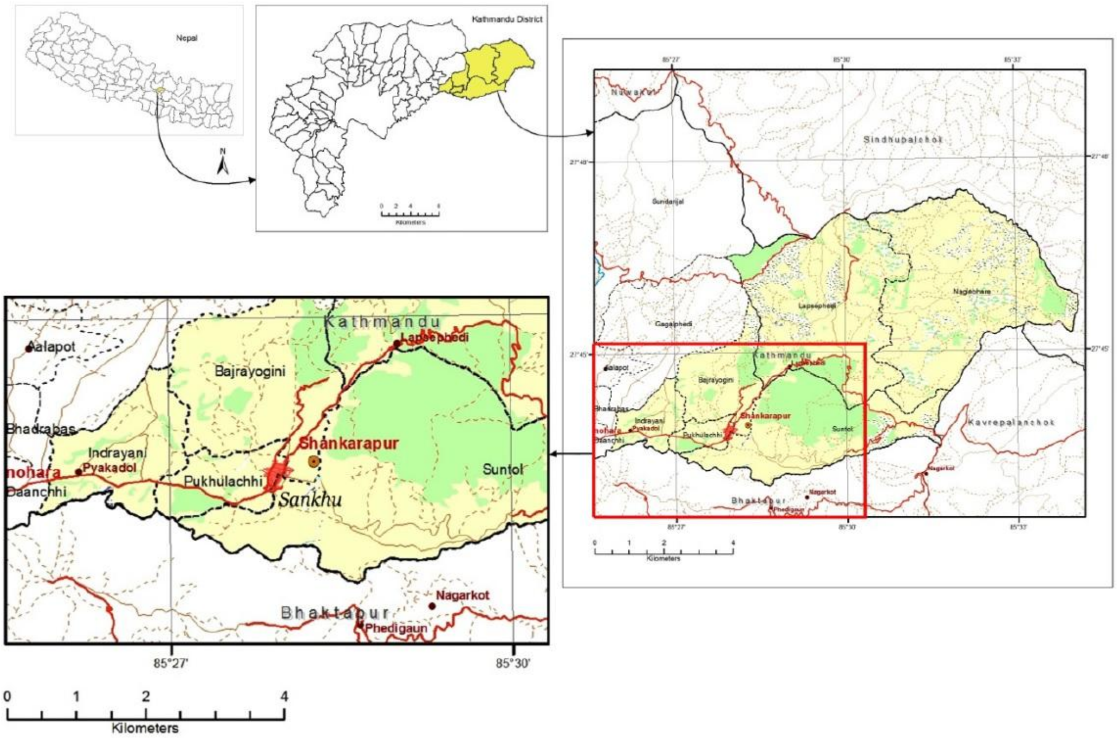


Figure 5 Location of Sankhu town, Nepal (map source Ministry of Federal Affairs and Local Development, GIS and Map Canter)

Sankhu is of particular interest for this research because it suffered severe damage during the earthquake. Most buildings of this ancient settlement were completely destroyed (Figure 6). This site also offered a unique opportunity to compare the images acquired from drone as well as satellite images for comparison. The drone images were taken by ICIMOD who conducted flight between 27th and 30th of April 2015. Within this same period, UNOSAT provided damage map with three damage classes based on pre disaster and post disaster satellite images. The post disaster image was from27th April while the final disaster map was available on April 30th.

Figure 6 Image of destroied buildings in Sankhu, Nepal 2015 (image source: www.abc.net.au)

3.2. Earthquake in Central Italy on 24 August 2016

Italy covers 302,073sq. Km and has 59,8 million inhabitants making it the fourth most populous state in the European Union (World Statistics Pocketbook, 2015). Italy is earthquake prone region because of the tectonic collision between the Eurasian Plate and the African Plate whose fault line lies within its boundary. Besides the earthquake, this collision also results in volcanic activities.

On 24th August 2016, in early morning hours Central Italy was hit by a magnitude 6.2 earthquake and subsequent aftershocks as reported by National Institute of Geophysics and Volcanology (INGV). The epicentre was situated near the town of Amatrice and was quite shallow at 4 km (European Commission, 2016). The magnitude of the earthquake has been set differently by various organizations. The European Mediterranean Seismological Center set the magnitude at 6.1 and USGS reported the magnitude at 6.2 at a depth of 10km. These discrepancies in values were later cleared by INGV stating that a crust velocity model was used specifically calibrated for Italy and gave higher weight to seismometric stations near the epicentre (Blog INGV, 2016). At least 297 people lost their lives, around 400 injured and almost 2100 people were displaced (BBC, 2016). It was followed by a number smaller scale earthquakes, with two bigger in scale followed on 26 and 30 October 2016 and 18 January 2017. Figure 7 shows the locations of four most badly damaged towns in Italy after the August 2016 earthquake.

Four villages were affected the most: Amatrice, Accumoli, Pescara del Tronto and Arquata del Tronto. Among them Amatrice and Pescare del Tronto suffered the most damage (European Commission, 2016).

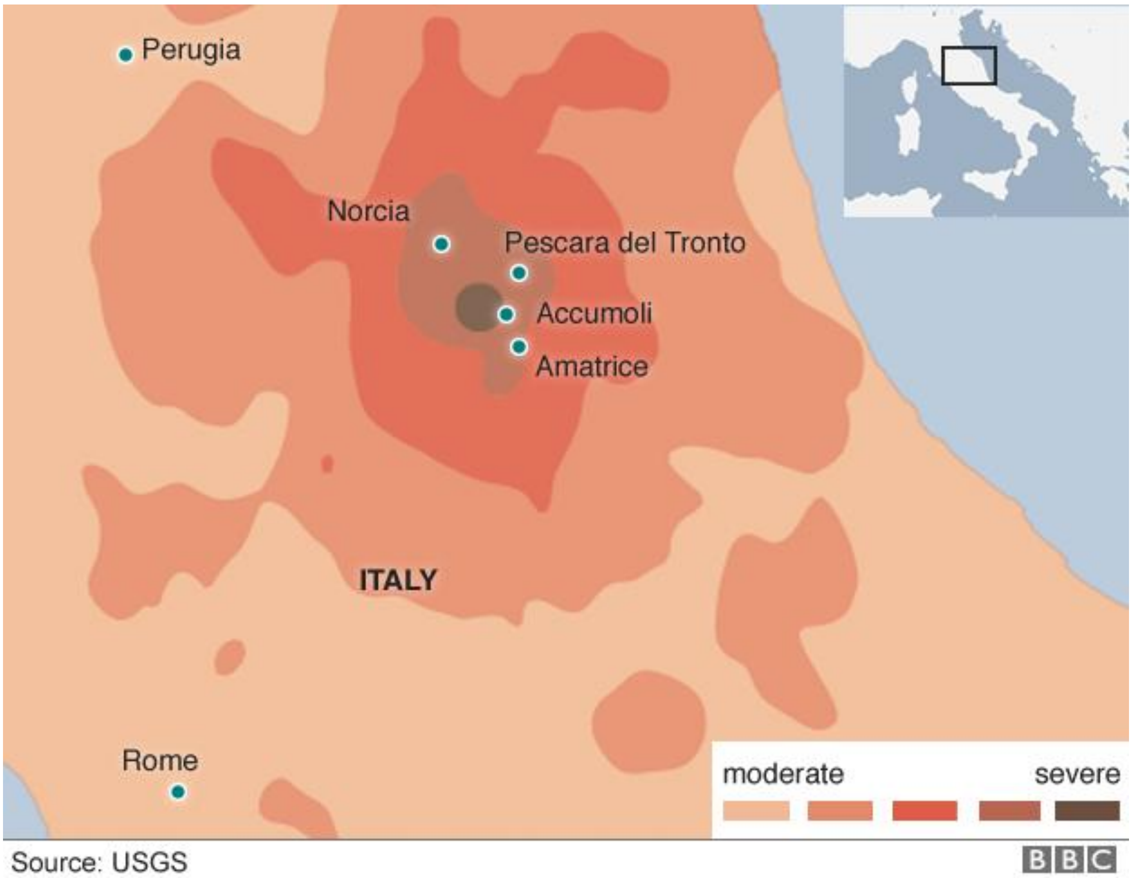


Figure 7 Location map of four most damaged towns in italy, August 2016 (image source: www.bbc.com)

There was extensive damage to the buildings in these locations and also to its cultural heritage as its churches, museums and historical baths suffered partial or complete destruction. One of the causes of massive destruction to buildings has been attributed to non-compliance of owners to construct and/or renovate the older buildings under the anti-seismic law of 1974 (TG com24, 2016). Thus, resulted in the houses turning into rubble rather than sustaining limited damage, especially in Amatrice and Pescara del Tronto.

Because the earthquake and its aftershocks caused a severe destruction over a large rural area The Italian Civil Protection Department, DPC ("Dipartimento della Protezione Civile") activated Copernicus EMS few hours after the disaster struck. Authorities used produced maps to show the extent of damages and to asses impact of damages. Maps showed damaged and destroyed buildings, disrupted roads and debris (Copernicus EMS, 2017). For creating these maps satellite images as well as aerial images were used. Destruction of Pescara del Tronto could be seen in Figure 8.

Figure 8 Image of destroyed Italian town Pescara del Tronto. (image source: www.theguardian.com)

4. METHODOLOGY

In this study, the methodology is divided into two parts. First part is the research on all the different stakeholders that were present during the response phase in observed case studies, primarily Nepal. This phase included a design of the interview, selection of relevant stakeholders, and then contacting and interviewing them. The second part of the methodology is the analysis of gathered information and data. The different analysis will be explained through the description of the data that were used, the purpose of the analysis, software, and methods that were used and, at the end, expected outcomes.

4.1. Interviews and questionnaires

At the very beginning, blogs, expert reports, media reports, etc were examined in order to determine which organisations were flying drones after the earthquake in Nepal. For Italy the information was obtained that use was limited to media broadcasting and by civil protection/fire-fighters actions but not in a search and rescue phase. Therefore the focus was made on organisations working in Nepal. The questionnaires and instruments (lists of questions) for interviews were prepared in order to gain insights into most relevant aspects of UAV use in post disaster response. Upon making a list of these predominantly international humanitarian organizations and foreign companies, their representatives were contacted as to provide more information through the means of interviews or alternatively questioners.

Among various types of interviewing, the individual semi-structured type was selected for this research due to specificities of the research subject. This type of interviewing enabled directing the interview towards specific details that emerge during the interview. They were also the way to get more in-depth information about data usage on the ground after the disastrous event and some personal opinions on the value of the technology in the context of that case study.[3]

Main information concern for the master thesis research was: for what purposes were drones used, in which areas where they filming, which data have been collected and processed. Furthermore, questions have been asked about the products that were made from gathered data and about data sharing among other organizations, institutions, etc. By this set of questions it was envisaged to get information relating to all research questions formulated above.

Interviews were conducted with the experts who have experience in flying drones. The majority of them were engaged with humanitarian organizations which utilised drones in their missions. There was a total of four Skype interviews (one respondent was interviewed twice), and three answered questionnaires received, as those experts opted to provide their feedback in writing.

These experts shared their experiences related to: challenges of legislation and flying rules, ethical issues related to type of data obtained (explicit/graphic high-resolution images), sharing products that are not usually shared with other parties and challenges of getting to these products both for research (as this one) and for other purposes.

In total, four interviews have been done with three major companies/organisations that were flying drones in Nepal. Interview was also done with Italian expert in satellite remote sensing who has provided

[3] Interview question can be seen in Annex I

a number of insights on the use of that technology but also comparisons with data gathering from the UAVs and aeroplanes. Furthermore, some info on the use of UAVs in Italian case was also provided. Questionnaire was also received by an expert from the company producing software used for UAVs. Even though sample was limited, it was representative for the study of UAVs in Nepal. Experts who were interviewed or completed the questionnaires can be seen Table 1.

Table 1 List of interviewed organisations and experts

Name of the company or organisation	Name of the expert
TEAM RUBICON Disaster response non-governmental organisation, from USA	Steven Hunt, chief information officer
DEPLOY MEDIA Video production company, from Hong Kong	Oliver Lun Jeff Gambel Yu
AERYON LAB Drone producer company, from USA	Andrea Sangster
SKYCATCH UAVs technologies company, from USA	Eugene Kwak
PIX4D Software and map production company, specialised in drone imagery, from Swicerland	Jorge Fernandez Galarreta
ITHACA The non-profit association/centre of applied research devoted to support to humanitarian activities in response to natural disasters by means of remote sensing techniques, from Italy	Fabio Giulio Tonolo

Interviews are analysed qualitatively. First, major topics were recognised, and afterwards connected with indicators of value. In this way, points of agreement and disagreement between organisations interviewed are emphasised.

4.2. Data acquisition and information needs assessment

The first analysis included examining and comparing the temporal resolutions of satellite and UAV platforms as well as counting the products created during the response period. The purpose of this analysis was to establish the availability of remote sensing data (satellite and UAV) in rapid response timeline. Moreover, the goal was to determine how available data is corresponding with the information needs, especially in the early stages of rapid response.

Data that was used was collected from the interviews and online articles and reports about different UAV missions during the post-disaster rapid response. Also, information about the production of satellite-based maps that were created by the Copernicus Emergency Management Service (Copernicus EMS) and The International Charter was used. Only the flights and products that were carried out/created during the response time frame were taken into account.

The expected output is a clear and comprehensive info-graph that illustrate if the stakeholders' needs were met in a timely manner with the data and information that was available at any given time of the rapid response phase. It should provide a more clear picture if the available data were sufficient to help the stakeholders by meeting their information needs.

4.3. Visual interpretation of building damage using the ortho-mosaic image created from high-resolution UAV images

The purpose of this analysis was to examine the advantage of high-resolution UAV ortho-mosaic image over a very high-resolution optical satellite image.

Used dataset contained 100 high-resolution images obtained by fixed-wing drone and a high-resolution satellite image obtained from Google Earth. Drone post-event images were created between 27th of April 2015 and 30th of April 2015. The satellite pre-event image was from 12th of March 2015.

Software used for this analysis was Pix4D and ArcMap. Pix4d was used for creating the ortho-mosaic by using the high-resolution images obtained by fixed-wing UAV. This was done in an automated way that is following the photogrammetry workflow. Ground control points (GCPs) were not used for georeferencing of the UAV images. Instead, coordinate information integrated in the images from the navigational system of the drone were used for retrieving true camera position in the calibration step. In Pix4D calibration is done in Initial Processing step, where the process of structure from motion (SFM) is performed. Geo-tagged images are located in computed locations in space during this step. Program then searches for the key points on overlapping images, he compares the key points and then matches them. They are used then for bundle block adjustment, and the software is computing the exact orientation and position of camera for every image. Matched points are then assigned with 3D coordinates and put in chosen coordinate system. With this step automated image orientation is finished (end of initial processing in Pix4D). From here generation of 3D point cloud is possible. This is done through the process of dense image matching. This is done in stereo pair and ideally for each pixel in one image there is a corresponding pixel on the other one, the point is to have as much as possible matched similarities on reference image to the similarities in compared image. If t here is not enough matches between the image pair it is possible to optimise them by smoothing, the more matches we have the less optimizing we need. This si done in Pix4D in step called: Point cloud and Mesh section. From this we get point could and a mesh layer that gives more real appearance to the 3D model. Now it is possible to create Digital Surface Model and to use it to ortho-rectify images. When the orthorectification is done with DSM true othomosaic (orthophoto) is created. This is done so that relief distortions could be corrected. Final product is an orthomosaic that can be used for mapping.

ArcMap was used for creating polygons on top of the damaged buildings on the post-event ortho-mosaic image. Each polygon was assigned a damage score in the attribute table.
The method used for determining building damage was visual image interpretation. To determine the building damage at a building level, ortho-mosaic created from high-resolution post-event UAV images was visually inspected. The pre-event satellite image was taken from Google Earth. Pre and post event images of buildings were compared, and the vector data (polygons) of damaged building outline was created by hand on top of the UAV ortho-mosaic image. Buildings were compared one by one, and each drawn polygon was assigned a damage class in an attribute table. The EMS-98 scale for grading structural damage levels of buildings was used. Only damage grades 3, 4 and 5 were assigned. Damage level 5 represents destroyed structures, damage level 4 severely damaged structures and level 3 moderately damaged structures. More detailed description of damage classification can be seen in Figure xx in Literature review chapter.
Only grades 5, 4 and 3 were assigned because of the possibility of later comparison between the results of this analysis and the results of damage analysis that was carried out by Disaster Charter, who used only these three grades in their assessment.
Expected output for this analysis was detailed damage assessment on a building level. Even though it is not possible to determine damage levels 2 and 1 without oblique view it is possible to determine higher damage scores 5 and 4 and with somewhat lesser certainty it is expected to estimate damage score 3 as well.

4.4. Validation of satellite-detected damage map

The results of the previous analysis were compared with the results of the official damage analysis carried out by Disaster Charter where the satellite optical images (50cm spatial resolution) were used. This analysis is relevant because UNITAR/UNOSAT claims that they are providing maps with building level damage estimation. This way it was possible to test this claim and investigate the performance of damage assessment on VHR drone ortho-mosaic image.
ArcMap was used for overlaying the orthorectified UAV image with graded damage polygons on top of the satellite damage map that was created by Disaster Charter. Damage map is manually georeferenced using the ortho-mosaic so that they are aligned. The points representing damaged structures on the map are digitized manually, keeping their original damage grade. The points are then overlaid on top of the damage polygons for comparison. An additional column in attribute table is created, and every damage grade polygon is compared with the damage grade point. If the damage score is the same in polygon and point, then the score stays unchanged, and they are a much. If there is a difference between the two damage scores, then the point damage score is entered to the table, and those polygons are unmatched. Because the number of polygons is higher than the number of points (reason being the higher resolution of the image used to create them), it is not possible to always assign one polygon to one point. All the polygons that did not have a point that corresponds to them were coded in the attribute table as undetected. The same thing is done in cases where the points did not have a corresponding polygon.
The attribute table is exported in Excel file, and the count of matched, unmatched and undetected damaged buildings is performed.
Expected result was higher number in matched buildings that are graded with damage grade 5 and lover in case of damage grade 4. A significant number of undetected buildings was expected (cases of under estimation).

5. RESULTS

This chapter gives an overview of results obtained through the analysis. Results are presented through the information chain, starting with information need, data acquisition, data production, and finishing with products. This includes the results of the analysis of interviews, together with results of the technical analysis.

5.1. Information need

The first part of the information chain is definition of what type of information is needed in order to properly inform involved stakeholders in rapid response situation. Immediately after the disaster, or even during one, information about disaster type, the exact location of the disaster and the magnitude are needed.

Different stakeholders in disaster response need different information. Stakeholders are all the participants in the post disaster rapid response and they are all potential users or producers of geospatial data for further decision making. It is relevant that definition of relevant information coincides with necessities different stakeholders have, from decision-makers, consultants, emergency response workers in the field, to victims, journalists and general public.

Different priority levels of information needs have been acquired through interviews and literature review. Based on information gathered from the 2015 Nepal earthquake case study, infogram that describes the information needs and maps that were produced (Figure 9). Infogram shows that the highest intensity level of importance is in first 72 hours after the disaster involve information on critical infrastructure, damage extent, transportation network damage and building damage (based on the perspective of involved search and rescue teams).

Different information needs presented in infogram have different levels of significance in the rapid response situation. For example, building damage from the perspective of search and rescue (presented in orange colour on the inforaph, figure 9), has the strongest importance level in the response phase. Building damage from the perspective of reconstruction (presented with blue colour on the infograph, figure 9) has lover importance level in the response phase and its importance becomes stronger and stronger until it reaches its maximum level of importance in recovery phase for the purpose of reconstruction and insurance. Communication network damage and energy supply damage have more or less the same priority level and it increases gradually during the first three days of response phase and it continues to remain strong for a period of time. Information about utilities damage becomes more important some time later after the rapid response phase.

There is a strong connection between information need and data acquisition, because acquisition itself is directly influenced by the need.

Interviews with experts gave an overview about what kind of information different stakeholders were looking for and for which purpose. The result derived from the interviews is about what kind of information is needed. In the rapid response phase it is connected with everything that can be used to ease the first moments after the disaster and help the process of decision making. This refers to images of the affected area focused on the extent of the disaster for the purpose of damage assessment, clearing up the area and search and rescue.

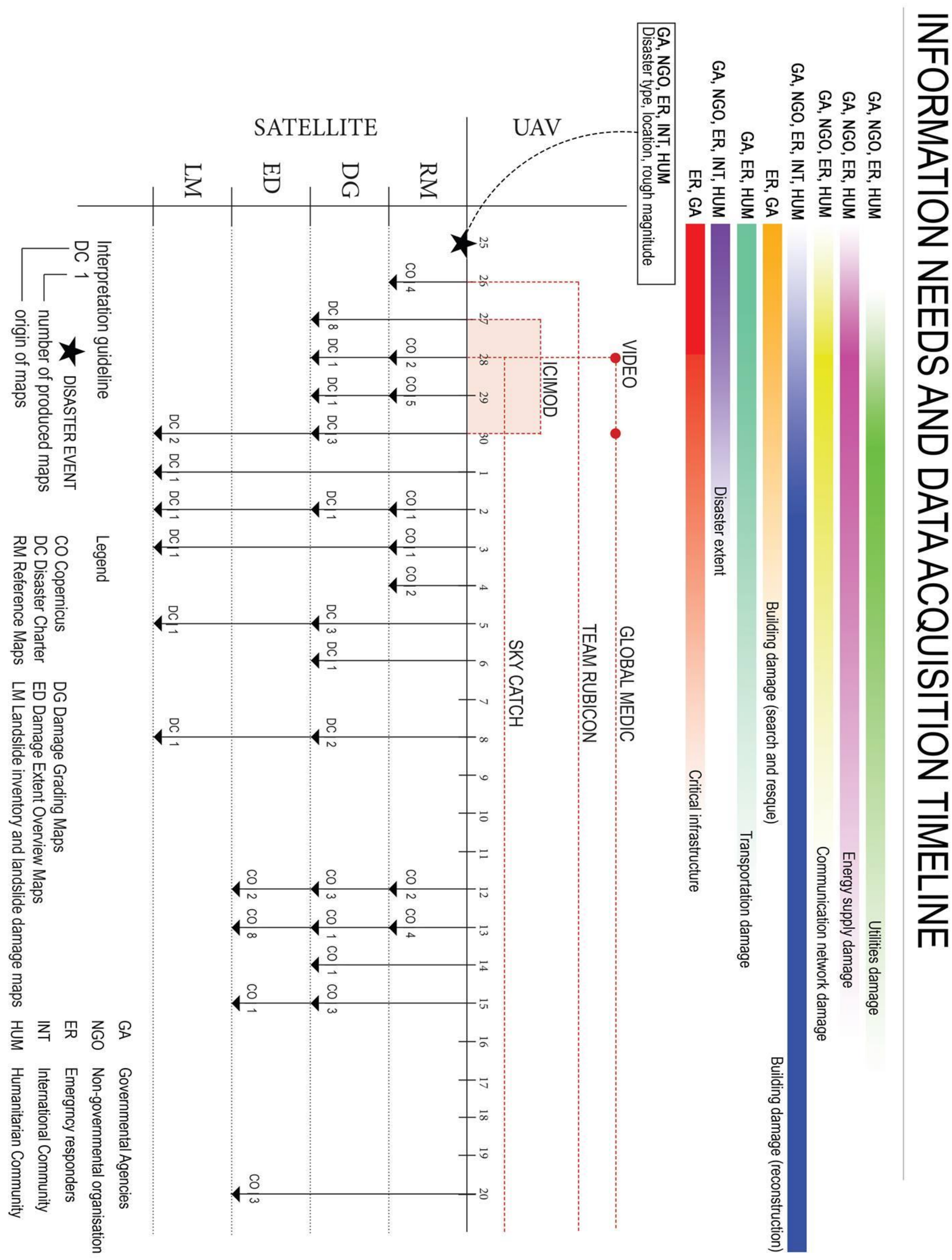


Figure 9 Infogram on information needs and data acquisition. Created based on the information from the Nepal case.

Overall, majority of experts have same opinions about the purpose of using UAV's and information it can provide. Stakeholders *"used UAV technology to: create maps of the affected area to understand the damage, but also help plan the rebuilding efforts, search for missing persons, fly ahead of convoys on roads to determine any blockages due to landslides, other debris etc."* (AERYON LABS). Moreover, teams were *"doing a lot of damage assessment"* (TEAM RUBICON) Similarly, "*by providing aerial mapping, UAV's could chronicle current state of the structures which were hit by the earthquake and, as they begin the rebuilding process, actually map out the structure since there were no blueprints available.*" (SKYCATCH)

The analysis of the interview gave results that confirmed previous knowledge about drones and their use, but, on the other hand, produced relevant input in evaluating their value. Some of the experts involved in the missions have very positive opinion about the usage of UAV's in the rapid response: "*The information that is capture by UAS is relied upon quite frequently. The information collected is highly accurate and often provides more detail than what is captured through other methods.*"(SKYCATCH) Similarly: "*I see UAVs playing a critical role in the future of rapid response."(*Pix4d) On the other hand, some experts have different thoughts on the topic: "*Drones do not make much sense in first response (searching for people, deceased people, people under rubble). There is no use of areal footage without having infrared sensor. It just takes time of first response. You are taking resources, like electricity and you are using a person to fly a drone instead of going through roubles.*"(Deploy Media)

It is relevant to observe the conclusions derived from interviews through the indicators of values. The information needed in the first response situation and provided by UAV's has to have a positive value in order to increase the value of UAV's itself. Therefore, based on the analysis of the interview, in order for information produced by UAV's to increase their value, it has to be useful, rapidly acquired, produced with reliable technology, cost effective, and shared with relevant stakeholders and involved parties.

The challenge in defining what kind of information is needed and for which purposes is connected mostly with incompatibility of involved stakeholders. "*There was a chaos on the ground, very little sharing of resources and very little coordination on the ground. One company even had a drone sitting in the customs for a while.*" (DEPLOY MEDIA) Overall, the chaos created by disaster, combined with non existence of clear legislative rules and negative social perspective, is challenging parts of defining what kind of information is needed and their collection in timely manner.

Moreover, information need differ when observed from different perspectives. Experts do agree upon the kind of information needed in the first response phase, however, different teams responded to different requests coming from third parties involved in the process. For example, Team Rubicon worked under UN, World Bank, UNOCHA and collaborated with local government. "*United Nations / World Bank wanted an overview of the area, structural damage extent. Local government wanted assistance in search and rescue (people locating, body count in case of desist people)."(*TEAM RUBICON) This shows how need and priority is changed based on the situation on the ground. The search and rescue and collaboration with police were more relevant in the first moment, while flight for the purpose of mapping was conducted afterwards. Timeliness as indicator is the most relevant in this point because the time of information needed to be defined influence the number of life saved. Already at this point, according to interviews, it is clear that the biggest value point of drones is their use in immediate search and rescue and their use in saving lives. This is elaborated more in the discussion part.

5.2. Data acquisition

One of the most challenging tasks when using remote sensing imagery during the disaster and post-disaster event is acquiring the data/information promptly. Right after the disaster event, emergency responders go to the field to take an overview of the impacted area and to provide situational awareness. Information value drops as the time passes and the needs change. This is why it is essential to quickly respond to the users' needs and obtain the information in timely manner.

Infograph (Figure 9) shows mission durations of the different organisations that were using UAVs in their response efforts. All involved organisations are international humanitarian organisations, except ICIMOD[4], a local environmental protection organisation from Nepal. Exact mission durations of the humanitarian organisations were not precisely determined. Based on the online reports and conducted interviews it was established that the missions lasted around month and a half.

ICIMOD conducted UAV flight over the town of Shankhu between 27th of April 2015 and 30th of April 2015 (coloured space). The data (images) obtained in that mission are the part of data set used in this study. They made 100 images, which were used in this study for creating an orthomosaic which was used for damage assessment of Sankhu town, near the Kathmandu. Global Medic came to the Nepal on 26th of April and on the same day they created a video using a drone in one of the city squares in Kathmandu. Second flight was performed on 30th of April and for the rest of the time of their mission precise dates of flights could not be confirmed. Sky Catch arrived on the date of disaster, however they were obtaining the necessary permissions and they performed eleven missions in Kathmandu area, starting from 28th of April until the end of May. Team Rubicon came on the scene among the first humanitarian organisations (on 26th of April). They performed a number of flights in urban areas as well as in the mountainous areas. Unfortunately precise dates and locations were not given.

With data acquisition, timeliness, usefulness, reliability and economic costs are the most relevant indicators of UAV values. Timelines in this case is observed not only through the time necessary for collecting the needed data, but also through the time of arrival and getting all the necessary permissions for performing the flights. Interviewed organisations agree on the existence of number of issues preventing them to be time and cost effective. These are mostly about the legislation and technical problems with the equipment. The part of the challenge to effectively utilise drones was a lack of regulatory framework regarding the use of drones and that administrative procedures were changing on a daily basis with different requirements put to the teams on daily bases. "*The government did require a permit to fly*." (AERYON LABS); "*The arrival of equipment was delayed because of customs clearing, etc*." (SKY CATCH) Moreover, "*at one point the government halted all UAV flights, so flight approval became difficult.*" (SKY CATCH) Furthermore, "*at that point in Nepal there was no constitution, soft government, ad rules about flying drones were changing day after day. At one point even a flight ban was in charge*." (TEAM RUBICON)

Team Rubicon and Skycatch did most of the flights, according to the interviews. Team Rubicon seems to be an organisation providing a waste part of the data for the very reason of being escorted and working closely with the local police forces. Because of previously mentioned bans and legislative issues, the recourses that were available were not properly used. That lowers the value of drones observing it in the sense of the usefulness indicator. Still, Skycatch covered in total 11 locations and produced 3D maps.

[4] International Centre for Integrated Mountain Development

For the purpose of comparing the area covered with satellites and UAV's in Nepal, Figure 10 is presented. The maps give an overview of the spatial coverage by the satellites and locations of conducted UAV flights by Sky Catch.

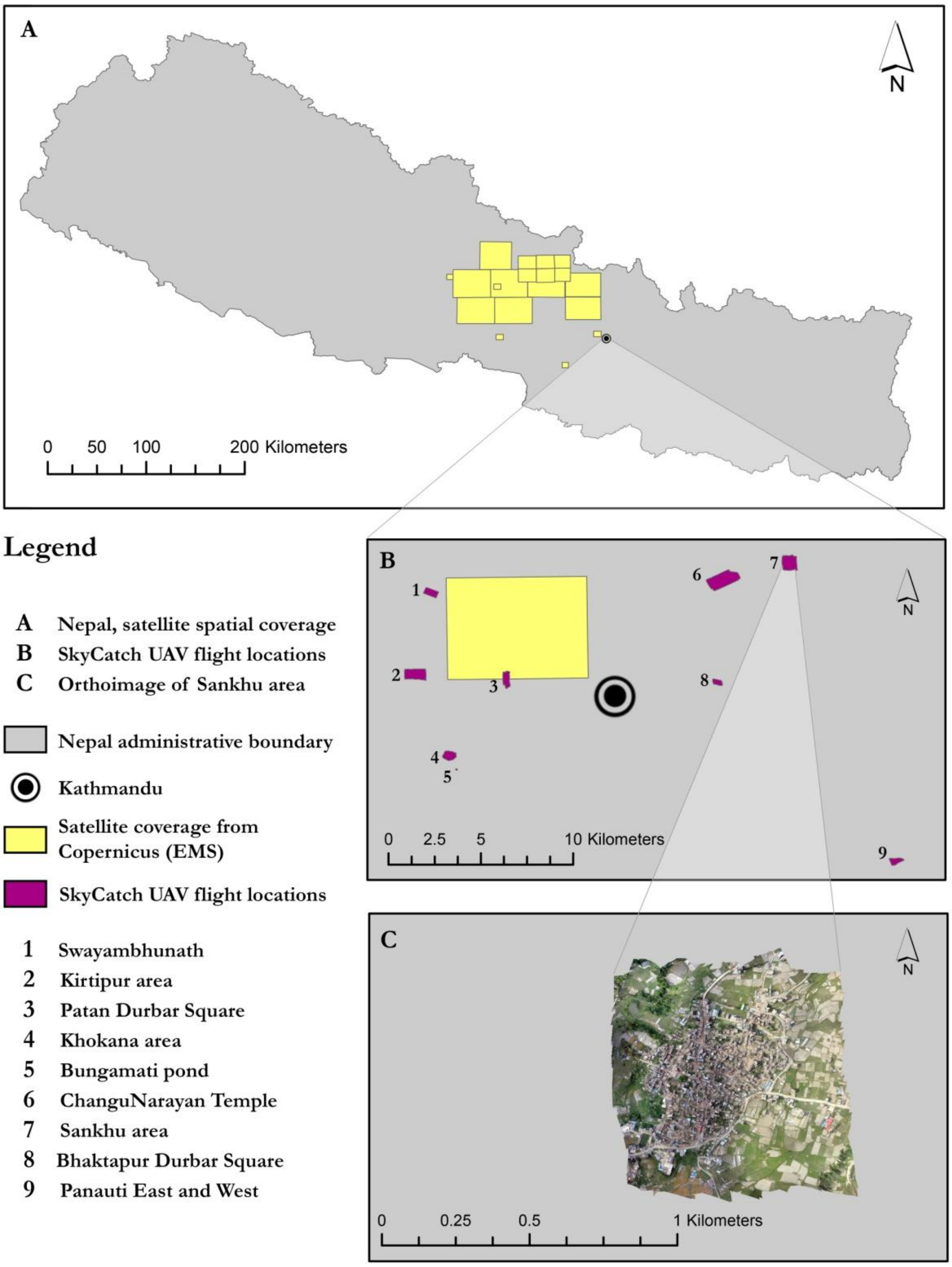


Figure 10 Image A represents the satellite coverage of Nepal after the 2015 earthquake. Image B represents the locations covered with drone flights by the Sky Catch. Image C presents a closer look on the Sanku town

The vast area was covered with satellite imagery. Satellite covered areas are represented with yellow polygons and the purple ones represent the areas covered by UAVs, flown by SkyCatch. Here, only Sky Catch provided the covered area, while other interviewed organisation only gave descriptive indications. Besides the satellite coverage from Copernicus EMS, there were maps provided by Disaster Charter.

Unfortunately polygons of Charter coverage were not found, so this map does not represent full satellite coverage of Nepal from that period. It is clear that satellites covered large area affected by the earthquake while UAVs were used to cover certain "hot spots" that were of special interest to different stakeholders. Area coverage of both platforms can be seen in the Table 2.

Table 2 Sums of areas covered by satellites and Sky Catch UAV flights, after the earthquake in Nepal

Nepal	
Satellite coverage	UAV (SkyCatch) coverage
8808,989 km² (880898,9 ha)	3,5483 km² (354,8338 ha)

From the infogram that refers to Nepal (Figure 9) it can be observed that the first available product came on 26th of April 2015, one day after the disaster event. Four reference maps were produced, and they require only pre event imagery. First damage grading maps came two days after the disaster event and they were damage grading maps, provided by Disaster Charter. In first three days we have 15 maps, 6 reference maps and 9 damage grading maps. In the same time period Team Rubicon was conducting its flights with in cooperation with the local police and United Nations. Several other teams started their missions on the third day after a disaster.

Map of mapped areas in Italy was created as well and is presented in Figure 11. In Italy drones were used by the local fire departments, unfortunately it was not determined for what purposes they were flown and were they useful to them. On the other hand for more detailed damage assessment of villages and towns scattered in the mountainous area, aerial photos were collected by plane. The spatial airplane coverage is seen in Figure 11C. Table 3 shows area coverage of both used platforms.

Table 3 Sums of areas covered by satellites and aeroplanes, after the August earthquake in Italy

Italy	
Satellite coverage	Aerial (airplane) coverage
761,154 km² (76115,4 ha)	8,7159 km² (871,593 ha)

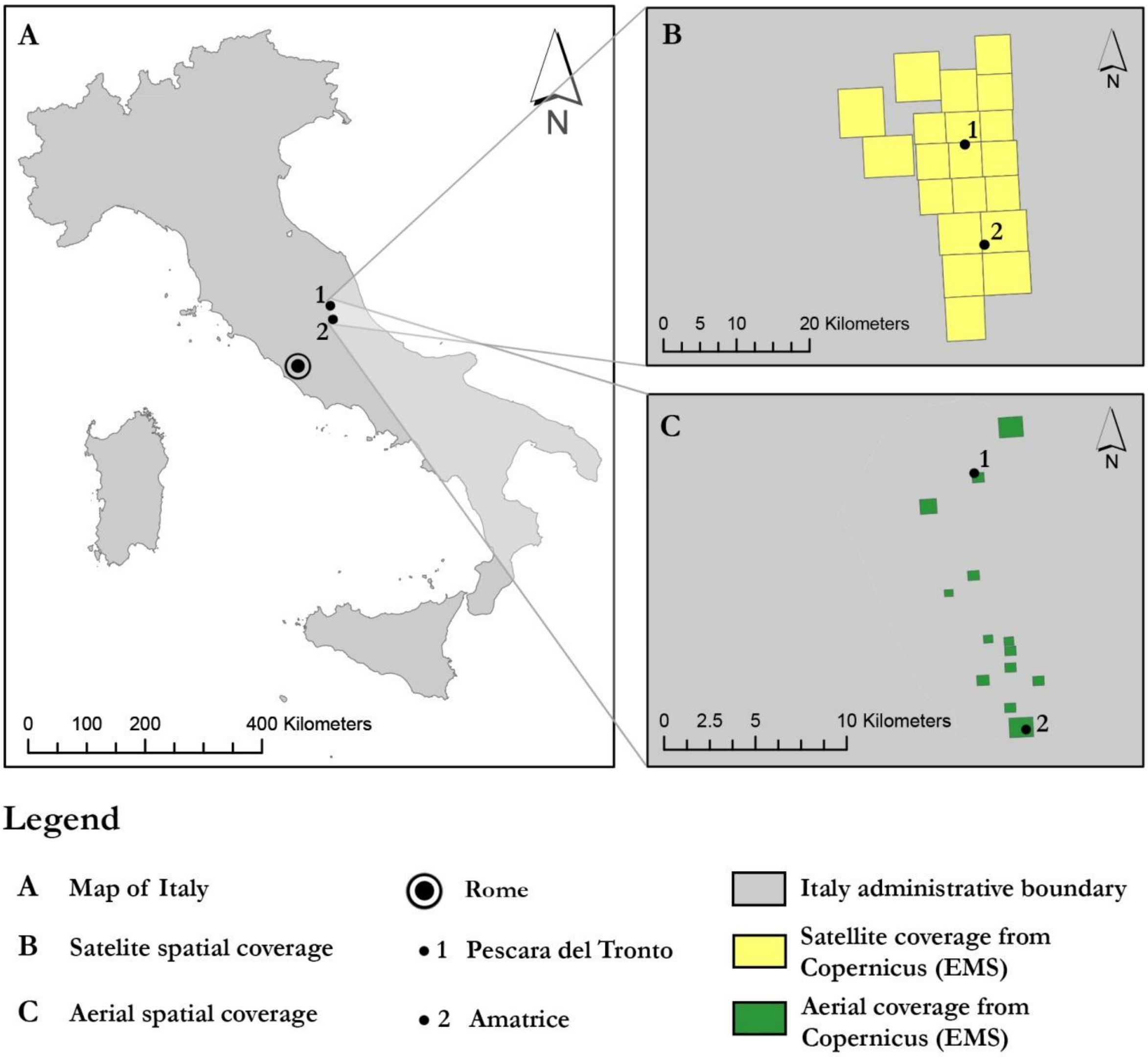


Figure 11 Image A the map of Italy. Image B represents closer look into the location that were mapped by Copernicus (EMS), using satellite imagery. Image C presents areas mapped by Copernicus (EMS), using aerial imagery.

Interviews show the use of different kind of equipment and sensors. "*RGB was the primary sensor. Using the datapipeline, 2d and 3d maps were created. There was no need at the time to use other sensors.*" (AERYON LABS); "*Since flights could only take place during the day, the EO (daylight) payloads were used predominantly. SkyRanger (drone) is equipped with a dual EO/IR payload, but for mapping the EO was the only sensor used. We had also just launched our zoom payload, so that was used as well.*" (SKY CATCH); "*Optical camera as well as infra red, however because of the challenging mission conditions, the results were inconclusive so at the end we used EO (optical) camera*." (TEAM RUBICON). In the opinion of Team Rubicon expert infra red has a great potential in search and rescue, however specific conditions need to be meet so that this technology reaches its full value. In this case IR was not that useful.

Most of the interviewed experts agree that they did not have technical issues with their equipment. "*Our batteries were delayed by customs, but I don't recall any technical issues preventing flights. I do remember reports of large flocks of pigeons being a concern, but they didn't cause any damage.*" (SKYCATCH); "*We had no technical issues with our UAVs.*" (AERYON LABS).

Other major issue is a mistrust of authorities and local population regarding the use of drones. The large number of media crews during disaster meant some of them using drones for news content production. Furthermore, local population on most locations was not properly informed who is using UAVs at which point and for what purpose, which raises doubt on the motives of those utilising technology.

In addition, having in mind geopolitical situation and the location of Nepal between two great powers – China and India, concern was also raised by some of representatives of authorities on the nature of the data that is being collected.

5.3. Data processing

For the data obtained by UAV's to be useful and reliable, data processing and the production of relevant information is essential part of the information chain. It can influence the value of UAV technology in different manners. Here, interviews were analysed to show the ways different organisations approach in data processing. Moreover, available data are processed as part of the study to show the ways products are created and comment on similarities and differences between different technology and value of UAV's in general.

Important issues to discuss were whether damage mapping (if damage maps were produced) was done in manual way (visual interpretation) or in any automated way. Experts opinions differ based on the used techniques. "*Automated processing tools were created to help extract the most useful data from the maps including measurements*." (AERION LABS); "*Geo-tagged images from our UAS are stitched together using Pix4Dmapper and then the appropriate output is generated through the same software. The team did not do anything manually, in creating the orthoimages. Final output (orthophoto) was used for damage assessment trough visual interpretation. Given the short timeframe of needing the information, automated processes are the most ideal for teams on the ground*." (SKY CATCH); "*Manual interpretation (visual interpretation) was used for damage detection. We had a team of 6 to 8 highly skilled professionals with the experience of using remote sensing data for damage detection*." (TEAM RUBICON)

Team Rubicon's team created maps and share them with the local police force. Team Rubicon had good cooperation with different commercial firms in acquiring very high resolution data. They used a pre-disaster satellite images as baseline for image interpretation and post-disaster UAV imagery. They used UAV orthoimages (created there in Nepal on their equipment) for damage assessment (structural) and people locating (and body count). Maps were produced and delivered to local police.

As it was mentioned before, when it comes to damage assessment using remote sensing data, visual interpretation is still the method that provides the highest accuracy (Voigt et al., 2007), but the problem is that this is a complicated task which requires a lot of time. That decreases the value of drones observed through the timeliness indicator, but increase it observed through the reliability indicator.

For the purpose of this research 100 images that were obtained by ICIMOD, using fixed wing drone, were used to create an ortorectified image of Sanku town. The orthomosaic was then used to the purposes of visual damage assessment.

5.3.1. Visual interpretation of building damage

Using the UAV dataset for performing the visual interpretation of building damage it is possible to closer examine how the use of UAVs changes production and use of data in rapid disaster response. As mentioned in the description of case study, he area of interest was ancient town in of Sankhu located 20 km northeast of Kathmandu city.

Detailed damage assessment on a building level using UAV was performed and the result is a damage map depicted in Figure 12. From the map, it can be seen that the damaged buildings are distributed all across the village. There are 550 buildings identified as damaged building with 95 buildings are moderately damaged, 157 buildings are severely damaged, and 298 buildings are totally destroyed. From the data, it can be seen that the UAV-based damage assessment recognized that most of the recognised damaged buildings in Sankhu Village are totally destroyed or severely damaged. EMS-98 damage scale was used for damage grading, damage levels 5 (destroyed structure), 4 (severely damaged) and 3 (moderately damaged) were assigned.

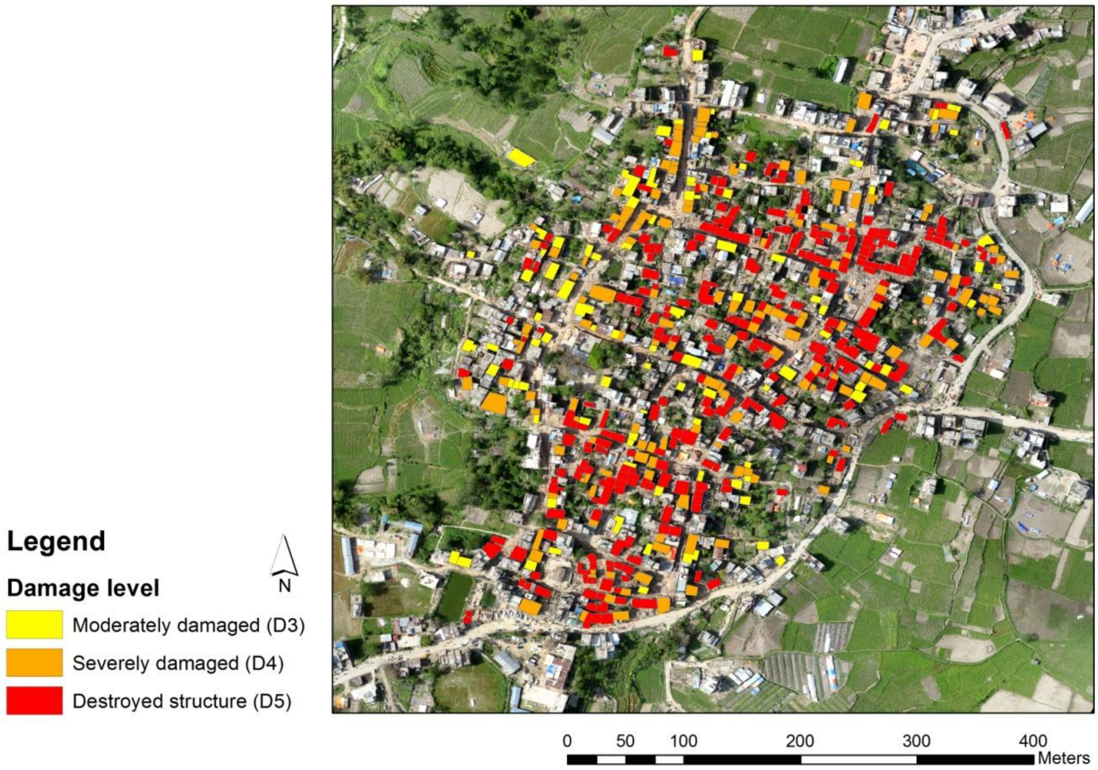


Figure 12 Damage map of Sankhu area. Map is created by analysing the orthomosaic that was created from ICIMOD images (original map)

5.4. The products

Different types of products are created from the data collected and processed. Moreover, data collected served as a data set used in this study to perform analyses and show the usability of UAV's.
Types of products according to experts: "*2d and 3d orthomaps. Some videos as well.3d maps were created to assist with the reconstruction of some of the fallen temples and structures.*" (AERION LABS); "*The photos captured were the main output used. I believe maps were created using Pix4Dmapper, but I don't think any 3D models were created.*" (SKY CATCH); "*3D images, damage maps and raw images*" (TEAM RUBICON)
Even though damage maps were produced from the drone imagery, Team Rubicon expert stressed that it is very useful to put information in a textual form, better than showing on the map, to provide content to the rescue workers in form they are used to (street names, addresses of the destroyed buildings).
Team Rubicon presented the "raw data" – images to the responders (police team) and they located people and bodies, they assessed the situation and went in to rescue mission. Therefore it is possible to conclude that there was use of UAVs in search and rescue operations.

On the infogram (Figure 9 and Figure 14) different products can be seen, in the form of different types of maps that were made by the satellites Disaster Charter and Copernicus (EMS), free of charge. We can see that there are four different map types: reference maps, damage grading maps, damage extent overview maps and landslide inventory and landslide damage maps. Reference maps are based on pre-event images that were obtained as close as possible prior to the disaster. They contain topographic features of affected area, particularly exposed assets other information that could be useful in crisis management. Infograms show production timeline for each type of map. Marked dates are the dates when the maps were delivered to the users and became publicly available. Example of damage grading map made using satellite image can be seen in Figure 16, it is a damage map of Sankhu area.
From the infograph in Figure 13 it can be observed that 60 maps were produced using satellite imagery and 20 by using aerial images acquired by the airplane. In first 72 hours 48 were created and delivered (45 satellite based and 3 aerial based). Example of aerial based damage grading map from Italy can be seen in Figure 13.

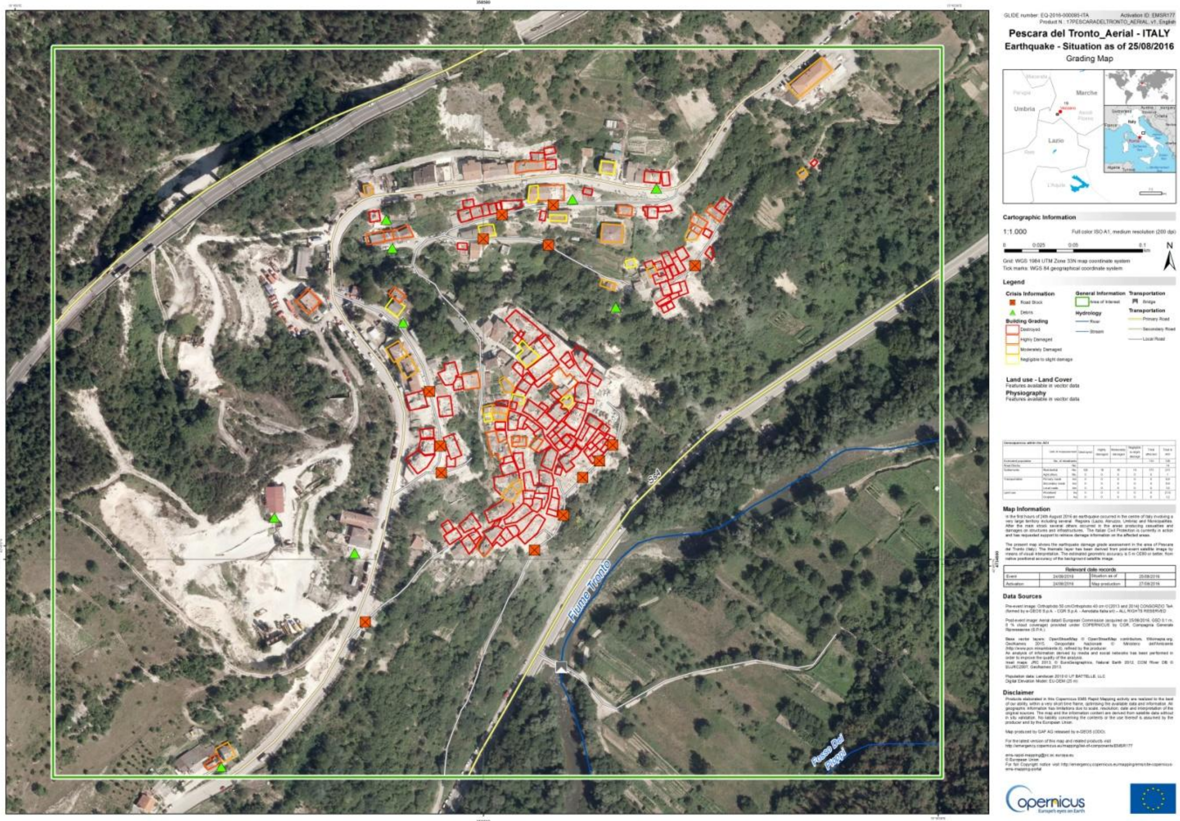


Figure 13 Copernicus Damage assessment map of Pescara del Tronto. (image source: Copernicus website)

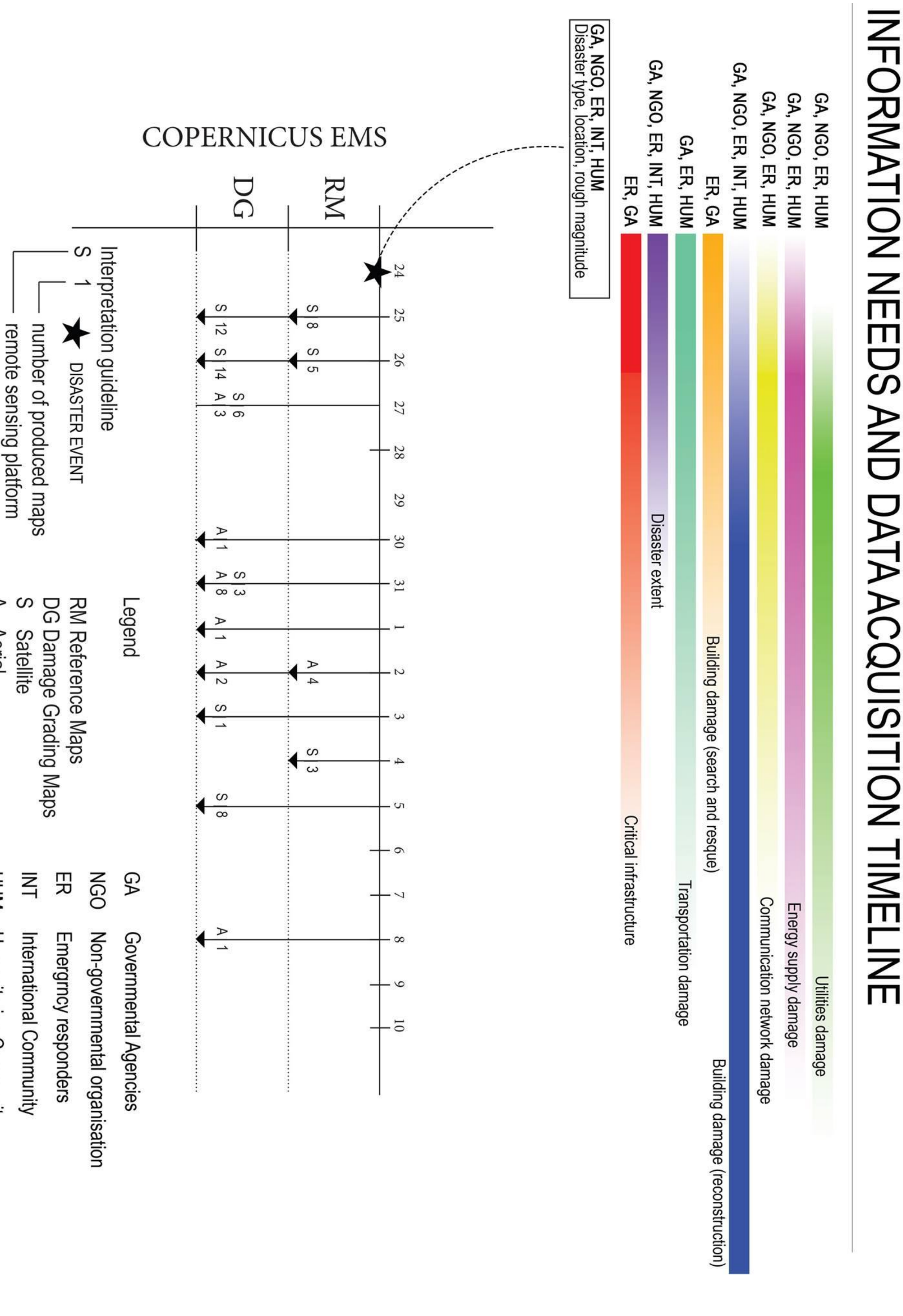


Figure 14 Infogram on information needs and data acquisition. Created based on the information from the Italy case.

Fabio Gulio Tonolo, a remote sensing specialist who works for ITHACA and produces maps for Copernicus (EMS), has stated that during emergency mapping fist version of final product is on average produced in two days from the moment the of the request. First version is then delivered to the user on line and updated on the site of Copernicus. If the request is made for the product that does not require post-event images then the map could be produced sooner. For Charter it was not established how long does it take to produce a finished product (map), however the main problem is not data processing but data acquisition. As attested by ITHACA expert in remote sensing there are two "*bottle necks*" in this process, one "*from activation of the system to delivery*" and another is user inactivity to trigger the mechanisms available. Furthermore, as attested by practitioner, "*If you lose an afternoon window you may wait another day especially for optical images*". In the case of smaller areas, UAVs might prove to be a valuable alternative as already outlined in literature.

From the infogram that refers to Nepal can be observed that the first available product came on 26th of April 2015, one day after the disaster event. Four reference maps were produced, and they require only pre event imagery. First damage grading maps came two days after the disaster event and they were damage grading maps, provided by Disaster Charter. In first three days we have 15 maps, six reference maps and nine damage grading maps.

Areal images, both from planes and UAVs, are a good solution for bridging satellite shortcomings like issue of timeliness, spatial resolution or cloud coverage (Copernicus EMS, 2017). However, there are two disadvantages, one is the cost of operation making it hard for developing countries lacking resources to implement such sensing and on the other hand as attested by practitioner *"it has to be fine tuned. You need to get permission from aviation authorities, in case of the planes it necessary to have a functional runway and you need to deal with a lot of datasets.*" (ITHACA). Copernicus Emergency Management Service, being aware of benefits that areal images provide, decided to deeper investigate potential of using manned and unmanned aerial systems and see how they could support emergency management actions. To do so they decided to use airplanes to collect areal images of affected towns and villages in Italy after the August earthquake.

In the case of Nepal with the limited resources and only one of the airports being functionally operational, damaged and overwhelmed with international rescue units, utilization of simple and cost effective UAV technology was able to provide high resolution images that are used for damage assessment. On the other hand, in Italy where a smaller part of country and population was affected, and with far more resources, a traditional technology was used in line with level of development of the country and existing disaster management infrastructure.

Moreover, the major difference between two analysed case studies is that many actors involved for the Nepal case where foreign responders who came in to help the relief efforts, as opposed to Italy where the response came mostly by local teams. Having in mind the capacities and level of development in two countries, this was expected.

From images obtained by ICIMOD, an orthomosaic was created for the purpose of conducting damage mapping. Images were taken between 27th of April 2015 and April the 30th 2015 (infogram, Figure 9). Figure 15A represents a detail from that orthoimage. Figure 15B represents an orthomosaic of the same area, Sankhu town, provided by Sky Catch. Sky Catch was in Nepal between April 28th and end of May, that can be observed on the Infogram (Figure 9), and in that period of time 11 flights were performed. On May 26th the mission update has been published on the Sky Catch website and public access to hi-resolution maps of 11 sites impacted by the quakes was provided through Sky Catch Relief Dashboard. Unfortunately, the link became disabled and maps were no longer accessible to public. Image that is being used in this study, and 8 other images, was provided by Sky Catch in late February.
Figure 15 shows selected details from ICIMOD's image and details of the same area taken from Sky Catch image, by comparing them it is possible to detect changes. Figure 15A presents us with the view of a road being covered in rubble. In Figure 16B the same area has been observed, and it is obvious that part of the rubble is cleared to the sides of the road. Conducted interviews confirmed that images created by Sky Catch were taken 3 weeks after the ICIMOD’s flight mission. The two organisations acted independently without any knowledge about each other's missions. This example tells us on one hand how drones could be used for monitoring purposes and on the other hand it depicts the problem of insufficient transparency in data acquisitioning process as well as the problem of duplicating data.

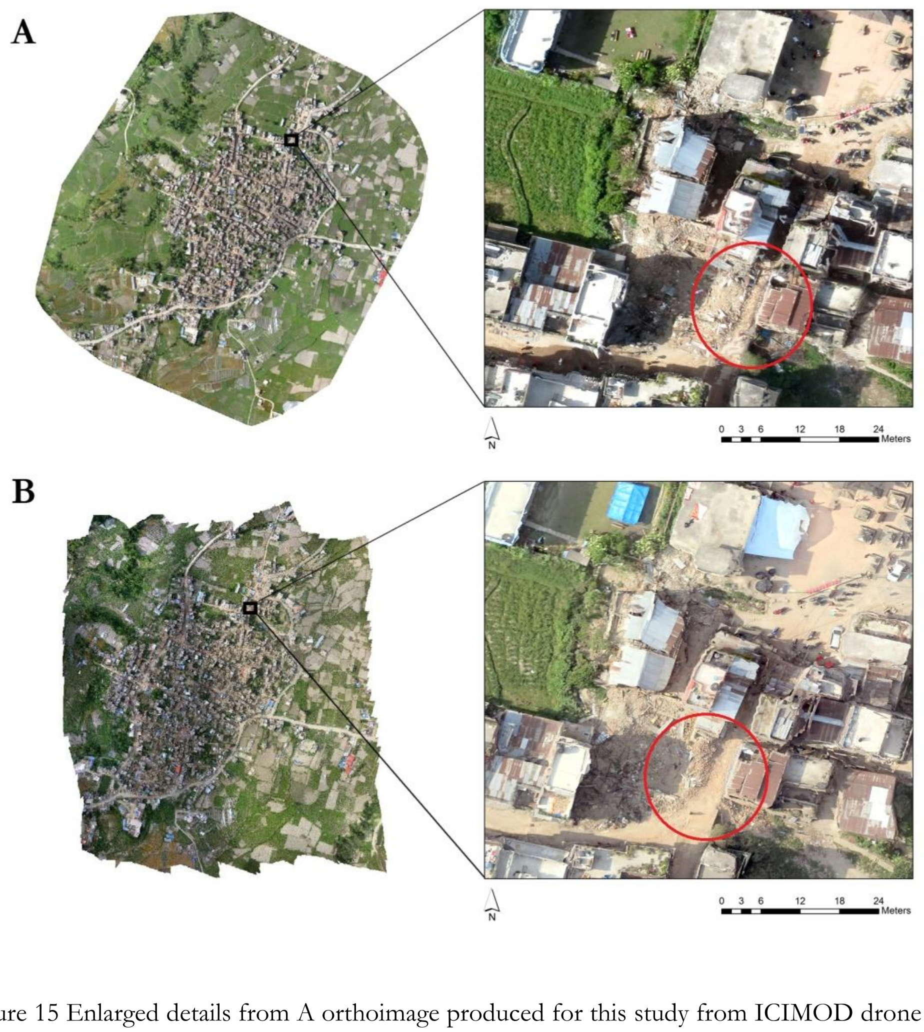


Figure 15 Enlarged details from A orthoimage produced for this study from ICIMOD drone imagery and B from otrhomosaic, provided by SkyCatch. Changes in rubble piles beside the road and on the road are noticeable on the enlarged image details (red circle).

5.4.1. Validation of satellite-detected damage map

Figure 16 represents the damage grading map that was produced by UNOSAT and that was used as a base map for the validation.

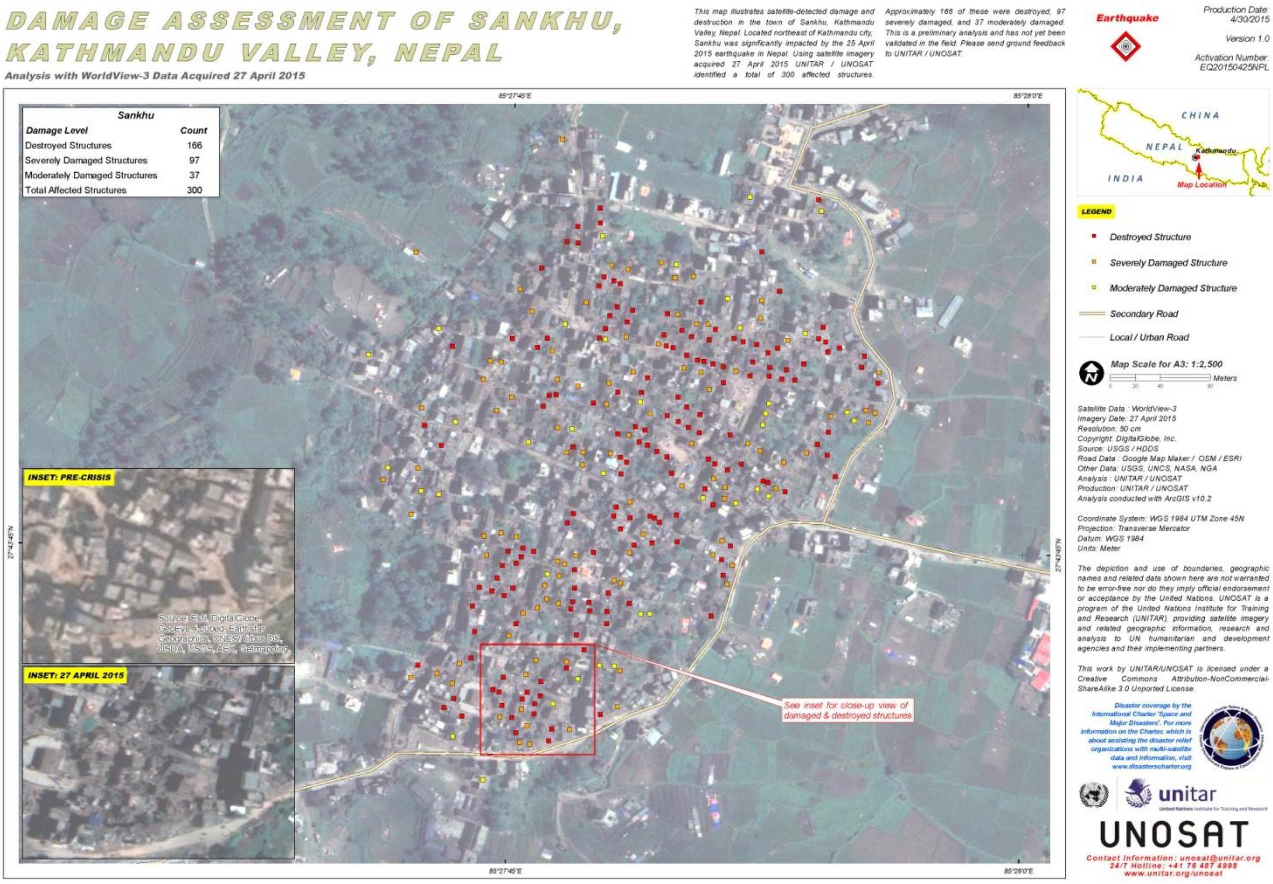


Figure 16 UNOSAT Damage assessment map of Sankhu. (image source: Disaster Charter website)

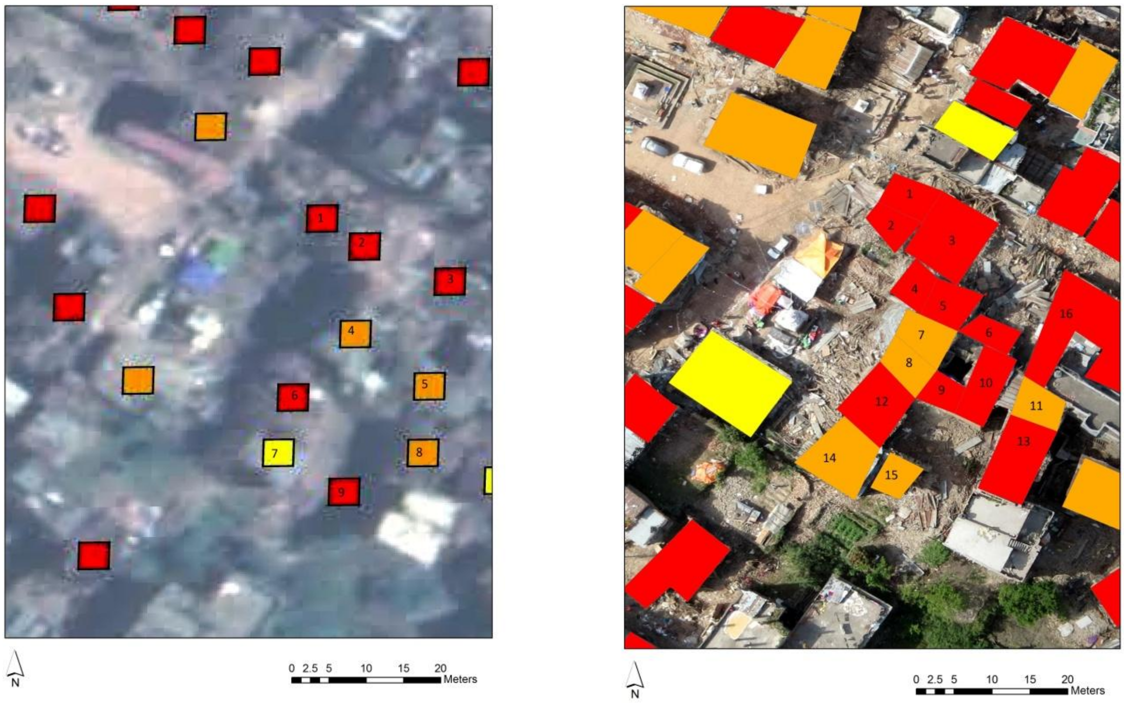
A comparison matrix was made to compare the damage assessment made from the UAV imagery and the UNOSAT data (see table 4). The comparison matrix results in the number of buildings that have the same damage level assessment (blue fields), the number of buildings undetected as damaged building (in any level) within both images (grey fields), and also the buildings that are having different level of damage assessment in both images (green fields)

Table 4 UNOSAT and UAV Damage Assessment Comparison Matrix

		UNOSAT			
		moderate	severe	destroyed	undetected
UAV	moderate	8	5	1	81
	severe	19	39	20	79
	destroyed	2	37	141	118
	undetected	6	10	5	

The data in Table 4 shows that there are 188 buildings having the same level of damage assessment: 8 buildings with moderate damage level, 39 buildings with severe damage level and 141 buildings with destroyed damage level. In contrast, there are 84 buildings assessed differently in both images. Furthermore, referring to the data in Table 3, it can be seen that there are 21 buildings not detected as damaged building in the UAV image whereas there are 278 buildings undetected as damaged building in UNOSAT data.

The fact that there are buildings assessed differently and the existence of undetected damaged buildings from the UNOSAT data, reflect the effect of the different image source used in the damage assessment. The UNOSAT damage assessment used world-view 3 with 50 cm spatial resolution meanwhile the UAV-damage assessment has more detail resolution (approximately 5 cm). As the consequences, the UAV image reveals more detail so that the spatial feature can be recognized better in the map. For instance, in one particular cluster of buildings there is 9 buildings recognized as damaged in the UNOSAT map, meanwhile on the same position, there are actually 16 buildings recognized as damaged in the UAV damage map (see Figure 17). It is noticeable as well that there is a difference in damage grading between the two image samples.



UNOSAT **UAV**

Figure 17 UNOSAT and UAV image Comparison. Images represent selected detail (from the UNOSAT and UAV damage maps) of the same area in Sankhu, Nepal. Yellow colour symbols damage level D3 on EMS-98 damage scale, orange D4 level and red symbols D5 level of damage.

This finding corresponds with the result of damage assessment conducted in Haiti (Corbane et al., 2011) which shows that higher resolution shows better performance of recognizing damaged building. Respectively, that explains the different level of damage assessment in some buildings produced by both assessments. This reason also explains why there are several buildings recognized as undamaged in the UNOSAT data but recognized as damaged in the UAV image. Furthermore, the existence of undetected building in the UAV damage assessment might be caused also by the effect of the detail resolution. The buildings that look damage in the UNOSAT appeared not damaged when they are seen in the UAV image. As result, these buildings are assessed as damage in the UNOSAT data but they are not assed as damaged in the UAV-damage assessment.

To get the overview of the UAV damage assessment result, the ground truth data is compared with the UNOSAT and UAV damage assessment data (see Table 5). Ground truth data was taken from the "Earthquake Damage Assessment in the Traditional Town of Sankhu: Lessons for Reconstruction " case study of Tribhuvan University Institute of Engineering (ADB, 2015).

Table 5 Number of Damaged Building Comparison

Source	Number of Damaged Building	GAP[5] with ground truth (%)
UNOSAT (3 classes)	300	54
UAV, visual interpretation (3 classes)	550	15
Ground truth (3 damage classes)	647	-

From the table it can be seen that the UAV damage assessment detects more damage building (550 buildings) compared to the UNOSAT data (300 buildings). Respectively, the UAV damage assessment gives a lower GAP of detected damaged building (15%) with the real condition (ground truth) compared with the UNOSAT data (54%). All in all, this finding shows that the UAV based damage assessment gives a better performance of recognizing the damaged building.

[5] The difference of the detected damaged building between UNOSAT results- ground truth and UAV damage assessment results - ground truth

6. DISCUSSION

This chapter focuses on the main themes for discussion. It is divided by the research questions of the study.

6.1. What are the functions of UAVs that could be considered of value?

Value of UAV's in the context of disaster rapid response can be observed through their two main functions: their function as a remote sensing tool and their function as a transportation tool. In case of Nepal drones were useful in remote locations which were inaccessible for many days after the disaster by sending emergency aids to the victims which shows its value in saving lives (Grumman & Guerra, 2015). However, the primary function of drones is seen in its use as a remote sensing tool. This is the value of information which the UAVs allow which could be crucial during rapid disaster response phase. Search and rescue, mapping critical infrastructures, damage assessment are some of the areas where drones can provide relevant information very fast. The approach to understand information value is more important and relevant also because of the scale it can influence and the urgency it allows to tackle complex challenges of rapid response. This can be observed in Nepal where drones were used in search and rescue operations by emergency aid workers where the immediate information was used to save lives of people (Kwong, 2015). Overall in grand picture, information is the key. To assign any aspect of value and to recognise the value indicators it is essential to put the value in precise context Information valuing could be performed after determining the valuation context and then assigning different levels, or positive and negative, value to relevant information indicators (Eaton & Bawden, 1991). It is also possible to regard the value of information through the benefits that are created as a consequence of its use (Engelsman, 2007). This is important because some information is not possible to value quantitatively such as human lives and safety (Poore, 2000). This also applies to Nepal case to some extent because according to the experts testimonies drone technology was used in search and rescue operations which did result in saving lives. This is the greatest benefit and the biggest value that this technology could bring and posses.

6.2. How can the value of information be conceptualized?

In general, conceptualizing value proved to be challenging initially. But after extensive literature review, the value of information was structured into 4 logical and sequential steps which is termed as information chain in this research. It consists of 1) information need 2) data acquisition 3) data processing and 4) Results. These four sequential steps is observed for information management and is also applicable to other RS tools. As such it could be considered a general framework that represents the necessary checkpoints for consideration and guides the assessment of value across its four steps. It also makes it easier to assess the value of UAVs across several indicators.

Framework is structured in a way that allows a quick overlook at all different value aspect and value indicators. Further researchers could use it as a starting point in evaluating UAV technology for different specific cases or for demonstrating the value of this technology to policy makers. It could be used in rapid decision making for quick estimation if the technology should be used for a particular case, or particular need. For example Copernicus which has not yet used it for their emergency mapping but could use this framework to expedite their shift towards the use of UAV.

6.3. What are the indicators to assess value of information in rapid disaster response?

In this research, value is observed through indicators recognized as relevant in rapid disaster response. Previous studies have stressed the importance of timeliness in acquiring key and relevant information (Andrienko et al., 2014; Bizimana & Schilling, 2010; Lippitt et al., 2015) which was also seen in case of Nepal. But the case study also highlighted other relevant indicators. By classifying these indicators into internal (usefulness, reliability, economic cost), and external (legislation and social perception) the understanding of value indicators is simplified and structured. A bridging indicator, data sharing, further hints at the intricate relationship of indicators with one another. Internal indicator are the inherent attributes of drones and its users whereas external indicators are additional factors which can influence the use of drones and hence its value. All of these factors interact with each other in a complex matrix which is further accentuated by the need of urgency demanded by the rapid response phase. As such context becomes very important which has been highlighted by previous studies(Bizimana & Schilling, 2010; Griffin, 2014).

In case of Nepal social perception has value influence in data acquisitioning and on the products that are made. The influence is reflected through negative perspective on this technology thus influencing on overall value in a negative way. This is the case when the UAV application is observed in the context of Nepal society. If this technology is applied in some other place the context is changing and the value changes as well. Study conducted in Australia showed that their society has a neutral opinion on drones (Reece et al., 2015). So it is safe to assume that social perspective will influence overall value in a different way, depending on the context in which it is observed. This is important because the framework could be applied to different cases and indicators could change their significance and influence depending on the context. Some could become more important, other less important.

6.4. What are the advantages/disadvantages in using UAV's in rapid disaster response?

Information chain, including information need, data acquisition, data processing and product processing are observed through value indicators.

First, this part of the information chain is observed through the value of time in the rapid response. Right after the disastrous event, emergency responders go to the field to take an overview of the impacted area and to provide situational awareness. Information value drops as the time passes and the needs changes (Bizimana & Schilling, 2010). Before the case of Nepal, there is no documented case that UAV's were the first source of information in rapid disaster response. In the case of Nepal, according to some experts, UAV's and satellites provided data in the same time. Based on that, the use of UAV's for data collection does not have direct value, when compared to satellites and observed through time. However, UAV data proved relevant in the process of search and rescue, and that is their biggest value in the first days after the disaster.

When compared to satellites, where the process is already established, very transparent, with official websites, platforms, and easy access to the information and information widely available, process of using UAV's is unreliable and new. This difference between satellites and UAV's is especially emphasised because of the UAV's not being established as the reliable source for acquiring data. With UAVs only certain organisations that are involved in collecting data with drones are familiar with possibilities and options, while respondents usually are not aware of their presence nor possibilities. Here, the value in the sense of reliability is not directly connected to the reliability of data itself, but with the nonestablished nature of drones.

The research has started on the assumption that the abundance of materials will be available due to a prominent place drones has in media reporting and accounts of post disaster response. The further assumption was that readily available data will enable to clearly determine what rapid response information needs were met with the data acquisition/production timeline and what can be considered useful in image-based rapid response from this technology. However, difficulties in getting relevant data on flights done in Nepal were present during the work on the thesis and pointed on one major disadvantage in using UAV's, data sharing. Firstly, what became apparent from interviews done with relevant actors was absence of a database containing images and/or products from different sources. Experts from the one of the organisations interview – Deploy media, who testified on numerous problems they had on the ground to actually engage in making footages, expressed their felling that the actual amount of data is very small and that only Skycatch and Team Rubicon, might have some data to share. In case of Italy, UAVs were flown by the fire department however more information on those flights was not available from any official reports so far, so only sources were on line news portals. What is known is that Copernicus EMS used airplanes to collect areal imagery, in addition to satellite images.

One of the disadvantages is the lack of interaction between involved organisations. For example, no evidence was found that ICIMOD and Sky Catch were cooperating, or that they knew about the each other's missions; this could illustrate the lack of general overview of acquired data. The fact that these organisations created images of same area in such close time period (less than 3 weeks) could indicate on a information sharing problem.

Unlike the International Disaster Charter or Copernicus EMS, where data acquisition, processing and delivery of final products is highly transparent, in cases of UAV flights and data acquisition it is difficult to keep track on who performed flights, when, where, for what purpose. This significantly influences their value in a negative way. Even though UNOCHA office in Nepal strongly advised that all organizations and individuals who are using drone technology during the disaster response report their missions and share their data and products with UAViators. This was done with the intention to prevent unintentional duplication of data and products as well for the reasons to see which areas were covered and to provide some sort of data sharing platform. In this way unnecessary efforts would not be made and the teams could be directed in other areas that are in need of assistance.

The part of the challenge, and the biggest obstacle to effectively utilise drones was a lack of regulatory framework regarding the use of drones. Furthermore, administrative procedures were changing on a daily basis with different requirements put to the teams.

"*Problem of licensing was huge. It was done by aviation department. They picked a Canadian model of relevant forms for issuing. Every department had different rules ("like catch 22") and rules were changing leading to confusion of team who came to fly drones.*" DEPLOY MEDIA. In their words: it is one thing to have rules and law that are limiting you but it is even worse when there are no rules and they are made as you go along, especially in a delicate situation such as disaster response.

6.5. What are the added values of UAV in rapid disaster response?

The highest added value in data collection is the flexibility of UAV's. They have unique advantage compared to other platforms. Users have high level of autonomy, being able to fly drones multiple times, and observing change.

Images (Figure 15) that compared orthomosaics made from data collected by different organisations involved in the data collection and production (chapter 5.4.) demonstrate the flexibility of UAV technology and their ability to be flown whenever it is needed. It also demonstrates their value trough use and timelines indicators from data acquisition aspect. It showcases how they can be used even when there are no other remote sensing tools at the disposal. They can monitor change, and this is important in fast changing situations such as rapid response as well as recovery (Zlatanova & Fabbri, 2009). Continuous monitoring of areas of interest could be performed with UAVs in prompt, timely and inexpensive manner.

The specificity of Nepal case is that the UAV data was acquired in the same time period as the satellite images that were used for the official damage assessment. This information and the confirmation from this analysis, on how higher resolution is improving the performance of damage recognition (Corbane et al., 2011), are proving the value of drones in rapid response. This case is clearly illustrating that it is possible to obtain high resolution images early on in response phase by using inexpensive remote sensing tool. Also it is possible to produce, in timely manner, the map that is more accurate than the satellite map. As well, by comparing the maps that used images obtained by plane in Italy (Figure 13) vs. from drones in Nepal (Figure 12), it could be confirmed that UAVs are cost effective alternative that enables stakeholders, especially responders on the field, to gain necessary data and insights with far less resources in the context of limited or severely damaged infrastructure. A much cheaper solution which has a potential to provide a service and a product of equal, if not better, quality as the traditional airborne alternatives. UAVs present more economic solution not only in a sense of cheaper technology (Matese et al., 2015) but as well counting in that for UAVs there is no need for well developed infrastructure , like airports, to operate it. As compared to satellite images, aerial images are able to provide more reliable info on damaged buildings. The confidence level is much higher. If the level of destruction is high, satellite images may be sufficient, however for a more detailed look which is often needed in rapid response areal images are very useful.
Finally, the main added value in using UAV's proved to be in search and rescue, in actual number of lives saved (which was not exactly determined in this study).

6.6. Limitation

From the available data is not fully possible to comprehend to which extent drones were used in the first response/search and rescue phase in 2015 Nepal earthquake as there are less data available than it seems, relevant actors are not making them available for research purposes and there are open doubts by some involved in the process on the very existence on these footages. This is a complete contrast from the overall impression gained prior to the start of the research from the media reports that there were many teams flying drones and that vast amount of data was produced and available. Also local organisations were not making themselves available so only interviews were executed only with foreign experts, who were in Nepal at the time to volunteer and help during a response phase.
Major limitations on the field in Nepal prove to be legislation problems and, at that time, non existing laws regarding UAV flights. As well as distrust and discomfort of people affected by the disaster towards the drone technology that was used in humanitarian action, as well as media drones.
In case of Italy there was a little information to begin with. No official reports about the drone use in rapid response, only information from the media an on line news sources. This is understandable since only a short period passed from the catastrophe so there was no time for official reports or scientific articles to emerge on the subject, plus two more devastating earthquakes happened in the mean time which made collecting information more difficult because new information was showing up again from non scientific sources.
In the meantime Copernicus published on their web site what was their involvement in emergency mapping after the earthquakes in Italy. There it is stated that they started a pilot study on using manned and unmanned aerial systems for their mapping purposes and that they are looking forward in incorporating UAV technology in their missions. Although, they used airplanes for image collection after the earthquake in August 2016 (Copernicus EMS, 2017).

7. CONCLUSIONS

This research is an attempt to add to the increasing literature of usage of UAV technology in disaster management, especially in the rapid response phase. Case of Nepal has highlighted the applicability of drone technology in disaster rapid response. It is also observed that the production of relevant images before conventional sources such as from satellites does have an added value to tackle challenges of urgency during the disaster. Drones acquired images for damage assessment in the early stages of rapid response were also used in search and rescue missions. This technology does bring change in disaster response, however Nepal case has as well highlighted many drawbacks in applying this technology.

This is further highlighted by the lack of clear framework for using drones during disaster response. Since the application of drones in disaster management is still in its infancy, there are many external factors that can hinder the potential of internal factors that UAV technology possesses. Theoretically, the significance and applicability of drones is undoubted. However, the case of Nepal showed that the full capability of UAV technology in rapid response was not possible due to many practical obstacles that were present in the site. Lack of coordination between the users of drones, incidental coverage in patches, insufficient sharing of data, flying restrictions. Nepal case did demonstrate that there is a significant value of having drones in rapid response, especially in early stages. This shows that context is an important aspect that needs to be considered while assessing the value of drones.

None the less, the fact that drones now can provide images before any other RS platforms does change disaster management by speeding it up and allowing quicker and more targeted response. That being said, without the proper institutional backing this technology won't be able to fully reach its potential. Existence of clear and transparent regulatory framework on who can flight drones, for what purposes, how relevant permissions are issued and by whom, what kind of data is being collected, how it is kept and processed, how the products are made from this data, how and with who it is shared with must be in place. Central handling of data by relevant public institution is needed as to avoid risks associated with sharing. These data and products derived from them should be available to relevant institutions (both national and international) and subsequently for research and development purposes.

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ANNEX I

General Questioners/ List of Questions for interviews:

1. How did your company/organization end up in Nepal after the 2015 earthquake (by request from some other organization, request by the government institution, you happened to be there at that time, some other way)?

2. With which organizations did you cooperate in Nepal (international, local, governmental, NGO)? How did you cooperate with them, in what capacity? Have you cooperated with those organizations/institutions before?

3. What were the needs of those organizations/institutions? What specifically could have been fulfilled with the use of UAV technology?

4. What was the purpose of your mission there (damage mapping, monitoring, search and rescue, some other reason)?

5. For how long did you stay in Nepal and when did you conduct the flights(precise time and dates would be highly useful because the main focus of this research is on the use of UAVs in rapid response situation)?

6. Were there any issues for conducting the flights?

6a Because of legislations (flight permissions etc)?

6b Because of organizational/logistic issues (accessing the area of interest, knowing where to go, difficult area for flight planning etc)?

6c Because of technical difficulties (battery issue, losing the contact with the UAV and losing the control over the aircraft etc)?

7.* Which areas were covered with your flights? (it would be helpful if you could provide the exact acquisition time, locations and size of those areas, so that they could be compared with the spatial and temporal resolution of satellites)

8. Why were those areas "areas of interest" to you (or to the organization/institution that you were working with)?

9. Which sensors were used in your mission in Nepal? If you used more than one sensor, could you compare them and explain if one sensor showed better results than the other(s)?

10. What kind of products was created from the data you collected from those flights (orthorectified photos, 3D models, DSMs, maps etc)?

11. Was the damage assessment (if it was performed) done in manual way (visual interpretation) or in automated way?

12. Was 3D point cloud used, and in what purpose? What kind of information did you get from it?

**In case of using UAVs for entering objects: Which objects? Why those objects? When were the flights performed? Was the data used for visual interpretation or was automated analysis performed as well (feature extraction, segmentation etc)? What kinds of products were made? What kind of information was gained from those products? What decisions were made (and what actions were taken) based on the information gained from UAV derived data?*

13. When were the products created and when were they provided to the responders? (precise date would be appreciated, if possible)

14. Do you know, and if you do could you tell me, with whom were these products (and data) shared? If they were not shared, what was the reason for holding that information?

15. Can you give me an example (or number of examples) of an action that was taken based on the information provided by the data you took or by the created product (for example: mapped locations of temporary camps used for people locating and estimating the need for water/food/medic supply etc)?

16. To your knowledge, how much is the UAV technology incorporated in disaster management cycle, especially in response phase of the cycle?

17. Do you find them being used more in some other phases of the cycle (recovery, mitigation phases)?

18. From the experience of your organization/institution (or personal experience), could you share some other examples of successful applications of UAV technology in rapid disaster response situations?

19. To your knowledge, do response teams count on information that could be derived from the use of UAVs or is this still just an added bonus to their response plans (are UAVs still not seriously taken in the account when response plans are made)?