A BUILDING DAMAGE AND SAFETY ASSESSMENT WITH MOBILE AUGMENTED REALITY

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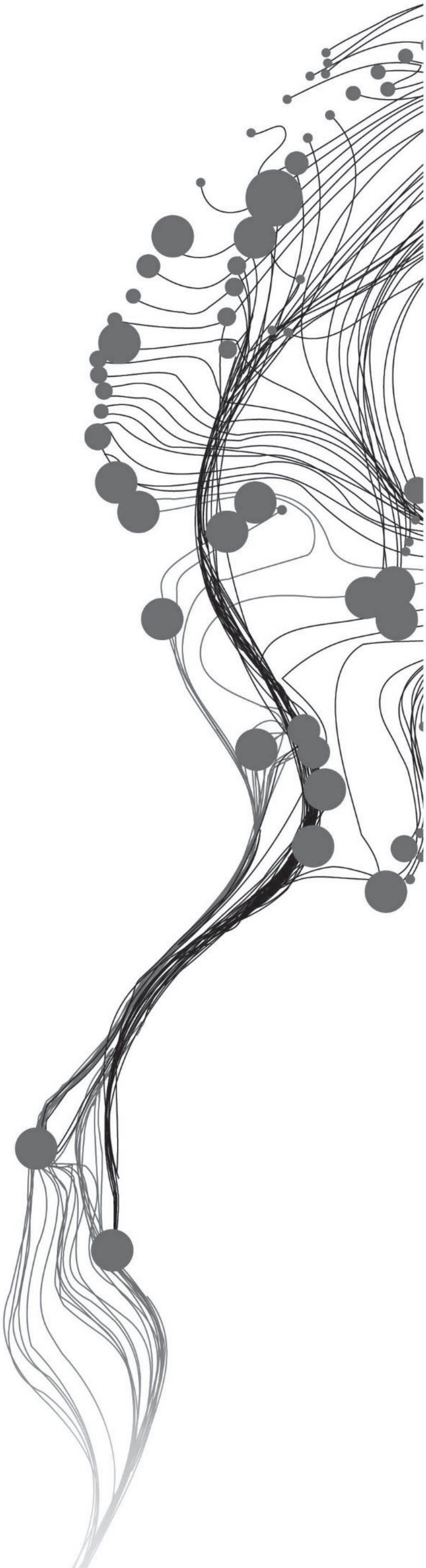

A BUILDING DAMAGE AND SAFETY ASSESSMENT WITH MOBILE AUGMENTED REALITY

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ABSTRACT

Rapid assessment of building damage and safety plays major role for recovery and rehabilitation of damaged society. For the damage and safety assessment of building, Remote Sensing (RS) technology has been widely researched with various RS platforms and sensors. However, RS-based assessment still has limitations to assess structural integrity and damage grade of individual building. Consequently, ground-based assessment is still essential for building damage assessment.

This study proposes mobile Augmented Reality (AR) to improve performance of ground-based damage assessment in situ. Mobile AR uses usual mobile device (e.g. smartphone, tablet PC) that is already including camera, GPS and compass module to superimpose various reference (virtual data) of pre-disaster on post-disaster building (real building).

In order to adopt mobile AR for the building assessment in a disaster situation, firstly, the procedure of ground-based building damage and safety assessment is identified with research of various procedures that come from different country. Then, main limitations of ground-based assessment are identified to find out value-added information and functions that should be delivered through mobile AR.

This study defines new concepts of mobile AR for building damage and safety assessment based on Level of Complexity (LOC). The main concept of mobile AR for the building assessment is divided into "visualization of exiting information" and "generation of new information". These concepts are again divided into six levels of complexity. Each concept presents conceptual image, procedure of damage assessment, data process, AR process and method of damage assessment with mobile AR. In addition, each procedure is examined with respect to accuracy and uncertainty.

Based on user requirement analysis and the defined concept, the prototype is implemented. The prototype consists of two systems: Indoor AR (marker-based) and Outdoor AR (sensor-based). In order to evaluate how much mobile AR can contribute to building damage and safety assessment in a disaster situation, online survey targeting structural engineers who have experience of the building assessment was conducted. The result of survey showed mobile AR can improve accuracy (objectiveness) of the assessment up to 24%, and can reduce assessment time up to 25%.

Keywords

augmented reality, mobile, disaster, building damage, building safety

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Wansub Kim
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1. INTRODUCTION

1.1. Background and problem statement

Natural disaster brings about economic damages and victims. 357 natural disasters were occurred in 2012, which caused 124.5 million victims (annual average 2002-2011: 268 million) (Guha-Sapir, Hoyois, & Below, 2013). Although the victims decreased, natural disaster still causes significant victims all around world. Besides, natural disaster caused huge economic damages also in 2012, which amounts to US$ 157 billion (annual average 2001-2010: US$ 143 billion)(Guha-Sapir et al., 2013). The economic damage of 2012 surpassed almost 10 % of annual average. These exemplary results show recent natural disaster causes enormous economic loss as well as huge victims.

In order to cope with these damages, rapid damage assessment is significantly important. Rapid damage assessment plays major role for initiating effective emergency response actions quickly (Brunner, Lemoine, & Bruzzone, 2010). Kamat and El-Tawil (2007) state that the speed of damage assessment is directly related to amount of economic loss. Rapid damage assessment is also key factor for the resilience and recovery of the society. In addition, accuracy as well as speed for evaluation of damage sustained by buildings is also critical to assess economic and physical loss correctly.

For rapid damage assessment after natural disaster occurred, Remote Sensing (RS) technology has been used in a variety ways. Kerle, Heuel, and Pfeifer (2008) reviewed various airborne platforms and sensors for emergency response, and Zhang and Kerle (2008) looked over the potential of current and future spaceborne platforms for disaster situation in various aspects. Substantial methods using optical and radar images have been proposed for damage assessment. For instance, Interferometry Synthetic Aperture Radar (InSAR) based methods have been used to find out co-seismic displacement and deformation (Catita et al., 2005). Gamba, Dell'Acqua, and Lisini (2006) have proposed new approach that is based on combination of feature-based and pixel-based methods for damage assessment. On the other hands, applications of optical data have introduced semi- or fully automatic damage assessment (Brunner et al., 2010; Turker & Sumer, 2008). In contrast to using optical and radar data, Gerke and Kerle (2011) used multi-perspective pictometry data which shows not only vertical view but also 4 oblique views of building.

Even though these image-based damage assessments showed its potential for rapid damage assessment, there are still substantial limitations. One of the main challenge for building damage assessment using optical and radar image is to evaluate not only roof of building but also whole parts of building especially in dense building area. Because building damage should consider its 3D characteristics (Ozisik, 2004), conventional remote sensing data that take vertical view of object is not appropriate. Gerke et al. (2011) have solved this problem with using pictometry data. The approach used five images taken from five different directions at oblique (45° angles) which includes almost every part of a building. However, low part of building in dense building area and vegetated area is still remaining inaccessible region with the images. Furthermore, image-based approach can detect only partial or complete building collapse, which still cannot identify suitable field information such as safety degree and structural integrity of individual buildings (Kamat et al., 2007) .

Because of the various limitations, image-based semi- or fully automatic methods for damage assessment have rarely been used in the real situation (Voigt et al., 2011).

On the other hands, ground-based approach can assess damage score of individual buildings which image-based approach cannot cover. The ground-based damage assessment is usually conducted by reconnaissance team comprised of certified inspectors or structural engineers according to the assessment guidelines such as ATC-20 field manual (ATC, 2005) and European Macroseismic Scale (EMS-98). ATC-20 focuses on visual inspection in order to identify safety status of each buildings. (S. Dong, Feng, & Kamat, 2013). In contrast to ATC-20, EMS-98 focuses on structural integrity of building that can be classified into five levels which cover grade 1 (slightly damaged) to grade 5(heavily damaged) (Grünthal, 1998). However, the ground survey is still inefficient in terms of cost and time of evaluation. In addition, the ground survey relies on the human skill and knowledge, so that human-induced errors can affect the quality of data during the mapping process (Kerle, 2010). Moreover, the task mostly depends on the human knowledge, which cause inconsistency of the assessment.

To make up the ground survey's limitations, Curtis and Fagan (2013) proposed video-based damage assessment. This method uses usual video camera with GPS to capture damaged buildings of post-disaster, then the data extracted from video camera is compared with Google Street View of pre-disaster to detect change between pre- and post-disaster. Even though video-based approach contributed to saving time and cost for the data acquisition of post-disaster, this method still require post-process for captured video images in the laboratory, so that the damaged buildings cannot be analysed in situ directly with pre-disaster data, which is essential for reconnaissance teams who conduct visual inspection in the field. Meanwhile, Chen et al. (2012) tried to integrate information system with Radio frequency identification (RFID) tags to manage building damage information efficiently. As the RFID tag stores damaged building information, user can handle the information through smartphone and tablet PC directly. The system could reduce the process time for data communication and edition, whereas it could not help improving the interpretation of building damage itself.

The drawbacks of ground survey is mainly caused by lack of efficient tools that can provide pre-disaster reference to compare pre- and post-disaster situation effectively in field as same manner of RS-based change detection. As providing this kind of tool, following effects can be expected: 1) visual interpretation of building damage can be done rapidly; 2) without any post-processing of obtained data, the inspectors can analyse the damage in real-time in situ; 3) as providing objective reference, subjectivity of the interpretation can be reduced.

Hence, this study propose state-of-the art technology called mobile augmented reality (Mobile AR) that can be adopted for building damage assessment efficiently and rapidly. Augmented Reality (AR) superimposes computer-generated graphics or contents on real world with view of camera. The main purpose of AR is to combine real and virtual world and provide real-time interaction to users (Azuma, 1997). Suyang and Kamat (2010) state that a typical AR system has three main characteristics that are 1) coexistence of real and virtual objects in a real environment, 2) interactive running in real environment and 3) registration of real and virtual objects. In contrast to AR, data overlay of GIS (Geographic Information System) is a interaction between virtual data (non-live) in virtual environment, which is not interactively run between real (live) and virtual object in real environment. In addition, the data overlay replaces reality while AR supplements it (Azuma, 1997). Because of its usefulness and innovative characteristics, AR has been adopted in many fields such as urban landscape simulation (Fukuda et al., 2012), geological survey (Ababsa et al., 2012), urban terrain modelling (Julier et al., 2001) and so on. As mobile device such as smartphone and table PC has propagated rapidly, the applications of AR also has expanded its domain quickly.

AR can improve user's comprehension and enhance visualization, which allow more efficient interpretation about real object (Chi, Kang, & Wang, 2013). This means user can directly make a decision in situ with reference data that is interactively matched with real (live) data. Thomas, Daniel, and Pouliot (2011) categorized AR application into two types: weakly augmented and strongly augmented. Weakly augmented application simply displays point of interest (POI) using relative distance and direction from user location. POI is contents (image, text, video and so on) that have unique map coordinates. Wikitude ("Wikitude," 2013) and Layar ("Layar," 2013) are good examples of such applications. In contrast, strongly augmented application provides more sensitive and complicated information so that it can increase the level of interactivity and immersivity of the user. Strongly augmented application is implemented using close-range photogrammetry, which establishes a relationship between 3D objects and 2D photo images (Dai et al., 2011). Traditional photogrammetry uses aerial photos to extract 3D information of terrain, while close-range photogrammetry use general hand-held camera to extract 3D model of real object.

AR for building damage assessment can be also approached by two methods. Firstly, enhancing visual interpretation between real and virtual object (weakly augmented) can be performed. For instance, when damage inspectors assess building damage, they need to know information relevant to building such as building structure and building material since the assessment process becomes different with respect to building structure. However, it is not easy identify those information especially when building is almost collapsed. As AR superimposes not only pre-disaster 3D model, but also building information onto real situation. The inspectors can recognize matched information directly onto real object in situ, and also enhance visual interpretation for the assessment. Secondly, strongly augmented approach can provide quantitative information such as volume reduction, inclination, and height reduction between pre-disaster and post-disaster dataset. Consequently, AR can support direct interpretation of real building in situ with combined virtual data which includes not only qualitative characteristics but also quantitative characteristics.

Traditional AR was utilized mainly to support visual (qualitative) interpretation, while a few study showed possibility of quantitative change detection through AR. Golparvar-Fard, Pena-Mora, and Savarese (2011) used AR to manage building construction site. They displayed change of 3D building on AR, so that user can recognize progress of building construction. Kahn et al. (2013) also proposed a method for precise real-time 3D difference detection for industrial application. These studies commonly extract 3D geometry of a real object (post-event) from 2D images using Structure from Motion (SfM) algorithm. Then 3D geometry of post-event is compared with 3D model of pre-event using voxel-based 3D change detection. To find 3D discrepancy, 3D model of pre- and post-event is changed to voxel structure which is 3D data structure comprised of volumetric pixel.

A few studies have already tried to apply AR technology for damage assessment. S. Dong et al. (2013) and Kamat et al. (2007) tried to measure horizontal displacement of a building with CAD data using AR. S. Dong et al. (2013) measured structural integrity of individual buildings using AR. These approaches measure Interstory Drift ratio (IDR) to quantify building damage based on AR. The IDR, which is interstory drift divided by the height of the story, is a structural performance indicator that shows correlation between internal damage and external deformation (S. Dong et al., 2013) . As superimposing 3D wireframe of building onto real building, horizontal drift of each story can be computed. In spite of its innovative approach, they have still some issues in order to apply in real situation. First of all, it only takes into account

IDR that measures horizontal displacement. Furthermore, they require big equipment that comprises of GPS, Head-up display, digital camera and laptop. It is too big and expensive so that only few experts can use it. Besides, the information (IDR) generated from AR is very limited, so that only limited users can utilize it in specific situation.

Mobile AR can be a useful tool to evaluate the damage in efficient and user-oriented methods in which conventional remote sensing images cannot be accessible. Instead of using big and expensive equipment of AR, this study aims at using mobile device such as smartphone and tablet PC that already including GPS, gyroscope and camera module. Because mobile AR uses simple mobile device, it can be used not only for normal user who want to know simple status of change of building, but also for expert who need to check status of building damage like reconnaissance team and also for volunteer group of GIS expert who want to generate damage map.

This study focuses on how mobile AR can improve building damage and safety assessment in a disaster situation. Although mobile AR can provide efficient usability and immersivity in real environment with virtual data, if it does not deliver meaningful information, it cannot improve user's awareness in a disaster situation. As information channel, mobile AR can play major roles to improve various aspects such as subjectivity of assessment, risk of inspectors, locational and situational awareness of inspectors. For that, first, this study identify the process of ground-based damage and safety assessment and its limitations. Then, main obstacles in effective damage assessment is identified in order to define what information and functions are required for mobile AR. Lastly according to analysis of user requirement and main obstacles, the prototype is developed on android platform. The prototype superimposes significant information that includes building location, building information, building geometry (interior, exterior and frame), building-related multimedia and change detection.

1.2. Scientific significans and innovative aspecsts

Rapid building damage assessment has been widely approached by various methods that use RS-based and ground-based assessment. This study proposes novel method, mobile AR for building damage assessment in a disaster situation, which can improve performance of traditional ground-based assessment in situ. Mobile AR can be adopted as information channel to provide not only pre-disaster reference data but also mission critical information in the field, which can improve following factors in a disaster situation.

1) Rapid damage and safety assessment

Most of building damage inspectors still use analogue data (e.g. paper map, paper form) without any support of information technology. Besides, they don't have enough pre-disaster reference data that is very important for the assessment (Flesch, 2007) . This lack of reference data causes subjectivity of the assessment that relies on inspector's knowledge (German, Brilakis, & DesRoches, 2012). In addition, some of building information is very critical for the assessment such as building type because the method of building damage varies according to building type, and most of time-consuming part of the assessment is to classify building type (Flesch, 2007). As providing reference and value-added data through mobile device such as smartphone and tablet PC, user can improve efficiency of the assessment procedure and also reduce subjectivity of the assessment.

2) Reduction of risk in post-disaster situation

Ground inspectors are always exposed in risky situation during their operations. According to field manual, for detailed inspection, they need to get inside of building which is very dangerous. In addition, hazardous material can be spread because of explosion of chemical facilities. Yet, it is not easy to recognize the area where hazardous material is spread out since it is invisible information. In this study, information relevant to hazardous information is identified and its locational information is delivered through mobile AR. Additionally, 3D model of building interior is superimposed onto building exterior, so that user can judge building structure of building interior without entering the building, which can reduce user's risk substantially.

3) Improvement of situational and locational awareness

Although traditional mobile GIS can provide geographic information to user, user needs time to analyse the information and match the analysed information with real environment. It is mainly because GIS and reality is separated system. AR extent user's awareness from virtual to real environment so that user directly interpret information without processing of information interpretation between virtuality and reality. For instance, it is not easy to identify user's current location in post-disaster situation. As AR superimposes street address and coordinates directly onto real road, use can distinguish current location, which improve locational awareness. Moreover, superimposing various information on real environment improves situational awareness of user since it extends user's reality with not only display data but also interacting with data, which increase immersivity of real situation.

1.3. Research objectives and questions

1.3.1. Research objectives

General objective of this study is to improve efficiency and safety of ground-based building damage and safety assessment with mobile AR that can play a role as information channel in a disaster situation. Specific objects are:

- To identify main obstacles of building damage assessment in the field
- To define mission-critical information that can improve efficiency and safety of the assessment in situ
- To design mobile augmented reality following user requirement and data inventory
- To analyse how much mobile AR can improve current damage assessment.

1.3.2. Research questions

Following research questions are approached:

- How do user perform building damage assessment in the field?
- What are the main obstacles of the damage assessment in situ?
- Which information is value-added information for the assessment in situ?
- Which functions of AR are required in a disaster situation?
- How can AR get those information and deliver to user efficiently?

- What is the systematic process of AR approach for building damage assessment?
- Does mobile AR provide usability and functionality that can improve the assessment in a disaster situation?
- How much mobile AR can improve current limitations of ground-based building assessment?

1.4. Research design

Overall research frame is outlined in Figure 1-1. Detail of each phase in research framework is described in below.

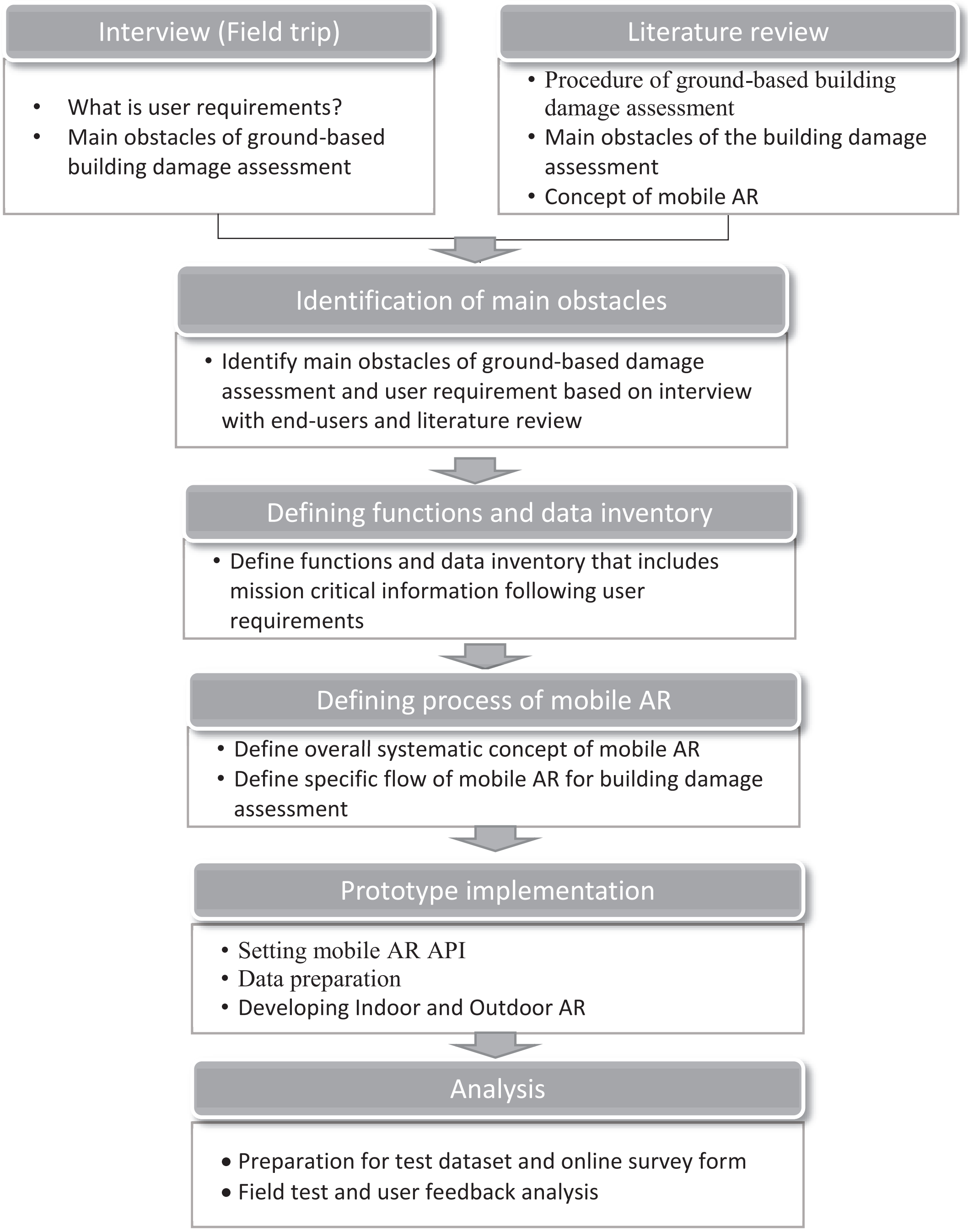

Figure 1-1 Research framework

Main frame of this study comprises of five parts. Firstly, main obstacles of current ground-based building damage and safety assessment are identified based on literature review and interviews. Secondly, mission critical information that is delivered through mobile AR is defined following user requirement. Thirdly, overall process and concept of mobile AR for building damage assessment is defined. Fourthly, prototype is implemented for both Indoor AR and Outdoor AR based on mobile platform (android). Lastly, analysis is carried out with prototype based on functional test and user evaluation.

1.5. Thesis strucure

This thesis comprises of seven chapters, as described below:

- Chapter 1 elaborates on the problem statement and background of the research. In addition, scientific significance and research objectives as well as research methodology are outlined.
- Chapter 2 presents comprehensive procedure of seismic building damage assessment and concept of mobile AR. After describing principle concept of both building damage assessment and mobile AR, current research status of AR for building damage assessment is discussed.
- Chapter 3 outlines research methodology. In this chapter, specific methodology is explained in order to achieve research objectives and to answer for each research questions.
- Chapter 4 analyzes user information requirement as well as user interface of mobile AR. Essential information and usability of mobile AR required by post-disaster situation is identified as well.
- Chapter 5 describes the approach of mobile AR for building damage assessment based on concept of level of complexity. In this chapter, procedure of mobile AR for building damage assessment is described. Then, accuracy and uncertainty for each procedure are discussed.
- Chapter 6 explains the prototype implementation and evaluation. Mobile AR's system structure and user interface are established, and the prototype is implemented according to the established design. Then, the prototype is evaluated in terms of functionality and user feedback.
- Chapter 7 gives conclusion with review of research objectives and questions. Lastly, future research work is discussed.

2. BUIDING DAMAGE ASSESSMENT AND MOBILE AUGMENTED REALITY

2.1. Introduction

To apply appropriate method of mobile AR for ground-based building damage and safety assessment, it is vital to understand how user conducts the assessment in the field. It is important to clarify that who is users of this mobile AR in this study. The users can be structural engineer, geotechnical engineer, architect, search and rescue team and volunteer group who carry out building damage and safety assessment in the field. This chapter, firstly, describes the procedure and method of the assessment. Then basic concepts of AR and current status of AR researches are explained. Lastly, previous studies of AR for building damage assessment is discussed.

2.2. Overview of comprehensivie prodcedure for the seismic building damage and safety assessment

2.2.1. Overall procedure

The procedure of assessment is various depending on the country and organizations. Therefore this study extracts and defines common procedure in Figure 2-1 based on literature review, which is commonly conducted in various organizations (EERI, 1996; FEMA, 1998; NCSEA, 2011; Vidal, Feriche, & Ontiveros, 2009). Details of each phase are explained in below.

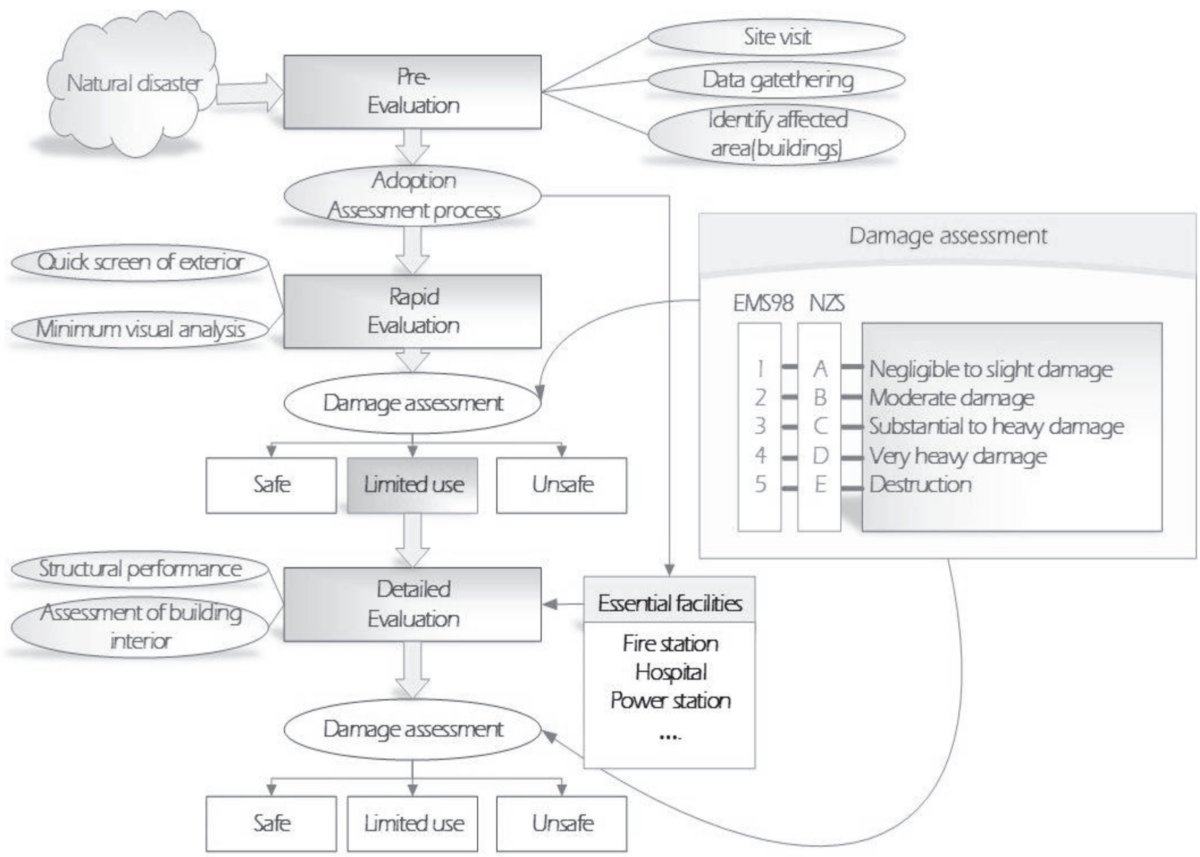

Figure 2-1 Overall procedure of building damage and safety assessment

Right after natural disaster occurred, local reconnaissance team and/or structural engineers who have license are deployed to the field within few hours for the damage assessment (NCSEA, 2011). Then they perform visual analysis based on the field manual of the assessment, which is quite divers depending on country and organizations. Unfortunately, there is no common procedure or field manual that can be used in any regions (Goretti & Di Pasquale, 2002). Although the assessment is usually done using assessment forms, the forms are also not unified (Goretti et al., 2002). For instance, in US, they use one page form for rapid evaluation and 2 page forms for detailed evaluation while, in Greece, only 1 page form for both rapid and detailed evaluation is used(Goretti et al., 2002).

Although there are various methods for the assessment, the procedure commonly comprises of three phases: Pre-evaluation, Rapid evaluation and Detailed evaluation. Detail of each phases is summarized in Table 2-1.

Pre-evaluation

Within few hours right after occurrence of seismic event, pre-evaluation are carried out by local emergency team or management personnel (NCSEA, 2011). In this phase, suitable evaluation process(or method) is adopted for the region firstly (FEMA, 1998). As mentioned above, evaluation process varied in different country and organizations, so that it is important to clarify which process is adopted in affected region. Then, affected area is identified quickly(NCSEA, 2011). If necessary, site visit and quick screening are also conducted to identify affected area (FEMA, 1998). In addition, relevant data and information are gathered which can support rapid and detailed evaluation (NZSEE, 2006). Main goal of this phase can be recapped for two task, understanding affected area and data gathering.

Rapid evaluation

Rapid evaluation is conducted for 1 to 10 days by structural engineer, territorial local authority and/or building officials (NCSEA, 2011; Vidal et al., 2009). They quickly screen potential damage of building, which takes 10 to 30 minutes per building (FEMA, 1998). According to damage level (damage scheme), building's safety is categorized into three groups: safe, unsafe and limited use (ATC, 2005; NZSEE, 2006). Building categorized into 'limited use' is re-assessed in detailed evaluation. For the record of assessment, field engineers take photos, and draw rough sketch of building damage on paper (NZSEE, 2006). Since this phase spends less than 30 minutes per building, evaluation speed is vital, so that damage level is decided only by overall damage status. For instance, ATC-20 rapid evaluation form requires checking only five conditions such as collapse, partial collapse, building or story leaning, racking damage to walls, falling hazard and ground slope movement (Appendix 1). With status of theses building conditions, damage level is estimated with specific damage grade such as EMS-98 (1-slightly damaged, 5-totally collapsed), NZS(A-slightly damaged, E-totally collapsed) (ATC, 2005; NZSEE, 2006). After deciding damage grade, the building is finally categorized to one of safety indication. For instance, if damage grade is 0 or 1 in case of EMS-98, building is safe. It is necessary to know that damage grade and relationship between damage grade and safety indicator are varied depending on countries and organizations.

Detailed evaluation

Detailed evaluation is carried out for 2 to 20 days by structural engineer, civil engineer, architect, geotechnical engineer and building owner (NCSEA, 2011; Vidal et al., 2009). This phase requires 1 to 4 hours per building (FEMA, 1998). For essential facilities such as fire station, hospital, power and so on, detailed evaluation is conducted with high priority (Vidal et al., 2009). While rapid evaluation quickly screens building exterior, detailed evaluation assesses several factors such as structural hazard, non-structural hazard and geotechnical hazard (ATC, 2005). It is important to mention that the method of assessment varied according to building structure type, and most time-consuming tasks is to identify building structure type (Flesch, 2007). Building structure type can be classified to word frame, concrete frame, unreinforced masonry, reinforced masonry and so on. For detailed evaluation, sometimes the engineer is required to get inside of building to evaluate structural performance of building, which is very risky.

Table 2-1 Method of building damage and safety assessment

Phase	Timing and duration	Conductor	Task
Pre-evaluation	Within few hours after event	• Local emergency team or management personnel	• Understanding evaluation process • Site visit and quick screening • Relevant data gathering • Identification of affected area
Rapid evaluation	1 to 10 days (10-30 min. per building)	• Building officials and/or structural engineer • territorial local authority	• minimum visual analysis is required • Quickly screen potential damage • Taking photos and drawing rough sketch of building exterior and damage • According to damage level (damage scheme), this phase identify the structure is 'safe' or 'unsafe'. If it is classified as 'limited use', it goes to detailed evaluation • Assess overall damage of building exterior
Detailed evaluation	2 to 20 days (1-4 hours)	• Structural engineer • Civil engineer • Architect • Building owner • Geotechnical engineer	• This phase evaluates the structure classified as 'limited use' during rapid evaluation • This phase can be conducted independently without rapid evaluation • if necessary, inside of building is also assessed • Structural, nonstructural, geotechnical hazard are assessed

2.2.2. Current technologies to facilitate building damage and safety assessment

cilitate building damage and safety assessment, many researches have tried with different approaches. For macro-level assessment, Remote Sensing (RS) technology has been adopted widely, which uses various platform and sensors to identify building damage (L. Dong & Shan, 2013). Although RS-based approach quickly extracts damage-related information in wide area, it still has limitations to evaluate micro-level damage that requires suitable field information such as safety degree and structural integrity of individual building (Kamat et al., 2007).

In order to make up the limitation of RS-based approach, video-based assessment system was introduced called VIEWS (Visualizing Impacts of Earthquake With Satellites) (Adams, Mansouri, & Huyck, 2005). This system uses not only satellite image but also video data and photos that are taken in the field after natural disaster. The captured video data and photo are georeferenced, so that user can combine and compare all the reference data comprised of satellite image, video data and photo for the damage assessment. Although

VIEW provides interface that can easily compare these reference data in one screen, it requires post-processing for video data and photo. Moreover, the assessment task should be done in the office with PC, not in the field.

To improve ground-based assessment, wireless sensor-based system has been developed for California Urban Search and Rescue team ("Wireless building monitoring system," 2013). This system allows user to monitor building's stability by checking change of building structure. For the monitoring, wireless remote sensors that consist of inclinometer and digital radio are attached to building structures. Then user can constantly check real-time status of structural change of building from a remote place.

Meanwhile, Chen et al. (2012) used RFID (Radio Frequency Identification) tag and mobile Ad-hoc to monitor and transfer digital information of building damage using system called 'SUPER-MAN'(Supporting Urban Preparedness and Emergency Response using Mobile Ad hoc Network (MANET). This system uses RFID tag store building damage and safety information. Once RFID tags are attached to structure of build, user can save and manipulate information related to building and damage status through mobile device like PDA and tablet PC with RFID reader. In addition, the information saved in RFID tags are transferred to the server in order to share information with other users through MANET (Figure 2-2).

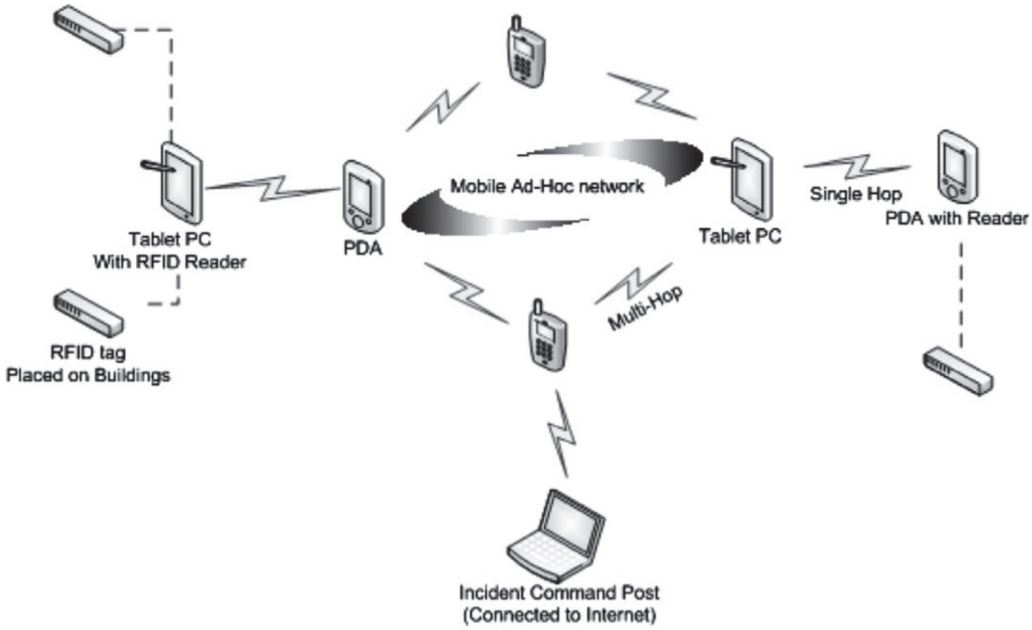

Figure 2-2 Mobile Ad hoc network (Chen et al., 2012)

In addition, Kamat et al. (2007) and S. Dong et al. (2013) introduced a method of Augmented Reality(AR) for building damage assessment. They used AR to measure building damage in terms of Interstory Drift Ratio (IDR) that shows how much deformation is occurred between stories. In order to measure IDR, 3D wireframe is generated and superimposed based on edge detection method. Details are described in next section 2.3.2.

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2.3. Concept of mobile AR

2.3.1. What is Augmented Reality?

Augmented Reality(AR) is a concept of visualization which supplements the real world information with virtual (computer-generated) data (Van Krevelen et al., 2010). It is important to know how AR can be characterised with its definitions. AR should have satisfy following characteristics (Suyang et al., 2010; Van Krevelen et al., 2010):

- Coexistence of real and virtual objects in a real environment
- Interactive running in real time
- Registration of real and virtual objects in real time

These characteristics of AR explain how AR is different from traditional data overlay of Geographic Information System (GIS). One of main purpose of AR is to supplement reality with virtual data, while traditional data overlay just replaces reality (Azuma, 1997). Because data overlay replaces reality, user needs more time to interpret and match relation between virtual and real object, and it is big advantage for AR that user can directly compare or interpret real object with virtual data/or information.

The phrase "augmented reality" was coined first in application that support assembling aircraft at Boeing in 1990 by Professor Tom Caudell who was scientist working at Boeing corporation (Valentini et al., 2010). Although the phrase was invented in 1990, first prototype of AR was developed by Ivan Sutherland at Harvard and Utah university in 1960 (Tamura, 2002). First prototype of "mobile" AR was developed by Feiner et al. (1997), which provided tour information for buildings with 3D graphical information.

AR can be categorized by display and positioning approach (Figure 2-3). In terms of display method, AR can be classified into three groups that are video see-through, optical see-through and projective (Van Krevelen et al., 2010). Video see-through AR uses live imagery of video camera, and virtual data is overlaid on digital image. Optical see-through AR uses transparent mirrors or lens, and virtual data is overlaid on reflected reality on mirrors or lens. Projective AR uses projectors to display virtual data directly onto real object.

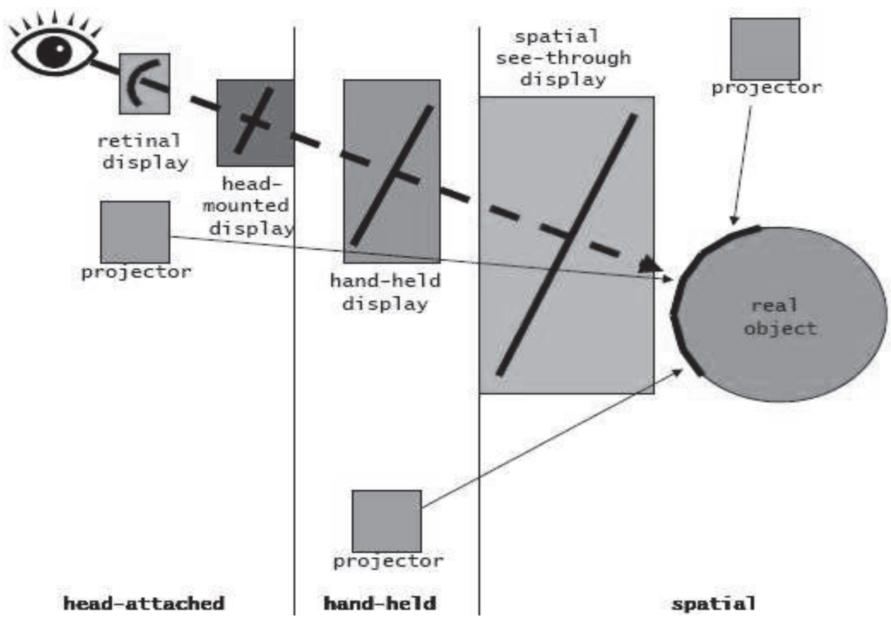
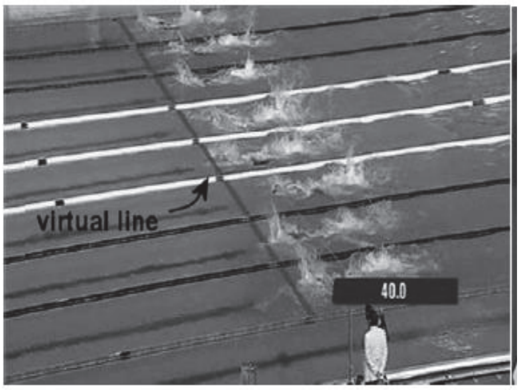


Figure 2-3 Classification of AR with display and positioning techniques (Van Krevelen et al., 2010)

In terms of position between viewer and real object, AR can be also classified into three categories: head-attached, hand-held and spatial (Figure 2-3) (Van Krevelen et al., 2010). Head-attached approach uses head-mounted display (HMD) machine that applies optical/video see-through method. Google glass is a representative example of head-attached approach, which uses a normal frame of glasses attached small display screen. Hand-held approach uses mobile device such as smartphone, PDA and tablet PC. This approach is currently most adopted in mass market because of low cost of device and easy use (Van Krevelen et al., 2010). Lastly, spatial approach has relation with projective approach mentioned above. This approach displays AR directly on real objet (space) or through monitor. This approach is frequently used sports broadcasting such as swimming and football (Figure 2-4(a)).



(a) (b)

Figure 2-4 (a) example of spatial approach of AR (Valentini, Gattamelata, & Pezzuti, 2010), (b) example of projective AR (Van Krevelen & Poelman, 2010)

In order to align virtual data with real object accurately, AR requires accurate data registration method that tracks user location and direction (Schall et al., 2011) One of main component of AR is data registration between real and virtual object. In terms of this registration, AR can be classified following categories: sensor-based, vision-based and hybrid (Rabbi & Ullah, 2013). Vision-based AR can be categorized again into marker-based AR and markerless AR. Maker-based AR uses physical object such as fiducial marker, QR code, image, map or real object to recognize target's location and orientation. Markerless AR analyses image of camera to identify unique features of real object, which is based on computer-vision technology. After identifying the features of real object, virtual object is superimposed on the extracted matching points in complex scene. Therefore vision-based AR gives the most accurate registration among this three approaches whereas it requires much time for the process than the other approaches (Rabbi et al., 2013). Sensor-based AR uses sensors of device such as GPS, compass and gyro sensor to obtain user's location and orientation.

However, sensor-based AR is inaccurate comparing to vision-based AR due to the drawback of each sensors (Yang et al., 2008). To make up limitations of both sensor-based AR and vision-based AR, hybrid AR has been developed which combines sensor-based AR with vision-based AR.
Gammeter et al. (2010) and Bae et al. (2013) introduced high-precision of mobile AR using hybrid tracking technology. They used sensor information to calculate camera pose and orientation of current location, and they combined several computer vision technology such as SfM (Structure from Motion) and SIFT (Scale Invariant Feature Transformation) to identify matching features. SIFT is the algorithm to detect correspondent features that have invariant scale, rotation and illumination in different images (Lowe, 2004). Using SIFT, AR can find matching features between virtual object and real object that is displayed through

live image of camera. However, because of limitation of mobile device's performance, they process vision-based algorithm in server-sides. Figure 2-5 shows the accuracy of hybrid AR. This hybrid AR shows potential of mobile AR for both outdoor and indoor with its high accuracy of registration.

Figure 2-5 High-precision mobile AR. Virtual data is superimposed accurately with different viewpoints (Bae, Golparvar-Fard, & White, 2013)

2.3.2. AR for post-disaster situation

A few studies have applied AR for post-disaster situation. Tsai et al. (2012) proposed mobile AR for escape guideline on nuclear accident site caused by earthquake. This system provides users escaping route and nuclear accident information using sensor-based AR. This system mainly focuses on route guidance to shelter place and information sharing between users. They used google maps and electronic compass function for route guidance, and they also used floor-plan map for indoor escape guidelines.

Boddhu et al. (2013) introduced context-aware event detection with mobile AR for first responders. This system gathers and analyses data that is distributed by SNS (Social Network Service) such as Twitter, Facebook and so on. Because SNS deliver various information representing user's locality in real-time, it can be good information sharing tool in a disaster situation. As gathering and analysing this spatiotemporal data, the system tried to support first responder to make decisions to manage overall situation of disaster (Boddhu et al., 2013). To display analysed data for first responder in the field, the system used AR that superimposes virtual data regarding historic or live events occurring around user's location.

While these two system, mentioned above, focus on visualization exiting information using sensor-based AR, Kamat et al. (2007) tried to generate new information from AR to assess building damage caused by earthquake. They compared baseline of pre-disaster 3D building with real building to identify difference, called IDR (Interstory Drift Ratio) (Figure 2-6). For the IDR measurement, pixel offset between image of real building and baseline of 3D model was counted using both vision(marker)- and sensor-based AR. While Kamat et al. (2007) measured displacement between pre-disaster 3D model and real building , S. Dong et al. (2013) achieved extraction of IDR without pre-disaster 3D model using vision-based AR. They use edge detection and corner detection method (e.g. Line Segment Detector) through analysing image to extract building baseline from image of real building. Then generated baseline model is superimposed onto the real object. To obtain enough accuracy, hybrid AR was used. Firstly, camera's location and orientation was defined using electronic compass and GPS, then vertical and horizontal edge of real building was extracted using method of Line Segment Detector. Lastly, IDR was calculated with horizontal movement of the floor relative to the ceiling divide by height of that story (S. Dong et al., 2013).

2.4. Summary

In this chapter, overall procedure of building damage and safety assessment was outlined. Then overall concept of AR and brief history of AR was also summarized. Although current technologies have facilitated the assessment procedure, most of them focuses on macro-level damage assessment using RS technologies, or focuses on digitalization of data to share and process information in the field. However, the technology supporting interpretation of micro-level damage and safety in the field is insufficient. Although some of AR system provided efficient method for the damage assessment, it still requires big equipment such as GPS, Head-up display, digital camera and laptop. In addition, the AR system only provides one indicator, IDR that is too narrow factor which cannot improve overall assessment procedure of building damage and safety in the field. For instance, evaluation form of rapid damage assessment asks inspector to fill out several information such as building address, building height for the overall assessment. Recent mobile device such as smartphone and tablet PC has increased its performance very quickly, and it has components that required by traditional AR such as camera, GPS, compass and gyro sensors. This improvement of mobile device is expected to elaborate AR's utilization in various field.

3. RESEARCH METHDODOLOGY

3.1. Introduction

This chapter describes specific methodology for the research questions listed in section 1.3.4. The methodology can be categorized by four tasks (Figure 3-1): identification of main obstacles and user requirements, defining functions and data inventory, defining process and concept of mobile AR for building damage and safety assessment, prototype implementation and analysis.

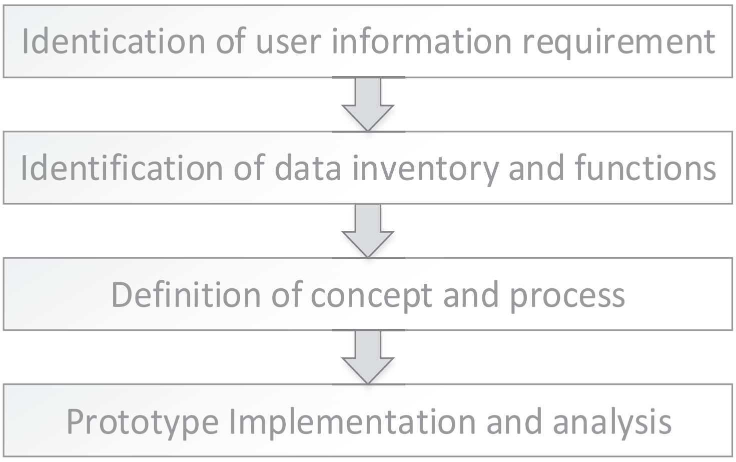


Figure 3-1 Research flow

3.2. Research Methodology

3.2.1. Task 1: Identification of main obstacles and user requirement of ground-based building assessment

In order to find out key obstacles of building damage assessment in a disaster situation, literature review and interview. Since some of literatures have been already done interview with users who have experience building damage assessment, this study focuses on literature review rather than interview. Additionally, field manual of building damage assessment are reviewed. Based on these interviews and literature review, main obstacles that interrupt efficient building damage are identified. In this task, following research questions are answered.

- How do user perform building damage assessment in the field?
- What are the main obstacles of the damage assessment in situ?

3.2.2. Task 2. Defining functions and data inventory

Based on the result of task1, functions and essential data of mobile AR are defined. Main functions of mobile AR is to superimpose virtual (digital) data onto real environment, so that this study proposes method of display which can improve usability of the system and user's immersivity in a disaster situation. For the usability and immersivity, existing display methods of various AR system are compared and examined. Then, data inventory is defined, which shows list of data, data type, data source and purpose. The data inventory is divided into categories that are identified by user requirement such as rapid damage assessment, safety, situational awareness, location awareness, data redundancy, pre-disaster reference, and value-added information. In this task, following research questions are answered.

- Which information is value-added information for the assessment in situ?
- Which functions of AR are required in a disaster situation?
- How can AR get those information and deliver to user efficiently?

3.2.3. Task 3. Defining concept and process of mobile AR for building damage and safety assessment

To apply mobile AR for building damage and safety assessment, overall concept is outlined. This concept describes following key factors of mobile AR: Level of Complexity (LOC), data source, method, accuracy and uncertainty. In this study, mobile AR is approached by two different types of system, Indoor (marker-based) AR and Outdoor (sensor-based) AR, so that each key factors are also separately described for Indoor and Outdoor AR. Indoor AR is to grasp overall status of disaster area, which shows pre- or post-disaster building dataset at indoor environment. Meanwhile Outdoor AR works for individual buildings assessment at outdoor environment. Details of key factors are described in table.

Table 3-1 Key factors of concept of mobile AR

Key factors	Descriptions
Level of Complexity	Classify LOC into 6 groups: LOC1 (building location) to LOC6 (4D)
Data source	Identify how and where the dataset can be acquired
external reference(API)	Identify external reference (or API) that can extract reference dataset through internet connection such as google street view and oblique images.
Assessment method	Define how AR can assess building damage and safety with different data type
Registration method	Define which registration method is required
Accuracy	Identify accuracy of data registration
Uncertainty	Identify uncertainty of each methods of AR in terms of accuracy

This concept takes into account from simplicity case to complexity case in terms of data type, which covers not only simple superimposition of exiting reference data but also generating new information to detect change between pre- and post-disaster building status.
Then process of mobile AR for building damage and safety assessment will be defined. This process will give overall process that show from data and system installation to utilization mobile AR both at indoor and outdoor. In this task, following research questions are answered.

- What is the systematic process of AR approach for building damage assessment?

3.2.4. Task 4. Prototype Implementation and analysis

Based on the result of task 1 to task 4, prototype is developed. The prototype is implemented based on Android platform with smartphone. For the implementation, several existing AR APIs are examined in terms of functionality to reflect the result of previous tasks. Then datasets defined by data inventory are generated and converted to suitable data format that mobile AR can manage. After data generation, two types mobile AR are implemented according to the process defined in task 3 which are Indoor AR (marker-based) , Outdoor AR (sensor-based). Final prototype is evaluated with functional test and user evaluation. In this task, following research questions are answered. Overall flow of implementation is described in Figure 3-2.

- Does mobile AR provide usability and functionality that can improve assessment in a disaster situation?
- How much mobile AR can improve current limitations of ground-based building assessment?

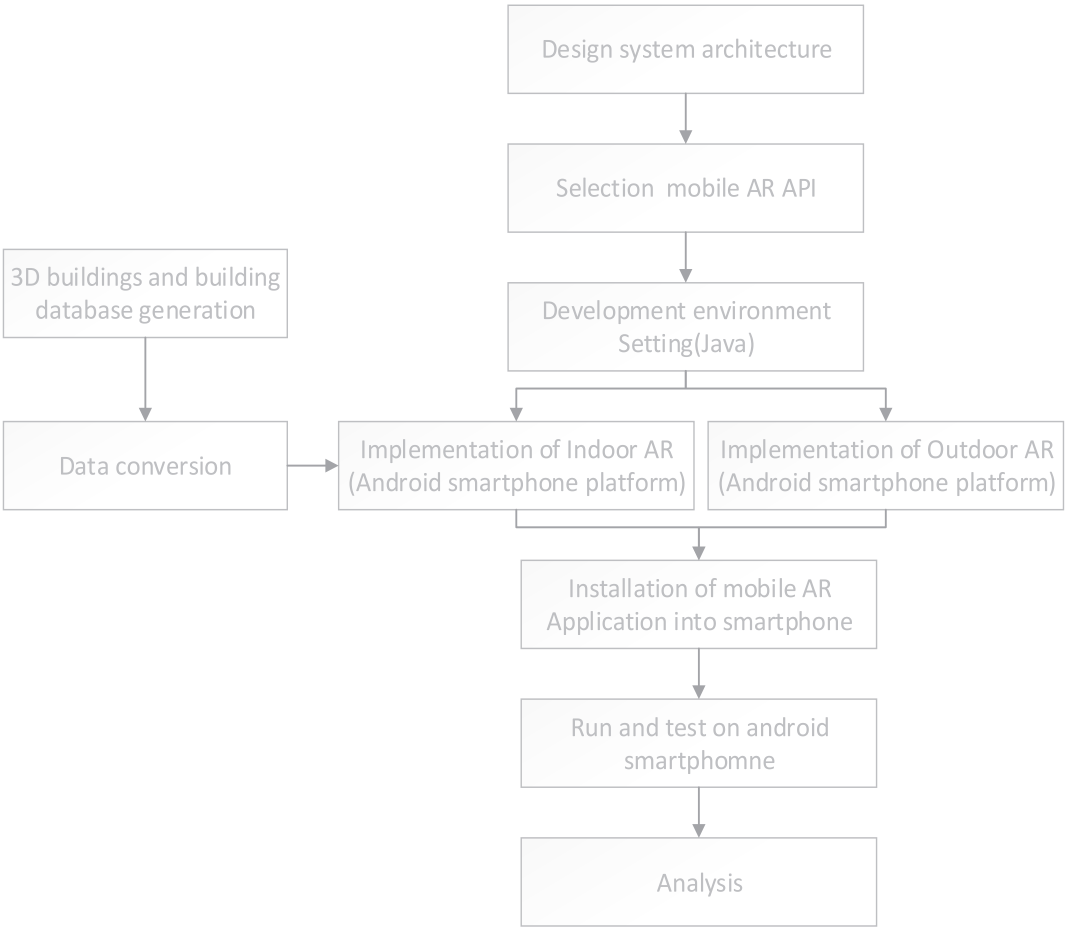


Figure 3-2 Implementation of mobile AR prototype

Analysis will be carried out from two perspectives. Firstly, accuracy and functionality of mobile AR will be analysed with test datasets at outdoor environment. Since this study uses sensor-based AR, accuracy of data registration between virtual building and real building depends on accuracy of mobile sensors. Therefore, it is important to analyse that mobile AR has enough capacity to improve current building damage and safety assessment in the field. Secondly, online-based survey will be conducted with structural engineer who has experience of building damage and safety assessment in the field. Based on these two evaluation, overall evaluation of mobile AR will be performed. Overall flow of analysis is described in figure 3-3.

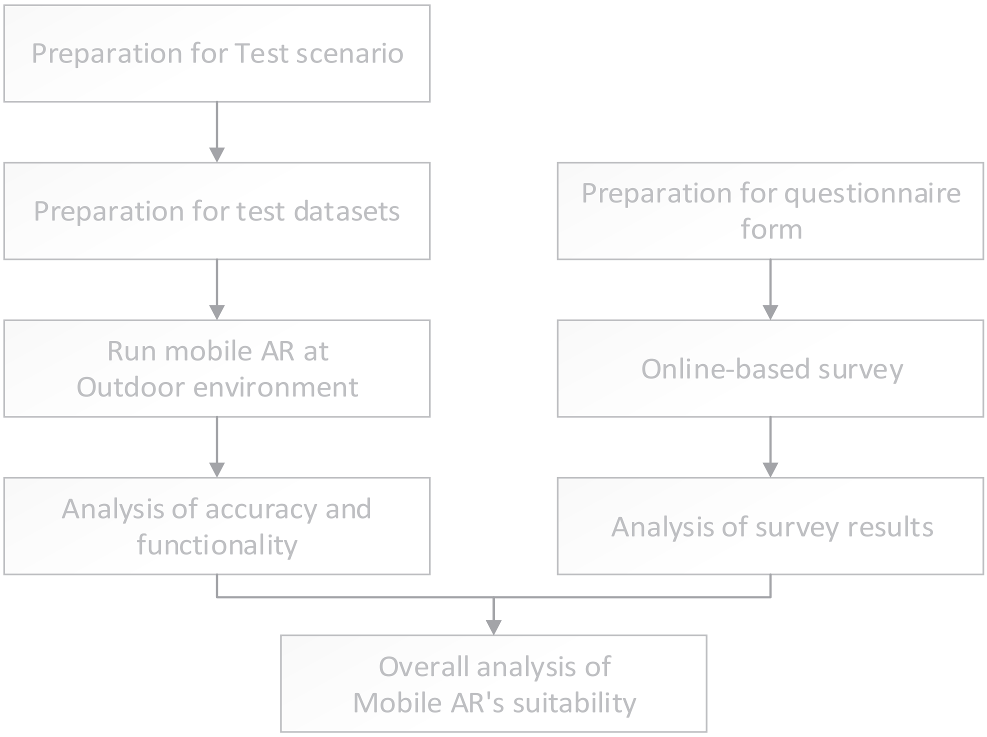


Figure 3-3 Analysis of mobile AR for building damage and safety assessment

4. USER INFORMATION REQUIREMENTS

4.1. Introduction

It is important to understand what information user requires in the field to fill the gap between AR application and ground-based building damage and safety assessment. Thus, this chapter identifies main obstacles of ground-based damage and safety assessment, then categorize these problems into specific user requirements. Based on this user requirements, essential information that plays a major role in the ground assessment is defined. Lastly, in order to deliver the essential information efficiently to users, methods of data visualization and usability are discussed.

4.2. Identification of main obstacles of ground-based assessment

Table 4-1 shows main obstacles of ground-based damage and safety assessment, which are extracted by literature reviews and interviews. In addition, solutions of the obstacles are also proposed. Identified problem is categorized into 10 groups, which need to be improved by mobile AR.

Table 4-1 Main obstacles of ground-based building damage and safety assessment

Identified requirement	Description	Solutions in this study
Data organization (redundancy)	• So many maps are generated which cause problem for user in the field (Corbane et al., 2011)	• Defining data inventroy that is including critical information for the field surveyor
	• First responders need to select relavant maps among a stack of maps that are not organized (Corbane et al., 2011)	• Information system that can provide organized information
Pre-disaster reference data	• Structural engineer needs to know original design and structure of building, which is very useful for building assessment (Peña-Mora et al., 2008)	• Augmented reality that shows pre-disaster buildings
	• Assessement is highly subjective relying on inspector's knowledge (German et al., 2012) • Providing pre-event data is very useful to faciliate the task of field surveyor(Flesch, 2007)	• Providing various reference data in the field
Safety	• If the integrity of the structure is appears qeustionable, engineer should not enter the building (NCSEA, 2011)	• Augmented Reality that shows pre-event structure of building interior
	• Hazardous material such as toxic gas, violent checmicals in the ares should be warned (NCSEA, 2011)	• Displaying location and attribute of hazardous material

Image data capture	• Structural engineers are strongly encouraged to take photographs in the field (EERI, 1996) • "Improve information storage using digital device"(Chen et al., 2012)	• mobile device that can record status of building damage using photographs and video clips with GPS coordinates
Familiarity with disaster area	• Before visiting the field, relavant information should be checked and collected (NZSEE, 2006)	• Indoor augmented reality that shows overall landscape of disaster area
Value-added information	• All evaluation procedures require a specific building type first. (FEMA, 1998) • "One of the most time consuming tasks is to classify building type identifiacation"(Flesch, 2007)	• Augmented reality that shows building attribtue • Defining data inventroy that is including critical information for the field surveyor
Situational awareness	• "Improve situational awareness of early responders with providing geographical information and damage assessement information toghether"(Chen et al., 2012)	• Augmneted reality with geographic information
Rapid assessment	• Rapid assessment should not take over 15 to 30 min. per building (NCSEA, 2011) • Information is distribributed through paper copies, which is very time-consuming (Chen et al., 2012)	• Augmented reality that provides pre-disaster reference • Providing digital data through mobile device
Locational awareness	• Field surveyor needs to aware current location and direction to target building(NCSEA, 2011)	• Street map that shows current street address • Radar(compass) that shows direction of target • GPS
	• Location of essential facilities shoud be identified for high priority assessment (Vidal et al., 2009)	• Radar(compass) that shows location and direction of essential facilities

Data organization (redundancy)

During Haiti crisis of earthquake, so many maps were generated. Within few days 120 maps were generated, and 2,000 maps were produced during first week after earthquake occurred (Corbane et al., 2011). This problem of data redundancy interrupted first responders to collect appropriate information. Therefore, this study defines mission critical information, and proposes mobile AR system that can deliver the information efficiently.

Pre-disaster reference data

For a rapid and objective evaluation, reference data that shows pre-disaster situation is required (Flesch, 2007; Peña-Mora et al., 2008). However, current assessment relies on only knowledge of inspectors which cause subjective assessment (German et al., 2012). Thus, this study proposes AR that can superimpose pre-disaster reference data (e.g. 3D building of pre-disaster, building attribute) directly onto real buildings.

Safety

In a disaster situation, field inspectors are exposed to many type of risks. In some case, for detailed evaluation, the inspector is required to get into damaged building for the assessment, which is very risky (ATC, 2005). Therefore, if building's status is questionable, inspectors should not enter the building (NCSEA, 2011). In addition, because of demolition of various facilities, hazardous materials can be spread through damaged area such as toxic gas and violent chemicals. However, the hazardous materials are normally invisible, so that field inspectors hardly recognize it. Hence, this study proposes AR system that can directly display building interior, so that user can assess the damage of building without entering building. In addition, when field inspectors approached to the hazard area, the AR system will give warning signal to user.

Image data capture

Field inspectors are required to take photos of damaged building for the record (EERI, 1996), and they need to store information in digital format . For that reason, they need brings digital camera(NCSEA, 2011). This study proposes to use mobile device that can take not only photos but also video clips with GPS coordinates, and that can be saved directly to various digital format.

Familiarity with disaster area

Field inspectors need to know about target area, so that they need to gather relevant information of the area (NZSEE, 2006). In order to give user overall status of the damages area, Indoor AR is proposed. This Indoor AR superimposes 3D models and attribute onto map, so that users can recognize overall status of pre- or post-disaster easily before they are allocated to the field.

Valued-added information

The most time-consuming task during the assessment is to classify building structure type such as concrete frame, wood frame, reinforced masonry and so on (Flesch, 2007). The reason they need to know building structure type first is that method of the assessment is varied depending on it (ATC, 2005; FEMA, 1998). However, without building information, it is not easy to judge building structure type visually. Hence mobile AR of this study displays building attribute that includes various building information as well as building structure type.

Situational awareness

In order to improve situational awareness of field inspectors, geographical information and damage assessment information need to be provided (Chen et al., 2012). This study proposes mobile AR that can deliver various geographical information.

Rapid assessment

In phase of rapid assessment, the assessment should be done within 10 to 15 minutes per building (NCSEA, 2011). However most of tasks are conducted with paper-based data or form, which disturbs rapid assessment as well as information sharing (Chen et al., 2012). For the rapid assessment, this study proposes mobile AR that can deliver various reference of pre-disaster in digital format.

Locational awareness

In a disaster situation, it is not easy to identify current location and target location especially in severely affected area due to collapse of several structures that include roads, bridge, rails as well as buildings. Thus it is important to improve location awareness of field inspectors (NCSEA, 2011). In order to improve locational awareness, current street address will be displayed through mobile AR. In addition, for rapid assessment of essential facilities with high priority (Vidal et al., 2009), Radar function will be adopted , which uses compass sensor to show direction of targets on radar interface.

4.3. Esesntial information for a disaster situation

Based on analysis of limitations of current assessment tasks, essential information is extracted in Table 4-2 that shows data, data type, data source, purpose and priority.

Table 4-2 List of essential information

Classification	Data	Data type	Data sources	Purpose	Priority
Building geometry	3D building(exterior)	dwg obj skp kml	• 2D building footprint with height • LiDAR(DSM) • Sketchup warehouse • Construction company	• Pre-disaster reference • Familiarity with disaster area	2
	3D building(interior)		• Construction company	Safety	5
	3D building(frame)		• 2D building footprint with height • Building plan	• Pre-disaster reference	3
Building attribute	Building classification	text	• Cadastral database(local government) • Private building management company • Emergency response organization	• Rapid assessment • Value-added information	1
	Date of construction	text			
	Material	text			
	Purpose	text			
	Building height	text			
	Building story	text			
	Address	text			
Hazardous Material	Location of nuclear facilities	shp	• Local government	Safety	4
	Location of LPG facilities	shp	• Gas management company		

	Location of chemical storage	shp	• List of company which has chemical storage		
	Location of ammonia facilities	shp	• Company list which handle ammonia		
Essential facilities	City map (hospital, fire station, police station, shelter)	shp	• Open street map • Map database(local government)	Locational Awareness	6
Multimedia	area-related video clip	mp4	• Internet service(YouTube)	Pre-disaster reference	8
	area-related pictures	png	• Internet service(Flickr)		
Street-level imagery	Street view image	png	• Google street view	Pre-disaster reference	7
Street address	Roads map	shp	• Open street map • ESRI world roads map	Locational Awareness	9
Landuse	Landuse map	shp	• satellite image • cadastral map • Open Street map	Rapid assessment	10

In this study, data acquisition method is one of important issue. Thus the table above indicates possible sources of data acquisitions. It is important to mention that some of critical information is generated and delivered by emergency response organization. For instance, in Haiti earthquake, an extensive dataset of building attribute and building shape were provided by Remote Sensing Laboratories at the University of Zurich and Swisstopo provided extensive building data (Corbane et al., 2011).

Main purpose of this study is to improve efficiency and safety of building damage and safety assessment. Thus, the most important information that leads to rapid assessment is building attribute (1) of pre-disaster and 3D building (exterior) (2). Then 3D building (frame) (3) and information relevant to safety such as Hazardous materials(4) and 3D building (interior)(5) is given high priority followed by essential facilities(6) such as power station, fire station and hospital.

The list of essential information also considers dataset that can be extracted from network connection like street level imagery (7). Recently, many photos and video clips taken by usual users have geographical coordinates. Therefore, photos and video clips also can be used as reference of pre-disaster. For instance, every photos and video clips around 10 meters of field inspectors can be superimposed on real location according to their coordinate. In addition, google street view also can be good reference since it provides 360 degree pre-disaster reference imagery of street level. Even though its usefulness, it is given lower priority (7) due to limitation of network connection.

Lastly, in order to increase location awareness, street address (9) of current location is distributed based on street (roads) map with current coordinate of users. Then it is followed by landuse (10) data that shows primary purpose of building such as commercial, industrial and residential area.

4.4. Data visualization and usability

4.4.1. Data visualization

Because this study focuses on visualization concept of AR, it is necessary to define efficient method of visualization. Therefore, the study summarize how current mobile AR visualizes their information in Table 4-3. For the comparison of visualization methods, three major mobile AR apps were chosen: Layar ("Layar," 2013), Wikitude("Wikitude," 2013) and Junaio ("Junaio," 2013).

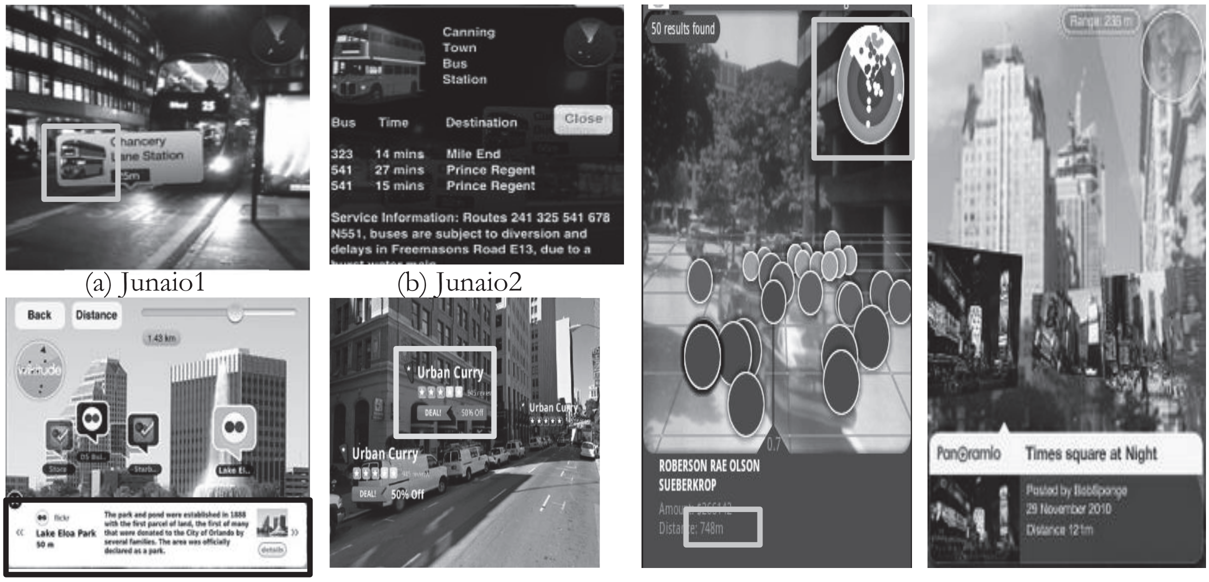
Table 4-3 Characteristics of Visualization

Classification	characteristics	Description
2D contents	Scale change	Fig. 4-1(c), (d) and (e) show that scale of icon is varied depending on distance from user.
	Transparent	Some icon is displayed with transparent background (Fig. 4-1(d))
	Distance	Most of icons display distance together that shows distance between user and object(content)
	Direction	Location of objects are displayed through radar interface (Fig. 4-1 (c), (e))
	Icon type	Icon is displayed in three different ways: picture only (Fig. 4-1(c)), picture and text ((a),(d)) and only icon ((e))
	Detail of contents	Details of content is displayed after clicking a content. Junaio displays it different page using whole screen(Fig.4-1(b)) while Layar and Wikitude only uses part of current screen (Fig. 4-1(c), (e))
3D contents	Interaction	Mobile AR's big advantage is allowing user to interact with contents using touch input.
	Animation	Not only statics 3D model but also animated 3D model can be displayed
	Scale change	According to distance from user, 3D model's scale is also adjusted to fit with real object.

4.4.2. Usability

For building damage and safety assessment, it is important to take into account usability of tool (or software). Because user is normally exposed to risky situation during assessment, low usability can disturb the assessment which cause delay of tasks. Comparing to traditional input devices such as keyboard, mouse and pen, touch handling on current mobile device gives user high usability since user can directly interact with contents. In addition, this usability of mobile AR is strong advantage that allows users to interact in real environment, which is not possible in traditional GIS.

Mobile AR lets users interact with 3D model of pre-disaster building with zoom-in, zoom-out and rotation by simple touch. For instance, users can check overall shape of pre-disaster (zoom-out), and also specific building texture and structure (zoom-in) in different view angles (rotation). That means users can not only interpret with given information passively but also interpret additional information actively.



(a) Junaio1 (b) Junaio2

(c) Wikitude1 (d) Wikitude2 (e) Layar1 (e) Layar2

Figure 4-1 Visualization of mobile AR apps

4.5. Summary

The process and method of ground-based building damage and safety assessment still has many limitations that are caused by lack of reference data and information technology in situ. As information channel of value-added information, mobile AR can play major role in situ to improve current status of the assessment. In addition, usability and visualization methods of mobile AR are very robust to improve situational awareness and immersivity in the field, which is not possible with traditional information system and device. In next chapter, specific structure of this mobile AR and how AR can be applied in different situation are explained in terms of mobile AR process for building damage and safety assessment.

5. APPORACH OF MOBILE AR

5.1. Introduction

This chapter elaborates how mobile AR can be applied for building damage and safety assessment. In order to specify method of mobile AR, overall concept of mobile AR is defined first. This concept shows how mobile AR can support ground-based building damage assessment, and which methods and datasets are required by user. Before describing this concept, it is important to mention again that who is users of this mobile AR in this study. As mentioned in chapter 2, the users can be structural engineer, geotechnical engineer, architect, search and rescue team and volunteer group who carry out building damage and safety assessment in the field. After defining overall concept of mobile AR, each parts of concept are shaped up with consideration of various factors of AR.

5.2. Concept of mobile AR for building damage and safety assessment

In order to apply mobile AR for building damage and safety assessment in the field, this study conceptualizes relationship between AR and the assessment in Figure 5-1. This concept comprises of concept image, data registration, complexity, datasets and approach. The concept image describes overall structure and relation between data resource and mobile AR. The data registration indicates appropriate methods to combine virtual data with real object displayed on camera image. The complexity points out technical level of AR that requires different level of accuracy, implementation and machines. This complexity increases from left (Binary) to right (4D). In order to indicate the complexity, this study uses term 'Level of Complexity (LOC)' comprised of LOC 1(low complexity) to LOC 6 (high complexity). The datasets outlines data type, which are demanded by each complexity levels. Lastly, the approach separates the complexity of AR into two groups in terms of utilization or generation of information.

As shown in approach section (Figure 5-1), AR can be conceptualized with two different perspectives called 'visualization existing information', and 'generation of new information'. Concept of visualization of existing information superimposes various reference datasets onto real building. This reference datasets can be binary (e.g. building coordinates), attribute (e.g. building information), linked attribute (e.g. street level imagery), and geometry (e.g. 3D building frame). With the various reference datasets that are defined as a mission critical information in section 4-3, users can do visual interpretation of real building.

In contrast to visualization concept, concept of new information is to extract change between pre- and post-disaster 3D models. This concept utilizes the characteristics of video see-through approach of AR that use live image of camera. Mobile AR superimposes virtual data on live feed of camera, which means camera images itself can be utilized to generate new information. To extract 3D geometry from sequential images, Structure from Motion (SfM) method is widely used in computer-vision and photogrammetry field (Quan & Wu, 2013). Using SfM, 3D model of post-disaster building can be reconstructed from images of camera. To find 3D discrepancy 3D model of pre- and post-disaster is changed to voxel structure which is 3D data structure comprised of volumetric pixels (Kahn et al., 2013). As a result, users can recognize quantitative change between two datasets such as volume reduction, height reduction.

Table 5-1 shows specific definition and example of each LOC comprised of 6 levels. The complexity increases from LOC1 to LOC6. LOC1 simply shows building existence. In case of totally collapsed building, user might not recognize building existence before. Thus it is important for user to recognize building existence firstly. After recognizing building existence, user needs to know what it was and how it

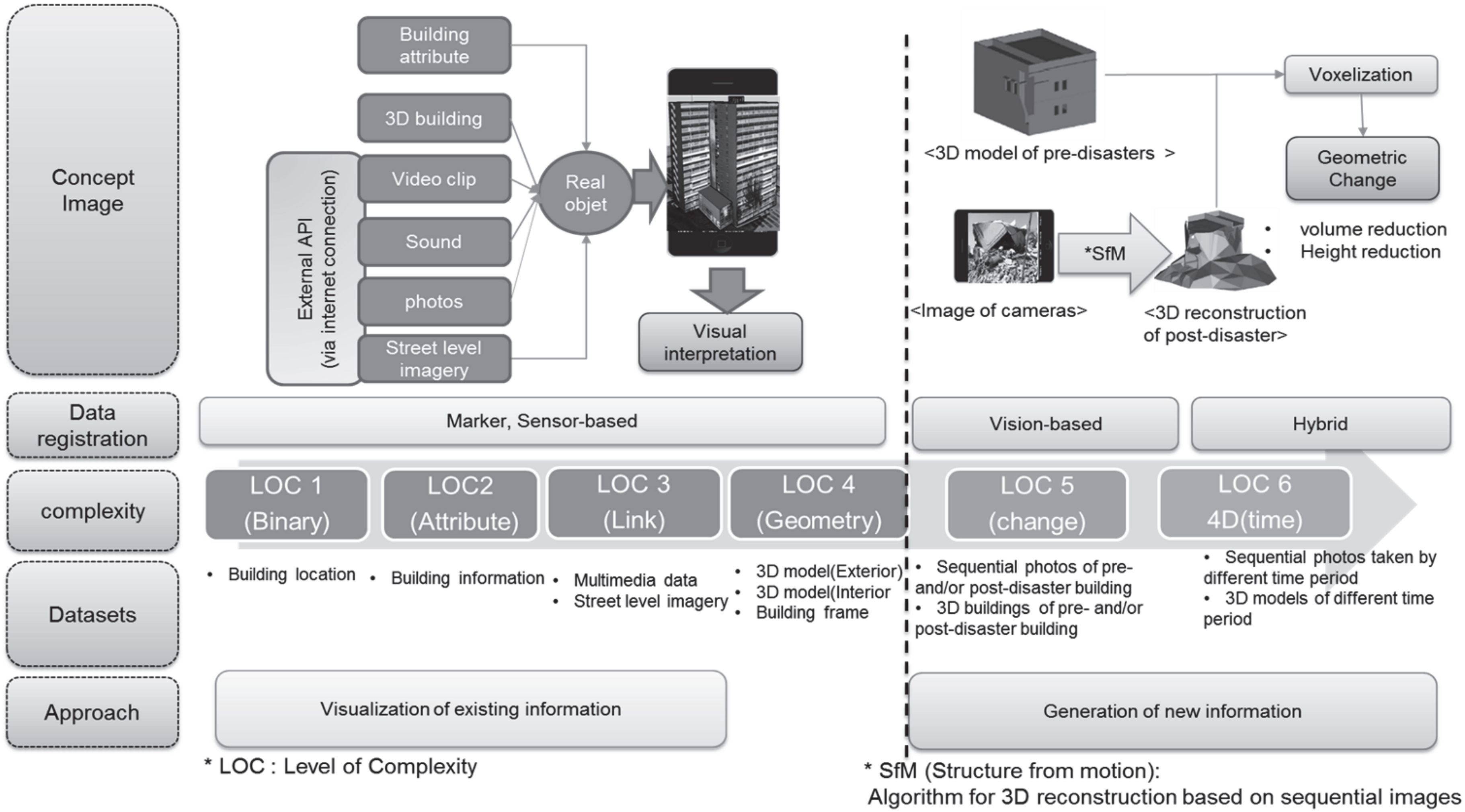
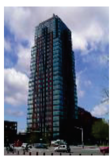


Figure 5-1 Concept of mobile AR for building damage and safety assessment

was. For that purpose, LOC2 provides building information such as building classification, materials height and story, so that user can identify status of pre-disaster building. LOC3 delivers external (linked) building information using external API that provides multimedia datasets and street level imagery through internet connection. LOC4 shows building shape of pre-disaster with not only building exterior but also building frame and building interior. With LOC3 and LOC4, user can find out how the building was before. While LOC1 to LOC4 focus on providing existing building information, LOC5 and LOC6 generate new information in terms of change. With LOC5 user can identify which part of building is changed while LOC 6 shows change progress of a building over different time period. Each of LOC level is specifically defined in terms of procedure, flow, accuracy and uncertainty in next section.

Table 5-1 Level of Complexity in Augmented Reality

	LOC 1	LOC 2	LOC 3	LOC 4	LOC 5	LOC 6
Definition	Existence of real building	Attribute of real building	Linked attribute of real building	Geometry of real building	Change of real building	Progress of change
Concept	Was it there before?	What was it before?	How was it before?	How was it before?	What is difference between before and now?	What is the progress of change over time?
Datasets	-Coordinates of building	-Building information	-Photos -Video clip -Street level imagery	-3D building (Interior) -Building frame	-3D building -Sequential images	-3D building -Sequential images
Example	Building A 52.232, 9.232	Concrete fame Date: 1-1-1980 Residential 50m/16 floors				

*LOC: Level of Complexity in Augmented Reality

5.3. Methods of mobile AR for building damage and safty assessment

Specific methods of each concepts are defined in terms of concept image, procedure, flow, accuracy and uncertainty. Concept image shows simple example of each concept with screen shot. Procedure is defined in following order: data source, data process, AR process, visualization and damage assessment. The damage assessment is the only procedure conducted by user (highlighted with orange colour in the table), while from data source to visualization procedure are performed by system and system (or data) provider (highlighted with green colour in the table). Then flow is identified for each procedure. Lastly, accuracy and uncertainty of each procedure are characterized.

5.3.1. Method of Binary (LOC1)- and Attribute(LOC2)-based visualization

The concept of LOC1 and LOC2 are to provide user simple information with simple registration method. LOC1 focuses on visualization of building existence on damaged area, while LOC2 provides additional information of building such as building classification, material, height, story and purpose. Although LOC1 provides the simplest information, it is very important information for users to identify totally collapsed building which is almost invisible to recognize to the naked eye. In addition, LOC2 can be key factor to reduce a building assessment duration since the most time consuming task is to classify building type (Flesch, 2007). Specific concept and method for LOC1 and LOC2 are shown in table 5-2.

Procedure and Flow

Building information can be extracted from cadastral database of local government, private building management company and emergency response organization. Especially emergency response organization is worthy of notice. In Haiti earthquake, emergency response organizations such as Remote Sensing Laboratories at the University of Zurich and Swisstopo provided an extensive dataset of building data (Corbane et al., 2011). Although several organizations provide building information, it still requires data refine and data conversion in order to process through AR. In this concept, data type is mainly text format that is very irregular according to data provider. Therefore, it is important to refine raw data into data format that can be imported to building database of AR. Main function of AR process is data registration that uses GPS and compass sensor of mobile device to superimpose building information onto real building of camera image. In order to avoid data redundancy and overlay on the screen, display range (radius) need to be defined. For instance, setting radius with 100 meters displays information of buildings that are located within 100 meters from current user's location. Lastly, AR visualizes only building name on target building to let user recognize building existence around damaged area (LOC1, binary). User can interactively touch building name to get detail of interesting building attributes. Based on the building information, user can conduct visual interpretation. For instance, with initial building height and story information, user can assess how much percent of building is damaged.

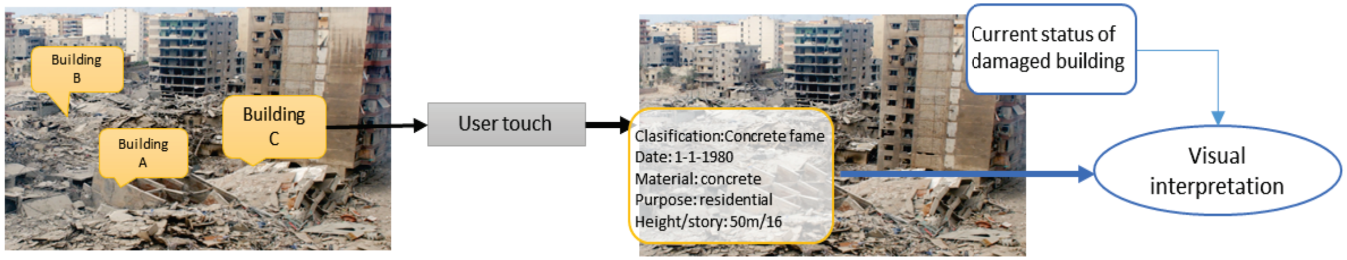
Accuracy

As mentioned earlier, text format data is usually irregular so that it is essential to refine raw data. However, the refine process cause data loss and data change. In addition, each building information (text) need to be georeferenced if it does not have a coordinate. Usually georeference (coordinate assignment) is performed by converting an address to a coordinate, which is called Geocoding. However geocoding process also can cause data inaccuracy during the conversion. In addition, most of AR concept in this study uses GPS and compass sensor for data registration which cause accuracy loss. Although visualization process depends on accuracy of data registration, it is not necessary to have high accuracy. For text information is a basically point data, as long as it is displayed within building boundary, it is till interpretable.

Uncertainty

"Uncertainty" means uncontrollable and unpredictable parameters that can affect each procedure. Irregularity of data sources and formats can affect uncertainty of data source and data process. Political and privacy issue can disturb information release as well. In terms of AR process and visualization, GPS signal in dense building area can be factor of uncertainty, which affect data registration and accurate visualization. For damage assessment, main problem comes from various evaluation forms. According to evaluation form, required building information are different. Therefore it is also important to define common building information that can be applied for different forms, which is already defined in table 4-2 in this study.

Table 5-2 The concept of Binary-based (LOC1) and Attribute-based visualization (LOC2)

Concept image					
Procedure	Data source	Data process	AR Process	Visualization	Damage assessment
Flow	Cadastral database (local government) Private building management company Emergency Response organization[1]	Data refine → Data Conversion → Data Georeferencing → Building Database	Data import → Data registration (using GPS and compass sensor → Setting display Radius[2] → Extracting building attribute	Display building Attribute on target building Building classification Building material Building name/address Landuse Building height(story)	Decision of building damage assessment method → Building identification → Visual interpretation based on provided information
Accuracy	• Accuracy of original data source	• Coordinate assignment for building attributes can affect display position	• Data registration accuracy is dependent on accuracy of sensors	• Data visualization depends on accuracy of data registration • Text information is point data. Therefore, if building attribute is displayed within building boundary, it is still interpretable.	• Visual interpretation depends on users' knowledge. • Providing objective information can improve assessment accuracy.
Uncertainty	• Data sources are irregular • Political and privacy issue • Administrative procedures	• Data formats are irregular	• Dense building area can affect GPS signal	• Dense building area can affect GPS signal	• Various evaluation forms and procedures are exist

5.3.2. Method of Linked attribute-based (LOC3) visualization

The concept of LOC3 (Linked attribute) is to provide users multimedia dataset such as photos and video clips that are linked (related) to a building. In contrast to LOC1 and LOC2, LOC3 gives users dynamic information that includes not only text information but also sounds and images. The datasets of LOC3 can be obtained from internet service such a YouTube (video sharing service, www.youtube.com), Flickr (photos sharing service, www.flickr.com). These services provide API (Application Programming Interface) that can extract geo-tagged video clips or photos through internet connection. For instance, user can extract all the video clips and photos around user's current location, which lets user understand the area. User also can define some keywords (e.g. building name, street name, city name) with specific location, which give user building-related contents. In addition, street level imagery (e.g. Google Street View) that shows panoramic photos with user's perspective can be a good reference in the field. Specific concept and method for LOC3 is shown in table 5-3.

Procedure and flow

LOC3 mainly depends on external API to extract data from service providers. In order to extract video clips and photos, YouTube API and Flickr API are used. These APIs require query parameters such as coordinates and keywords. To visualize in AR system, extracted dataset needs to be converted to appropriate data format that is required by AR platform since the data format varies depending on AR platform. For instance, some of AR platform can process only 3g2 format, while the others can process mp4 format. After data conversion, they are imported to AR system. With building-related video clips and photos, user can get the picture of buildings as well as regional characteristics around buildings.

Google street view API has function of registration that match street view imagery with user's perspective using compass sensor and GPS. Therefore, Google street view can be visualized in separated window without AR process. For the damage assessment, user can directly compare real image of camera (displayed by AR process) with street level imagery (displayed by google street view API).

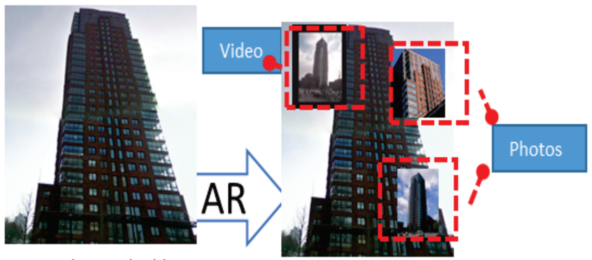
Accuracy

Accuracy of data source depends on query condition to extract meaningful data from API (e.g. keyword). Besides, locational accuracy of geo-tagged photos and video clips are not guaranteed. Although google street view does not rely on data registration method, it uses also locational sensor of mobile device, so that accuracy of google street view can be affected by sensor accuracy. Although visualization process depends on accuracy of data registration, it is not necessary to have high accuracy. For multimedia data is a basically point data, as long as it is displayed within building boundary, it is till interpretable.

Uncertainty

In this concept, main uncertainty comes from network connection since the dataset are extracted by external APIs that use network connection. Service coverage of google street view is limited as well. Another uncertainty is a size of the datasets especially for video clips. A storage of mobile device is limited, so that the device cannot store large size of video clips depending on the device.

Table 5-3 The concept of Linked attribute-based (LOC3) visualization

Concept image	 Post-disaster building Multimedia datasets are superimposed			 Street view mode	
Procedure	Data source	Data process	AR Process	Visualization	Damage assessment
Flow	YouTube API → Data query Flickr[1] API → Data query Google street View API	Data refine → Data Conversion	Data import → Data registration (using GPS and compass sensor → Setting display Radius	Display video clips and photos tied up with target building Building-related movie clip Building-related photos Display street view around user's location	User can understand regional characteristics around buildings User can directly compare pre-disaster building imagery with post-disaster building
Accuracy	• Quality of multimedia datasets depend on query condition to extract meaningful data from API(e.g. keyword). • Locational accuracy of geo-tagged photos and video clips	• Data refine condition for multimedia data should be well-defined	• Data registration accuracy is dependent on accuracy of sensors • Google street view is displayed seperatly(not superimposed), so that data registrtation accuracy is not relavant.	• Data visualization depends on accuracy of data registration • Multimedia data is point data. Therefore, if the dataset is displayed within building boundary, it is still interpretable. • Google street view is also affected by accuracy of GPS and compass sensor	• Visual interpretation depends on users' knowledge. • Providing pre-disaster building imagery can improve assessment accuracy and assessment duration.
Uncertainty	• Network connection • Service area is limited	• Size of multimedia data		• Dense building area can affect GPS signal	

5.3.3. Method of geometry-based (LOC4) visualization

The concept of LOC4 (geometry-based) visualization is to provide geometric information of building that includes 3D building exterior, interior and frame structure. The 3D building exterior shows building's original shape and texture while 3D building interior displays structures of building inside such as stairs, elevators and rooms. With building interior information, user can identify location of important facilities of building inside, so that user can assess building damage without entering the building.

Depending on the level of information availability, the building frame can shows structure of beam and column. With building frame, user can directly assess geometric change such as building deformation and inclination. Specific concept and method for LOC4 is shown in table 5-4 (building exterior and interior) and table 5-5 (building frame)

Data source and flow

Data source can be classified into two groups, primary dataset and secondary dataset. Primary dataset is 3D building that can be used directly without any data generation process. For instance, 3D buildings extracted from google earth or from building management company are the primary dataset. Whereas the secondary dataset needs data generation process to make 3D building such as 2D building footprint, LiDAR. The secondary dataset is processed on a PC, then it is converted 3D data format that is required by AR platform. In order to visualize these 3D buildings through AR, three key parameters should be defined: coordinates, scale and rotation of building. For damage assessment, user can visually distinguish change between 3D building exterior (pre-disaster) and real building (post-disaster), while building frame let user know structural change. In addition, building interior let user identify essential facilities such as stairs and elevators, so that user can identify building structural safety comparing damage of building exterior with location of the inner structures without approaching inside of building. Accordingly, the information can reduce risk of user in disaster situation.

Accuracy

Accuracy of original data (3D) and data conversion process can affect both data source and data process accuracy. Accuracy of primary dataset is variable according to generators of 3D data while the secondary dataset depends on data generation process. In addition, data conversion causes quality loss of 3D data. In order to locate 3D building on geographical location, coordinates, scale and rotation should be defined in the procedure of data generation. However, the definition of these parameters can also involve locational error. For AR process of building exterior and interior, as long as user can identify which 3D building belongs to which real building, the accuracy of data registration is acceptable. Whereas building frame requires accurate registration. Because accurately registered building frame lets user directly assess geometric change such as inclination and deformation of building.

Uncertainty

The more 3D data has precision and accuracy, the more performance and storage of mobile device required. File size of 3D data can affect performance of both data process and AR process. In addition, the number of 3D buildings that are displayed simultaneously can be limited depending on performance of mobile device. For building frame, if user gets closed to target building, user cannot recognize overall building shape. Because building frame does not have texture, user would see only small part of beam or column. However building frame only has line elements without texture, so that file size of the data is small compared to building exterior and interior, which reduce uncertainty that caused by file size.

Table 5-4 The concept of geometry-based (LOC4) visualization: Building exterior and interior

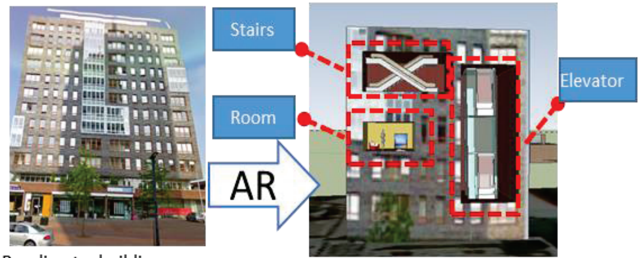
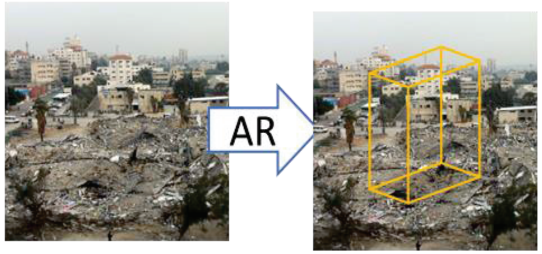
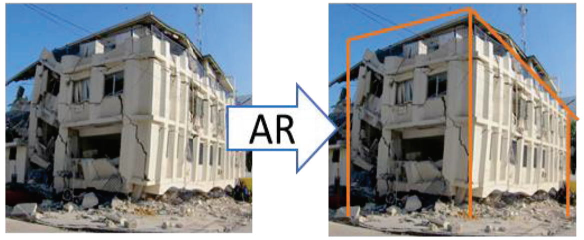
Concept image	 Collapsed building area / Pre-disaster building(Exterior)			 Pre-disaster building / Pre-disaster building(interior)	
Procedure	Data source	Data process	AR Process	Visualization	Damage assessment
Flow	2D building footprint with height LiDAR Google earth 3D warehouse[1] Construction company	3D building generation Data Conversion Coordinates setting Scale and rotation setting	Data registration (using GPS and compass sensor Setting display Radius	Display 3D building on target building 3D Building Exterior 3D Building Interior	Comparing 3D building of pre-disaster with real building of post-disaster Identify location of stairs, elevators and residential area
Accuracy	• Accuracy of original data source	• Data conversion can cause information loss of original 3D building • Coordinates, scale and rotation have its own error. • 3D data generation from LiDAR(or 2D footprint) can cause accuracy loss	• Data registration accuracy is dependent on accuracy of sensors • GPS accuracy of mobile device is 10m(open area area)~30m(dense building area) (Ababsa et al., 2012) • As long as 3D building is overplayed within boundary of real building, it is still interpretable as a reference	• Data visualization depends on accuracy of data registration • Location of building interiors such as stairs and elevators can have possible error originated from original source	• Visual interpretation depends on users' knowledge. • Providing initial building shape(3D building of pre-disaster) can improve assessment accuracy and assessment duration. • Visualization of building interior let user recognize building structure without entering building, which can improve assessement accuracy.
Uncertainty	• Data sources are irregular	• If size of 3D data are big, it can affect performance of applicaoin and memory of mobile device	• Device performance for multiple 3D datasets	• Dense building area can affect GPS signal	

Table 5-5 The concept of geometry-based (LOC4) visualization: Building frame

Concept image	 Collapsed building area	Pre-disaster building frame	 Partially damaged building	Pre-disaster building frame	
Procedure	Data source	Data process	AR Process	Visualization	Damage assessment
Flow	2D building footprint with height 3D building frame	3D building frame generation → Data Conversion → Coordinates setting → Scale and rotation setting	Data import → Data registration (using GPS and compass sensor → Setting display Radius	Display 3D building on target building 3D Building frame	Assess geometrical change visually between pre-disaster 3D frame and post-disaster building
Accuracy	• Accuracy of original data source	• Data conversion can cause information loss of original 3D building • Coordinates, scale and rotation have its own error.	• In order to compare 3D building frame with shape of real building, it requires accurate data registration. • Data registration accuracy is dependent on accuracy of sensors	• Data visualization depends on accuracy of data registration	• Visual interpretation depends on users' knowledge. • Providing building geometry(frame) of pre-disaster can improve assessment accuracy for geometric change of building.
Uncertainty	• Data sources are irregular		• Device performance for multiple 3D datasets	• Dense building area can affect GPS signal • Since it only displays frame without texture, user cannot recognize overall building shape if user is too close to target building	

5.3.4. Method of change-(LOC5) and time-based (LOC6) visualization

The concept of LOC5 is to provide the result of change detection between pre- and post-disaster data while LOC6 is to show progress of change during specific time period. The change means geometric change of a building such as volume reduction, height reduction, building inclination and so on. The progress of change shows how building has been changed during specific time period. The other concepts (LOC1 to LOC4) let user interpret the change visually with references of pre-disaster data while LOC5 and LOC6 detect change automatically and superimpose the change on real building. Thus LOC5 and LOC6 requires the highest accuracy of data registration such as vision-based registration and hybrid registration. In addition, these registration methods need high performance of device to process the registration algorithm. For these reasons, the concept mainly uses hybrid method that divides visualization process (by mobile device) and registration process (by desktop PC). This study also considers hybrid method. Specific concept and method for LOC4 is shown in table 5-6.

Procedure and flow

In order to extract change 3D buildings over different time period are necessary. In case of no existing 3D building, 3D building can be generated from sequential images of the building using Structure from Motion (SfM). Therefore, street level imagery (e.g. google street view) can be data source of SfM to generate 3D building. Sequential images for post-disaster 3D building can be obtained by users. Since mobile AR uses camera module of mobile device, user can directly take photos of target building in disaster area. If network connection is available, taken photos are uploaded to server directly to generate 3D building. Instead of using sequential images, recent technology, called 'Spike" (http://www.ikegps.com/spike/), showed possibility of scanning 3D object directly to generate 3D data from live images of mobile device. The system uses small hardware that can be attached smartphone in order to generate 3D data on the device. It does not require server-side process as well.

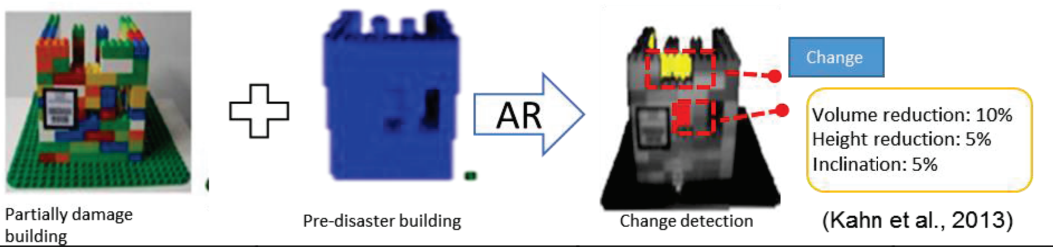
After processing change detection between pre- and post-disaster 3D building, server returns to user the result (extracted change). If network connection is not available, user needs to export the photos to server manually. After finishing change detection process, user need to import extracted change data into mobile AR. In order to extract change between pre- and post-disaster 3D (or data from different time period), pre- and post-disaster is changed to voxel structure which is 3D data structure comprised of volumetric pixel. Since extracted change is also 3D data, it should be converted appropriate data format that is required by AR platform. Unlike the other concepts, this concept uses vision-based registration to ensure high accuracy of registration. For damage assessment, user can check which parts of building are changed (or damaged) through AR. User can straightforwardly figure out how much of building is change with calculated information such as volume reduction, height reduction.

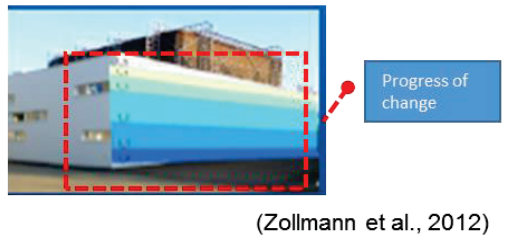
Accuracy

If user generates 3D from sequential images, quality of images strongly affects the quality of 3D building. Besides, 3D model generated by SfM has a lower quality than one from 3D warehouse (e.g. google earth). The difference of quality can affect accuracy of change detection. Accuracy of AR process is higher than the other concept (sensor-based) because it adopts vision-based registration method (SIFT). For damage assessment procedure, accuracy of user's assessment relies on accurate information calculated by system. However, final decision for building damage (safety) classification still depends on user's judgement.

Table 5-6 The concept of change-based (LOC5 and LOC6) visualization

Concept image





Procedure	Data source	Data process	AR Process	Visualization	Damage assessment
Flow	<Pre-disaster)> Sequential images of building (google street view) 3D buildings (3D warehouse) <Post-disaster)> 3D buildings (LiDAR) Sequential images of building (User takes)	3D building generation (Structure from Motion)[1] Voxelization[2] Change extraction Change calculation Data conversion	Coordinates setting Scale and rotation setting Data registration (image-based registration, SIFT)[3] Setting display Radius	Display extracted change with pre-disaster building Display quantitative information of change	Quantified geometric change between pre-disaster and post-disaster building : Volume reduction : Height reduction : Inclination
Accuracy	• Accuracy of original data source of 3D • Quality of photos	• Quality of 3D building generated from images is lower than manually made one • This process requires high accuracy to calculate accurate change • Voxelization and data conversion process cause data loss	• For the quantitative assessment, accurate data registration is required. • image-based registration method has higher accuracy than sensor-based registration.	• Data visualization depends on accuracy of data registration	• The assessment accuracy relies on objective information calculated by system. • Final decision for building damage(or safety) classification still requires user's judgment
Uncertainty	• Data sources are irregular • Condition of weather and Sun angle for photos	• SfM does not guarantee of accuracy • Data process time • Network connection	• Performance of mobile device is not enough for real-time image-based registration) • Network connection for server-client system		• For this concept, AR provide complicated information, which might cause delay of assessment duration.

Uncertainty

In data source acquisition procedure, main uncertainty comes from weather condition. Because condition of photos for 3D generation can be various according to weather and sun angle. The type of device and ability of users to takes suitable image can be critical variables as well. Data process also has uncertainty in terms of processing time. According to its processing time, it is determined whether the system can provide the change data in real-time or not. In addition, availability of real-time process is related to network connection as well. In damage assessment procedure, user possibly can experience delay of information interpretation provided through AR. Because the information provided in this concept has complexity, which might interrupt rapid assessment.

5.4. Summary

In this chapter, overall concept of mobile AR for building damage and safety assessment was defined. The overall concept presented relationship between registration methods and Level of Complexity (LOC). In addition, the purpose of AR was divided into two categories: visualization of exiting information and generation of new information. For visualization of existing information, various reference dataset can be distributed through AR such as building existence, building information, building-related multimedia, building interior, exterior, and frame in order of complexity. For generation of new information, change (e.g. volume reduction, height reduction, and inclination) and progress of change (e.g. building shapes between 1 year ago and now) can be provided through AR, which is the most complex concept among the AR concepts in this study. Furthermore, specific method, procedure, accuracy and uncertainty for each concept were defined. Various reference datasets and concepts mentioned in this chapter have potential to be extended with additional references and methods.

6. PROTOTYPE IMPLEMNTATION AND EVALUATION

6.1. System architecture

In this study, system architecture is divided into two type types with respect to internet connection: standalone AR (without internet connection) (Figure 6-1 (a)), network-based AR (with internet connection) (Figure 6-1 (b)). Although this study implemented standalone AR as a prototype, external map (google map) API was used to simplify development process.

Android API is a framework to develop android application which includes core modules of android. In this study, android API 4.3 (code name: Jellybean) is used. AR API is core part of mobile AR which includes registration and visualization (superimposition) function. Nowadays, there are many AR APIs existing for mobile device and PC. Table 6-1 summarizes AR APIs' characteristics. Since Metaio API is the only one that uses common 3D data format (e.g. obj format) without any conversion, this study adopted Metaio API that also supports video clip display.

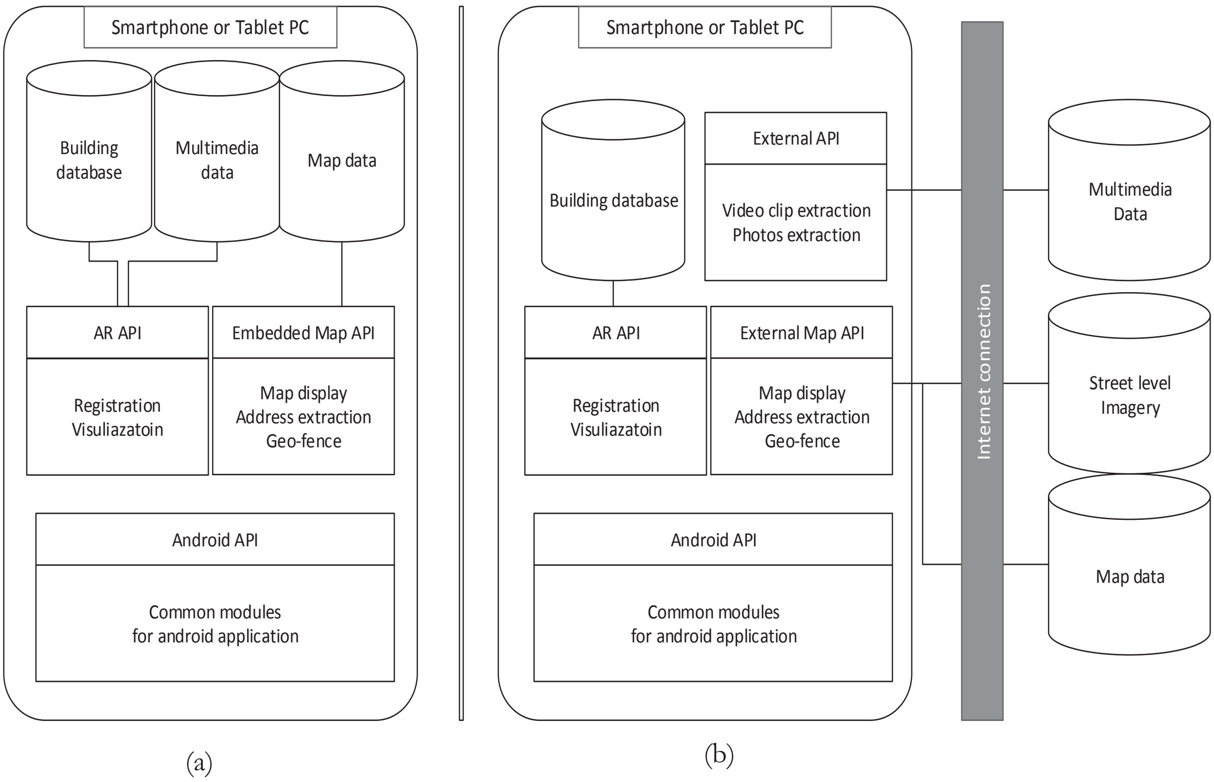


Figure 6-1 System architecture (a) Standalone AR (b) Network-based AR

Map API plays a major role to display map as well as to extract address of current user location. The Map API is divided into two types according to its internet availability: Embedded Map API and External Map API. Embedded Map API is embedded in mobile device which uses embedded maps, so that it works even for offline device. OpenStreetMap provides free offline maps and API that can be embedded in a mobile device ("OpenStreetMap," 2013). Whereas External Map API extracts maps and functions from external source via internet connection. Google Map API is a representative External Map API working on internet connection. In order to check whether user is within certain boundary, this system sets geofence using Google Map API. The geofence is a virtual boundary around specific position. For instance, mobile AR of this study uses geofence to give user a warning if user is within a 100 m radius from a chemical plant that produces hazardous material. In addition, Google Map API can be also used to extract street level imagery from Google Street View.

Table 6-1 Summary of AR APIs

	Detail	Junaio(Metaio)	Layar	Wikitude	ARToolkit
platform	PC(windows, Mac)	○			○
	Android(Java)	○	○	○	
	iOS(Object C)	○	○	○	
	Blackberry			○	
	Unity	○			
	mobile web	○	○	○	
Data	3D model	○ (obj, fbx, md2)	○ (need to convert to own format)	○ (need to convert to own format)	○
	text	○	○	○	○
	image	○	○	○	○
	video clip	○		○	
	sound	○			
	3D animation	○	○	○	
Tracking	Sensor-based(GPS)	○	○	○	
	Locational Marker	○			
	ID marker	○		○	○
	Image tracking	○		○	○
3D Effect	Light and Shade	○			

For network-based AR, External API can be used to extract multimedia data such as video clips and photos from internet services. YouTube API provides function that can extract geo-tagged video clips, and Flickr API also has same functions for photos.

Since standalone AR has limitation to connect external sources, every data sources are stored in the device. Building database stores building information and path of 3D building. For map and multimedia data, instead of database, they are saved into folder because they uses binary format following specific rule for data management that is required by Map API and AR API. Whereas network-based AR only has building database in the device. Because, multimedia, map and street level imagery are extracted from external data sources.

6.2. Functions and user interface

Prototype comprised of two systems: Indoor AR and Outdoor AR. According to user information requirement in chapter 4, following functions for each system were implemented (Table 6-2, Table 6-3).

Table 6-2 Function list of mobile AR (Outdoor) for building damage and safety assessment

Functions	Description	User requirements
AR Visualization of pre-defined dataset - Building information - Building exterior, interior, frame - Video clip	Essential information are superimposed on real world through mobile AR. This function uses GPS and compass sensor for data registration	- Data organization - Pre-disaster reference data - Rapid damage assessment
Map display	Google map is displayed around user's current location. "Map" button turns on/off map screen.	- Situational awareness - Locational awareness
Address display of user's current location	Address (including street name) of user's current location is displayed	
Radar	Radar indicates relative location and direction of essential facilities and target buildings	- Locational awareness - Rapid damage assessment
3D model rotation/zoom-in/zoom-out	User can handle 3D models with touch gesture	- Pre-disaster reference data (Improve usability)
Reset of a 3D model	It recovers initial sate of 3D model	
Mapping building location and address	When user touch a virtual object on screen, its location and address is marked on the map	- Situational awareness - Rapid damage assessment
Distance and direction display	Distance (meter) and direction (degree) to selected (touched) building from user's current position is displayed.	- Situational awareness - Locational awareness
Warning for a hazard area	If user approach within 100 meters from a hazardous facility, warning message and geo-fence of a hazard area is displayed.	- Safety
Data On/Off	Set selected object visible/invisible	- Pre-disaster reference data (Improve usability)

Table 6-3 Function list of mobile AR (Indoor) for building damage and safety assessment

Functions	Description	User requirements
AR Visualization of pre-defined dataset - Building information - Building exterior - Video clip	3D buildings and video clips are superimposed on pre-defined satellite image (Marker-based AR)	- Pre-disaster reference data - Familiarity with disaster area
Building information display	When user touch a building, building information is displayed	
3D model rotation/zoom-in/zoom-out	User can handle 3D models with touch gesture	
Reset of a 3D model	It recover initial state of 3D model	

With these functions lists, following user interfaces were designed for Outdoor AR (Figure 6-2) and Indoor AR (Figure 6-3).

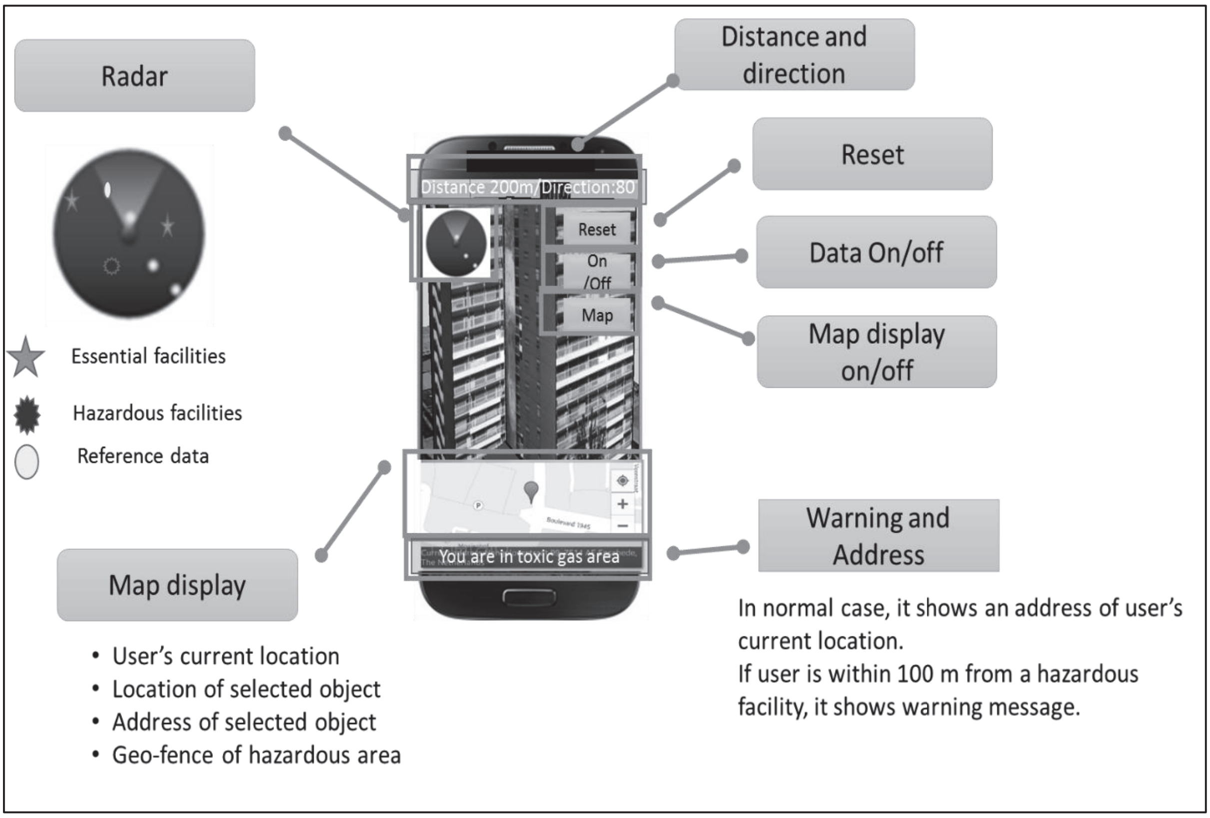


Figure 6-2 User interface of Outdoor AR

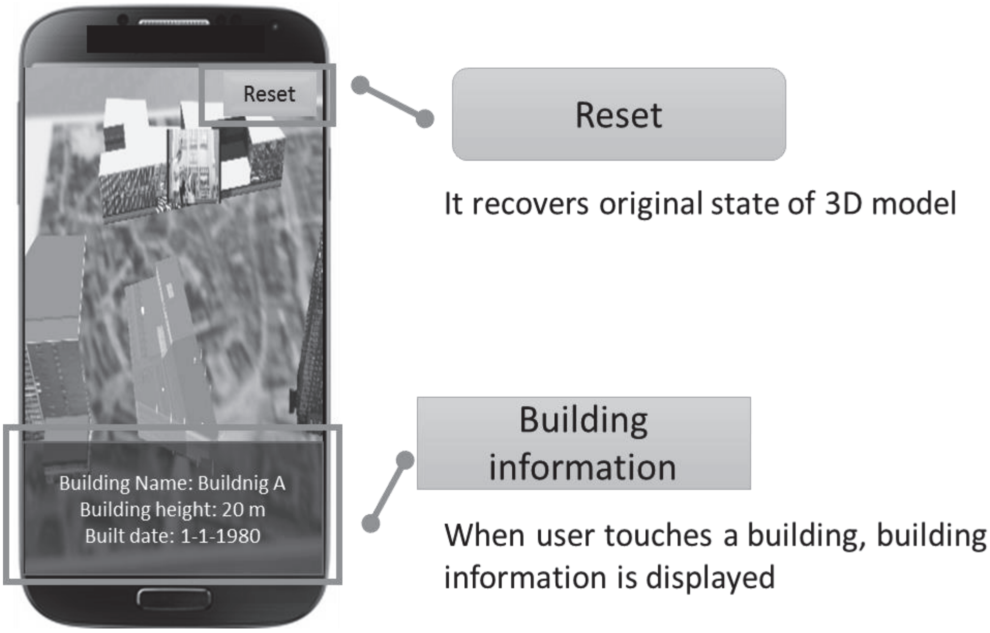
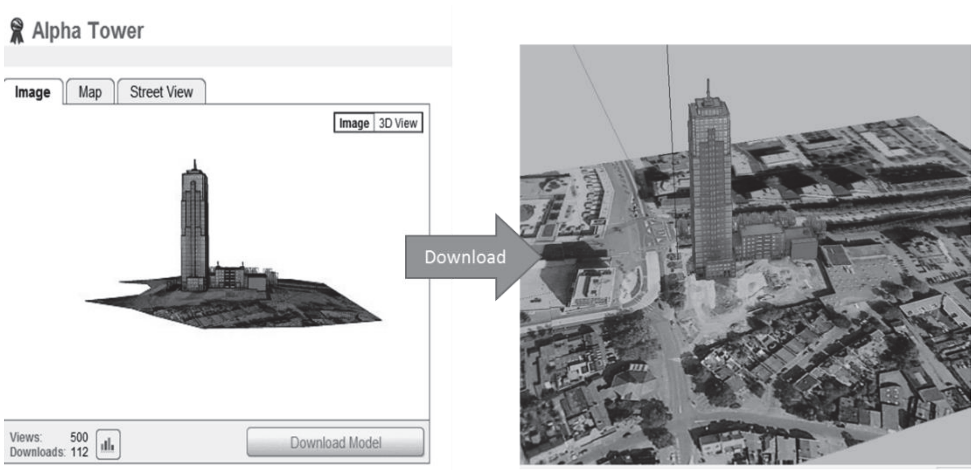


Figure 6-3 User interface of Indoor AR

6.3. Data preparation

6.3.1. 3D building models

3D model of building exterior, interior and frame were made using 3D design software, SketchUp (www.sketchup.com). In order to visualize 3D building exterior that has accurate scale, some buildings were extracted from the warehouse of Google Earth (Figure 6-4). Since SketchUp has linkage of 3D warehouse, the model can be directly downloaded into SketchUp.



(a) 3D warehouse of Google Earth (b) Direct import from the warehouse into SketchUp

Figure 6-4 Example of 3D warehouse of Google earth

In order to match a 3D building with a real building correctly, the building should have geographical information that includes geographical coordinate, scale and rotation. In addition, 3D building should be converted to suitable 3D data format that is required by AR platform. This study used OBJ format since it is open format and the most widely used 3D format, and it is also supported by AR platform, Metaio. Data conversion was performed using default function of SketchUp that converts skp (SketchUp format) to OBJ file. Figure 6-5 shows flow of 3D building generation.

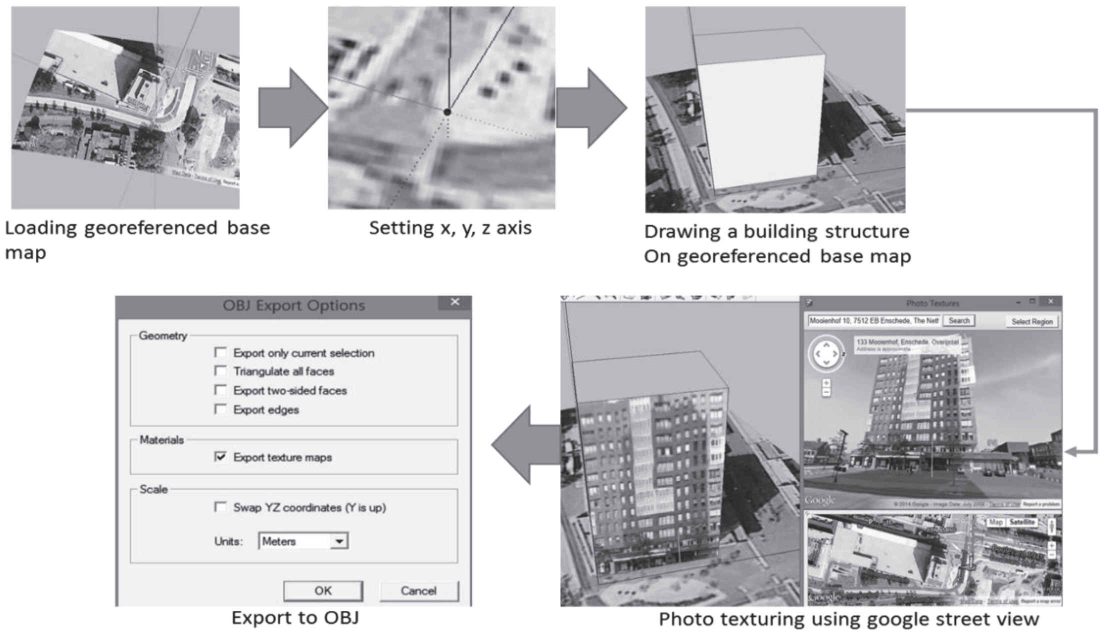


Figure 6-5 Flow of 3D building generation

6.3.2. Building attribute

Standalone AR uses embedded database to store building attributes. According to essential information defined in table 4-2 of chapter 4, following data can be store in database (Table 6-4). Since the prototype displays only a few information, the prototype didn't use a database.

Table 6-4 Database scheme of building information

Table name:	Building_info	
Field name	Type (length)	Example
Bld_name	String (50)	City hall
Bld_class	String (50)	Concrete frame
Bld_material	String (20)	Concrete
Bld_purpose	String (20)	Government
Bld_height	Integer	30 (unit: meter)
Bld_story	Integer	5
Bld_address	String (100)	7511, Enschede, Netherland

6.3.3. Multimedia dataset

For visualization of multimedia dataset, the prototype used video clips that were downloaded from YouTube. Then downloaded file was converted to 3g2 format that is a required format by AR platform. File conversion was conducted using conversion tool "FFmpeg" (www.ffmpeg.org). In order to convert MP4 to 3g2, following command was run with FFmpeg in a command line mode of windows.

```
ffmpeg.exe –i Ens3.mp4 –r 20 –vcodec mpeg4 –vb 215000 –s qcif –acodec aac –
strict experimental –ab 48000 –ar 22050 output.3g2
```

<Options>
-i : iniput file / -r : frame rate /- vcodec: video codec /-s: size of image /-acodec: audio codec/-strict: external codec /-ab: audio bitrate/ -ar: audio sampling rate

6.4. Develop environmet and implementation

6.4.1. Software and hardware

The prototype was developed based on android platform using following APIs, software and hardware.

Table 6-5 Software and hardware specification of the prototype

PC (development environment)		
OS	Windows 8.1	RAM: 8GB
Programming language	Java	
IDE (Integrated development environment)	Eclipse with android SDK	
AR API	Metaio SDK V5.2	
Map API	Google Map android V2	
3D generation	SketchUp V8	
Mobile device		
Android device	Galaxy S4	RAM: 2GB
Android OS	4.3 (Jellybean)	

6.5. Implementation

6.5.1. Indoor (marker-based) AR

In order to implement Indoor AR, following four factors should be defined: marker image, 3D object's rotation, scale and translation. Indoor AR uses markers such as image and fiducial marker to recognize plane of AR visualization. Figure 6-6 shows 3D objects that are displayed onto a marker image. The marker image is pre-defined as setting file path of the image in the configuration of AR. Then 3D object's rotation, scale and translation should be defined. The translation moves object from origin (0, 0, 0) that is centre of marker image. Rotation can be defined for each axis of x, y and z in unit of degree. Lastly, the scale is set using float number (1.0: original scale, less than 0: smaller than original scale, larger than 1: larger than original scale).

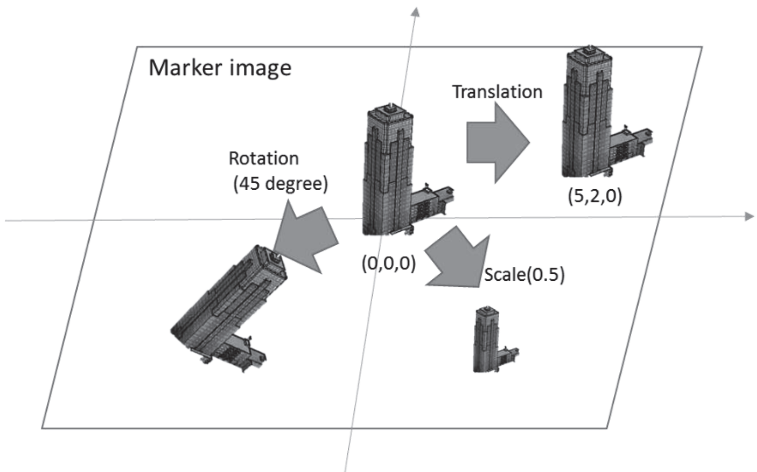


Figure 6-6 Conception of Indoor (marker-based) AR implementation

6.5.2. Outdoor (sensor-based) AR

Outdoor AR uses GPS to get user's current location (coordinates) and gyro sensor (yaw, pitch, roll) to get direction of mobile device. Figure 6-7 shows relationships between device pose, 3D object and camera image. After identifying user's location and direction, the AR system calculates distance from user's location to object's location. Then it uses yaw of gyro sensor and magnetic sensor to find out direction of mobile device (Figure 6-7). In addition, Indoor AR uses relative translation which is from origin of maker image, while Outdoor AR uses absolute translate which is based on geographical coordinates (latitude, longitude, altitude). Therefore, geographical coordinates should be defined for 3D objects in Outdoor AR.

In order to display map around user and building's location, the prototype used Google Map android API V2. And geocoding function of the Map API used to extract address of user's current location. The geocoding gets coordinates as an input parameter, and its output is string of the address that includes street name and street number. To check user's approach to a hazard zone, the program check user's current location and distance (100 meter) to pre-defined coordinates of a chemical plant whenever user's location is changed.

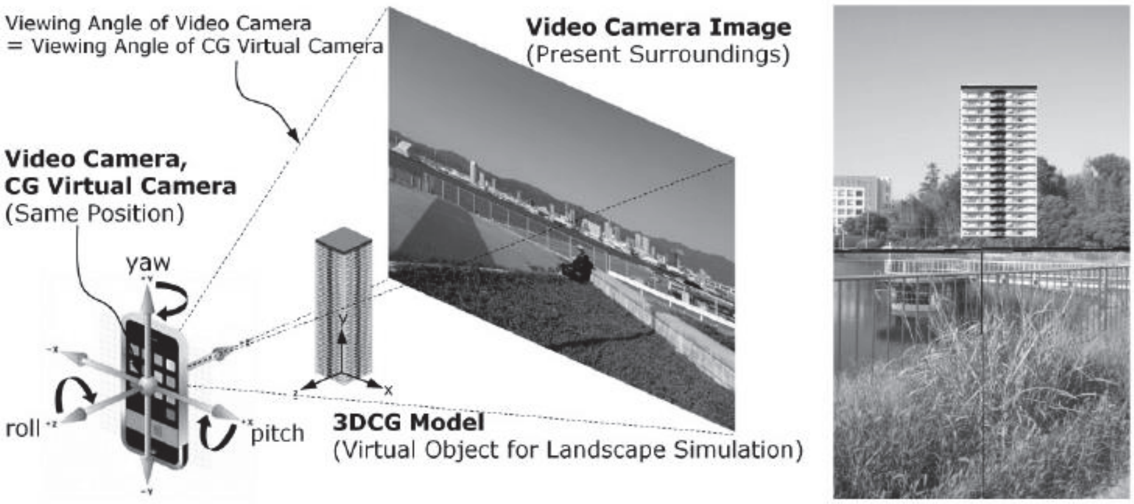


Figure 6-7 Conception of Outdoor (sensor-based) AR implementation

(Fukuda, Zhang, & Yabuki, 2012)

6.6. Analysis

6.6.1. Functional evaluation

In order to evaluate functional operation of Indoor AR, three 3D buildings and one video clip were prepared. For the marker image, satellite image of city Enschede in Netherlands was used. Table 6-6 shows functional test items and its result (recorded video clip that shows test operation and test result can be watched through following link and QR code: http://youtu.be/eADg2Up0weg). Figure 6-8 shows screenshot of Indoor AR.

Table 6-6 Functional test items of Indoor AR

Test items	Test result
Does AR display every dataset?	Yes
Does touch handling (zoom-in/out, rotation) for each dataset works?	Yes
Does video clip show sequential imagery (animated)?	Yes
When a building is touched, does it show building information?	Yes

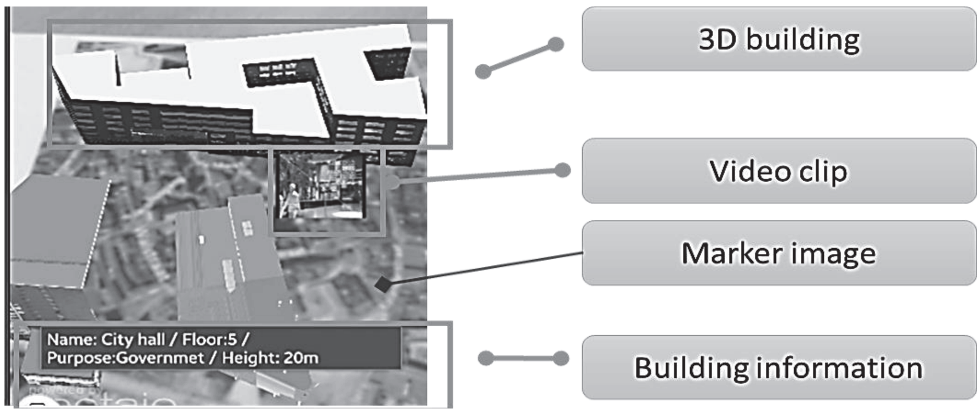


Figure 6-8 Screenshot of the prototype (Indoor AR)

In order to evaluate functional operation of Outdoor AR, following datasets located on Enschede, Netherlands were used: one building exteriors (extracted from Google Earth), two building frames (generated by author) , one video clip, one building interior, one building information and one location of chemical plant. To check Radar function that shows locations of essential facilities, location of building inside model was defined as a hospital. Locations of each data are marked on the map in Figure 6-9.

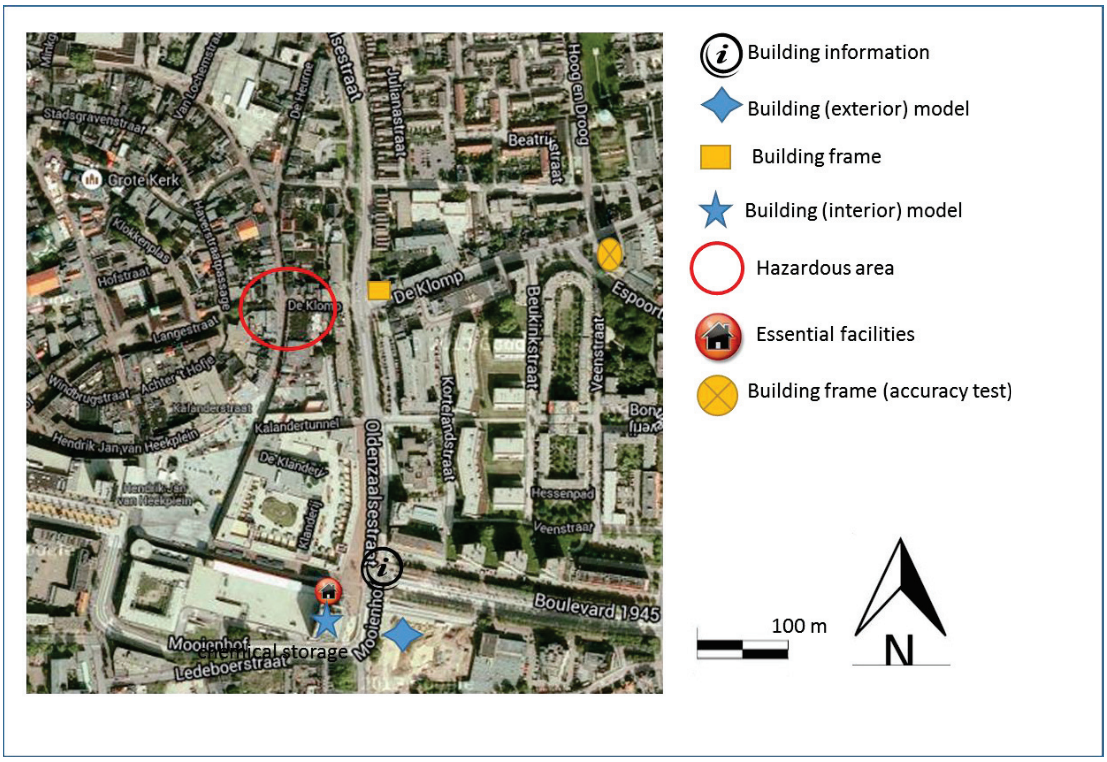


Figure 6-9 Test area and locations of test dataset (City centre of Enschede, Netherlands)

Table 6-7 shows functional test items of Outdoor AR and its result (Recorded video clip that shows test operation and test result can be watched through following link and QR code: http://youtu.be/0tCzXaGMx4Y).

Table 6-7 Functional test items of Outdoor AR

No.	Test items	Test result
1	Does AR display every dataset?	Yes
2	Does touch handling (zoom-in/out, rotation) for each dataset works?	Yes
3	Does video clip show sequential imagery (animated)?	Yes
4	When “Map” button is touched, does map display around user’s current location?	Yes
5	When a building is touched, does map display its location with a marker?	Yes
6	After map displayed the location of touched building with a marker, does the marker display address of the selected building on the map?	Yes
7	Does Radar display essential facilities with a marker of blue star and other reference dataset with a marker of yellow circle?	Yes
8	When “Reset” button is touched, does it recover original state of 3D model?	Yes

9	When a building is touched, does it display a distance and direction between selected building and user's current location?	Yes
10	When "On/Off/ button is touched, does selected model change its status of visibility?	Yes
11	When user is within 100 m from a pre-defined chemical facility, does map display user's current location with hazardous zone?	Yes
12	When user gets out of the hazardous zone, does it display current address instead of warning message?	Yes

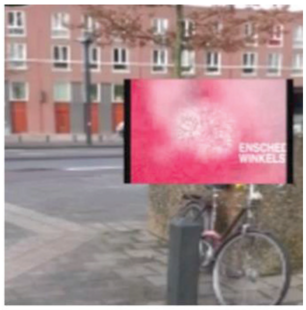
Table 6-8 shows screenshots of the test results. Screenshot of some test items such as No. 2, 3, 8 and 10 were not taken since those tests requires continuous change of data or function like touch handling.

Table 6-8 Screenshots of Outdoor AR test results

<table>
<tr><th>No.</th><th>Screenshots</th></tr>
<tr><td>1</td><td>Display every dataset

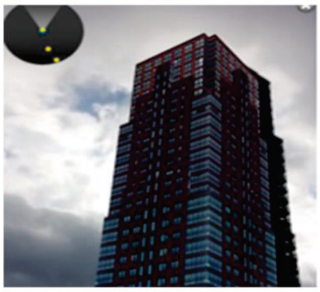
<Building frame>

<Building information>

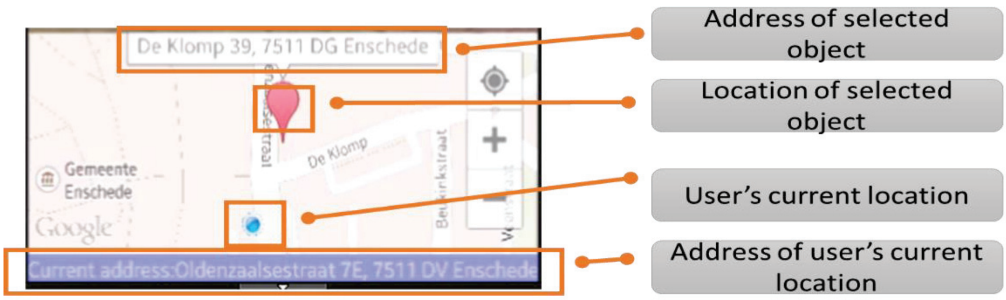


<Video clip>

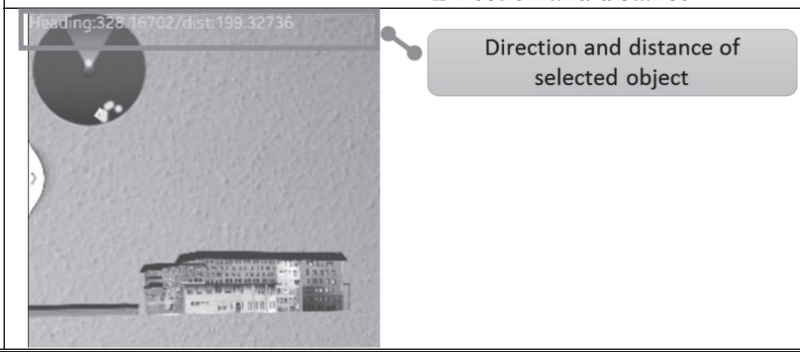
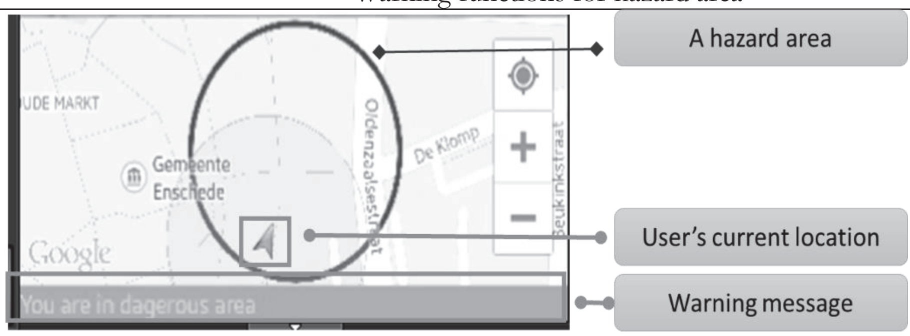
<Building interior>



<Building exterior>
</td></tr>
<tr><td>2</td><td>Touch control (zoom in/out, rotation) : Screenshot is not possible</td></tr>
<tr><td>3</td><td>Video clip play: Screenshot is not possible</td></tr>
<tr><td>4~6</td><td>Map display (location and address)



</td></tr>
<tr><td>7</td><td>Radar display essential facility (hospital)</td></tr>
</table>

	
8	Reset button: Screenshot is not possible
9	Direction and distance
	
10	Visible/Invisible button: Screenshot is not possible
11~12	Warning functions for hazard area
	

6.6.2. Potential problem

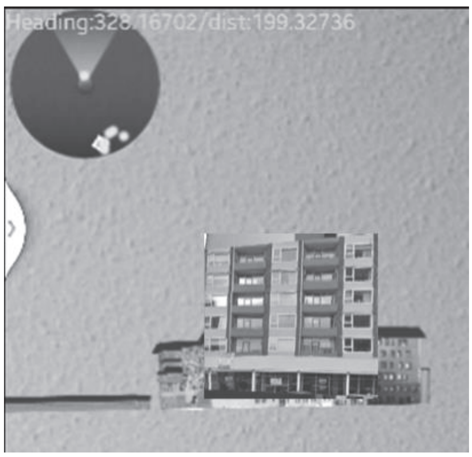


Figure 6-10 Example of data overlap

During the test, following two factors were identified as a potential problem: data overlap and accuracy of registration. For instance, two different 3D buildings could be located on same direction but different distance from user perspective, so that the building located in front of the other building can block as shown in Figure 6-10. This is the problem caused by data overlap. To avoid this problem, following two approaches can be provided as user interfaces: display radius setting and visible/invisible setting. Display radius setting allows user to adjust maximum distance of object that needs to be displayed. For instance, if user set display radius as 1 km, user only can see objects that are within 1 km from user's current location. This function can eliminate unnecessary information, and reduce data overlap problem. Furthermore, it can improve system's performance by limiting the number of object that are displayed at a time.

Second problem is about data registration. Since Outdoor AR uses several sensors to get user's location and pose of the device, its registration accuracy can cause confusion of user to match a virtual object with a real object especially when virtual objects are located closely to each other. To solve this problem, following functional approach can be applied.

1. User touches the virtual object to find out which real building is matched with the selected object.
2. Map is opened in separate window.
3. Location of selected object is marked on the map.
4. User can identify visually which real building is related to the selected virtual object

No 4~6 of functional test described before are related to this approach.

6.6.3. Evaluation of registration accuracy

In order to evaluate registration accuracy between a real and virtual building, screenshots were taken from different distances (100m, 150m and 200m) and different angles (standard degree, +5 degree and +10 degree) (Figure 6-11). To find out how much compass sensor affects accuracy of data registration, different angles from magnetic north were set for the experiment. The standard angle was decided with the angle that is the most accurately matched from the distance. Then +5 and +10 degree from standard angle at each distances were tested.

For the test, 17 floors building of Enschede, Netherland was selected with 3D building generation ('X' mark in the map of Figure 6-9). The 3D building was generated using SketchUp with georeference mode. Although SketchUp gives a model geographical coordinates for horizontal location (latitude, longitude), it does not support vertical location (altitude). Accordingly, height of 3D building was set with an approximate value (17 floors x 2.5 meter = 43 meter). Because of flatness of the area and inaccurate height of the 3D building, only horizontal displacement between a real and virtual building was evaluated.

The horizontal displacement was measured based on variation of building edge ("A" in Figure 6-11). After measuring pixel numbers between virtual edge "A" and real edge of the building, the number of pixel was converted to real distance that was calculated with following formula for each distance:
Distance per pixel =
Real length of building width ("B", 10.2m) / number of pixel.

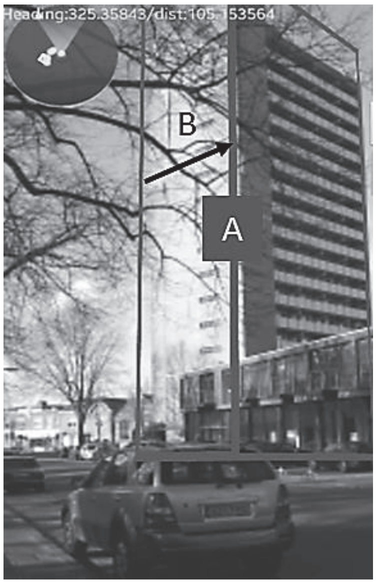


Figure 6-11 Measuring horizontal displacement

Table 6-9 shows the result of test. Overall horizontal accuracy is 1 to 4 meter on standard angle. The accuracy becomes lower when user moves away from the building, and when the angle (based on magnetic north) increases. The result shows that accuracy of compass sensors affects the registration accuracy. When the angle gets larger, the displacement error increase, and the degree of the displacement error caused by the angle gets larger as user becomes more distant from the building. However, maximum displacement error is 7 meters from 200 m distance which is still in tolerance level. The screenshot of the case (200m, +10 degree) in Figure 6-12 shows that user still can identify matched real building with virtual building and its overall shape and status.

Table 6-9 Evaluation result of registration accuracy

Distance from real building	The number of pixel (between real and virtual object)			Distance per pixel	Displacement distance between real and virtual building		
	Standard degree	+5 degree	+10 degree		Standard degree	+5 degree	+10 degree
100 m	4.47	6.71	12.65	0.23 m	1.04 m	1.56 m	2.94 m
150 m	7.8	8.76	8.5	0.45 m	3.54 m	3.98 m	3.86 m
200 m	4.47	6.71	8.6	0.81 m	3.64 m	5.46 m	7.01 m

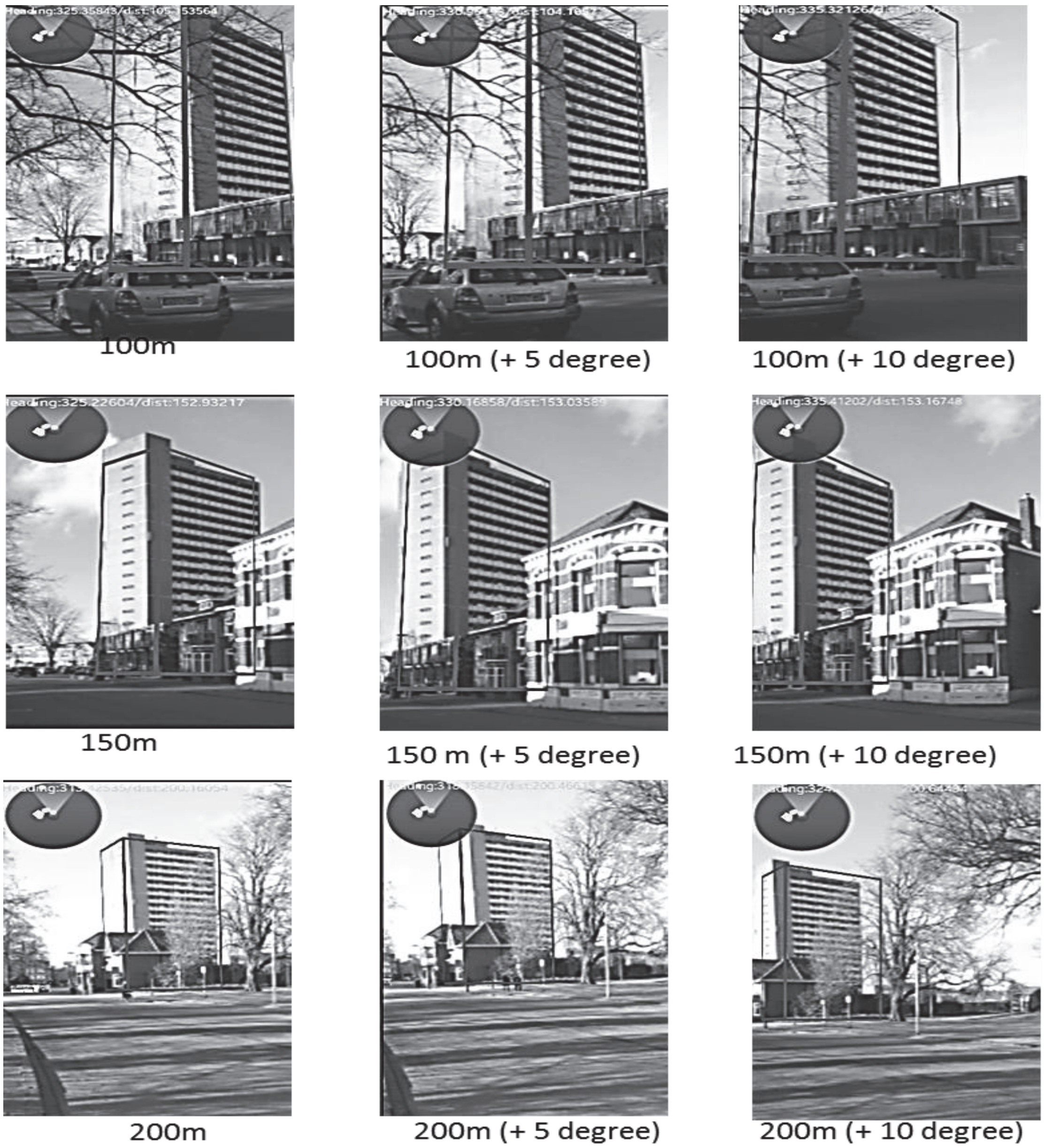


Figure 6-12 Screenshots for the test of registration accuracy

6.6.4. User evaluation

In order to evaluate how much mobile AR can contribute building damage and safety assessment in a disaster situation, online questionnaire form was distributed to the several associations of structural engineer and online communities of structural engineer and first responders. The questionnaire consisted of six parts: (1) demonstration of Indoor and Outdoor AR for each concept (online video clips were used) (2) questions about experience of building damage (safety) assessment, (3) efficiency of mobile AR, (4) locational awareness, (5) usability and functionality and (6) essential information. In order to get correct response, video clips of demonstrating Indoor AR and Outdoor AR were shown first. The questionnaire form is attached in appendix 2.

Altogether 39 responses were collected, 5 responses were excluded since they did not have any experience of building damage assessment. Although 34 responses are not enough for statistical analysis, they are meaningful as real user's feedbacks. Because all the response were from real users who have experience of building damage assessment. Moreover, 24 (70%) out of 34 responses were from structural engineers who had more than 5 years' experience of building damage and safety assessment (Figure 6-14). Most of responders were structural engineers (91%), rest of responders (9%) were post-graduate students and building manager. 8 (24%) responses showed they had experience of mobile AR. Table 6-10 shows the result of online survey.

Table 6-10 The result of survey (statistic result). Means (M), Medians (Md), Standard deviations (Std)

N=34	Questionnaire	Scale	M	Std	Md
Efficiency of mobile AR	How much do you think Indoor AR can improve familiarity with the disaster area?	1-5	3.1	1.1	3
	How much do you think mobile AR can reduce assessment time compared to traditional method of building damage assessment?	%	24.5	15.4	20
	How much do you think mobile AR can improve assessment accuracy (objectiveness) compared to traditional method of building damage assessment?	%	23.9	13.7	20
Locational awareness	If you can identify the current street name of your position in disaster area, do you think it can improve your locational awareness?	%	35.7	13.8	35
	If you know the location of target building in the disaster situation, do you think it can improve your locational awareness?	%	32.7	13.1	40
Usability and functionality of mobile AR	How much do you think touch handling of mobile device can improve operation performance in the field?	%	34.4	13.2	35
	Do you think mobile AR can be practical tool for building damage assessment in real disaster situation?	1-5	3.6	1.7	4

Efficiency of mobile AR

To ask how much Indoor AR can improve familiarity with the disaster area, scale 1 to 5 was used. 5 was best value. The result shows that Indoor AR's contribution for understanding the disaster area is not significant (3.1). Users responded that mobile AR can reduce assessment time about 25 % more than traditional method which relies on only user's knowledge without any support of mobile system. Users also think mobile AR can improve assessment accuracy (or objectiveness) about 24 % more than traditional method. The graphs of Figure 6-13, 6-15, and 6-16 show overall means and means of each experience level of building damage assessment.

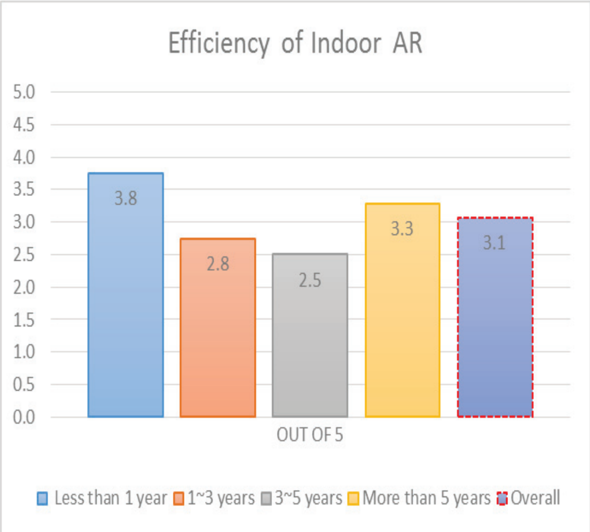


Figure 6-13 How much Indoor AR can improve familiarity with the disaster area? (Out of 5)

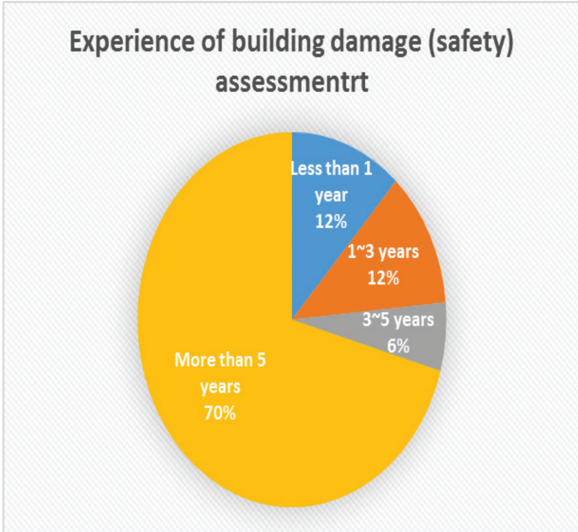


Figure 6-14 Building damage assessment experience of the responders

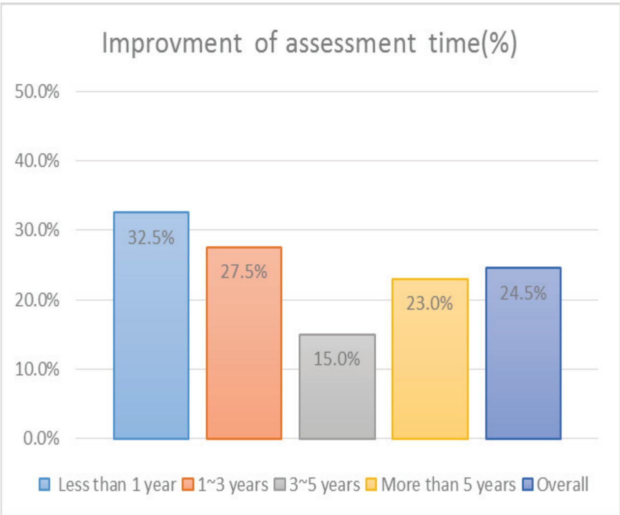


Figure 6-16 How much AR can reduce assessment time compared to traditional method? (%)

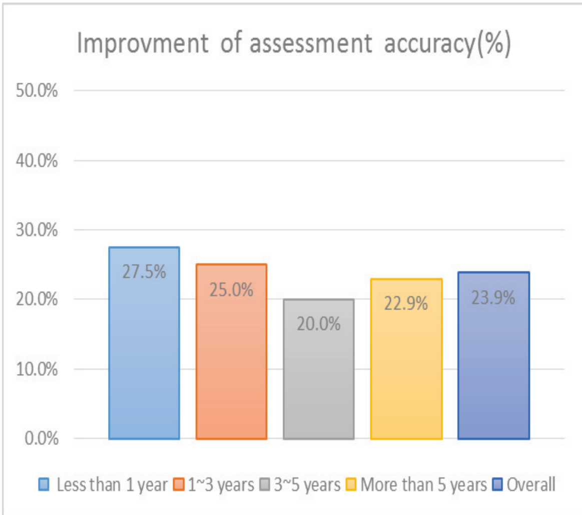


Figure 6-15 How much AR can improve assessment accuracy (objectiveness) compared to traditional method? (%)

Locational awareness

The result of survey about location awareness shows that providing map and street name of user's current location significantly improve user's locational awareness up to 36%. In addition, it suggests that the Radar function can also improve user's locational awareness to find target buildings up to 33%. This is because most of the user are dispatched to an unfamiliar area in a disaster situation. Moreover, if the area is severely damaged, it is not possible to identify user's current location. The graphs of Figure 6-17 and 6-18 show overall means and means of each experience level of building damage assessment.

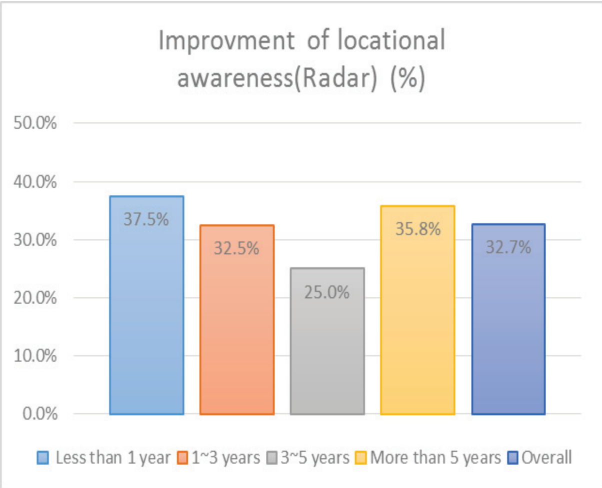


Figure 6-17 How much Radar function can improve your locational awareness in a disaster situation? (%)

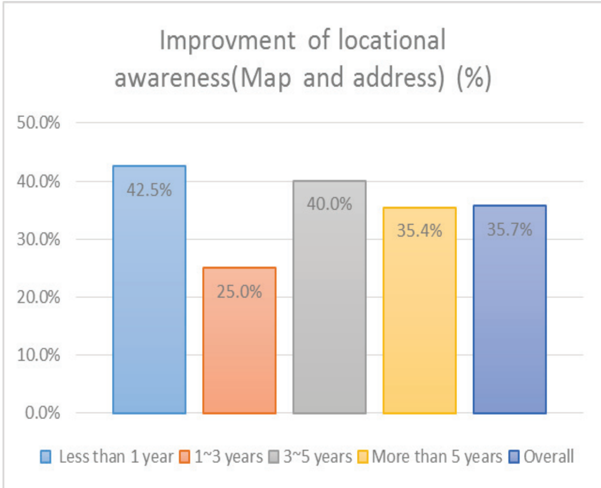


Figure 6-18 If user can identify the current street name of your position in disaster area, do you think it can improve your locational awareness? (%)

Usability and functionality

The result of survey about usability and functionality shows that touch interaction can considerably improve operation performance up to 34 %, which is big advantage of using mobile device. Practicality of mobile AR in real situation was scored 3.6 (mean) and 4 (median) point out of 5. The graphs of Figure 6-19 and 6-20 show overall means and means of each experience level of building damage assessment.

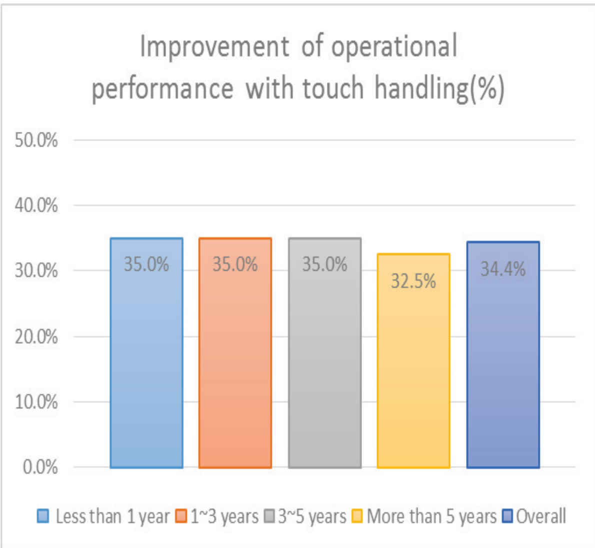


Figure 6-20 How much touch handling of mobile device can improve operation performance in the field?

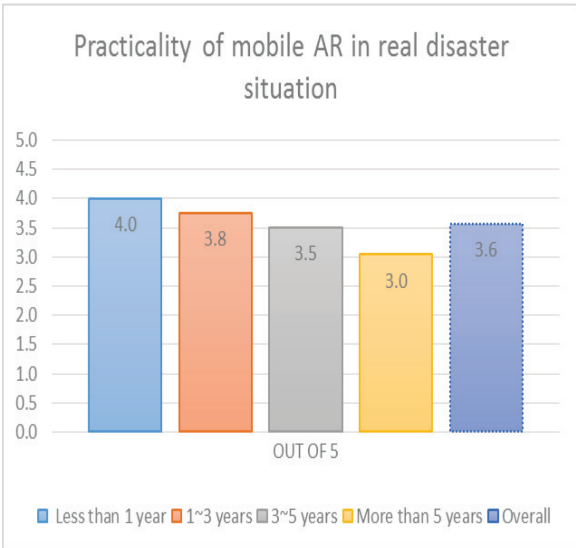


Figure 6-19 Is mobile AR practical in a real disaster situation?

Essential information

In order to ask level of importance for each reference data, the survey showed simple illustrations of each concept which cover building information, street level imagery, 3D building exterior, 3D building interior, 3D building frame and automatic change detection in order of complexity. Then the survey asked user to mark from 1 (not necessary) to 5 (very important). Table 6-11 shows the result of survey about essential information.

Table 6-11 The result of survey (Essential information). Means (M), Medians (Md), Standard deviations (Std)

N=34		M	Std	Md
Essential information (Level of importance) Scale 1 to 5 1: not necessary 5: very important	3D building frame	4.2	1.1	5
	Building information (Building classification, material, number of floor etc.)	4.1	1.2	5
	Street level imagery	4.1	1.2	4.5
	3D building exterior	3.7	1.1	4
	3D building interior	3.7	1.3	4
	Automatic change detection (volume reduction, height reduction)	3.5	1.3	3
	Building-related multimedia data (video clip, photo)	3.1	1.3	3

The result shows that users think the most important reference data is 3D building frame (4.2) followed by building information (4.1). It also indicates that there is strong needs for street level imagery (4.1). On the other hands, necessities of automatic change detection (3.5) and multimedia data (3.1) are lower than the other one. However the score of those data still shows they are necessary data for building damage assessment. The graph of Figure 6-21 shows the mean score of each reference data.

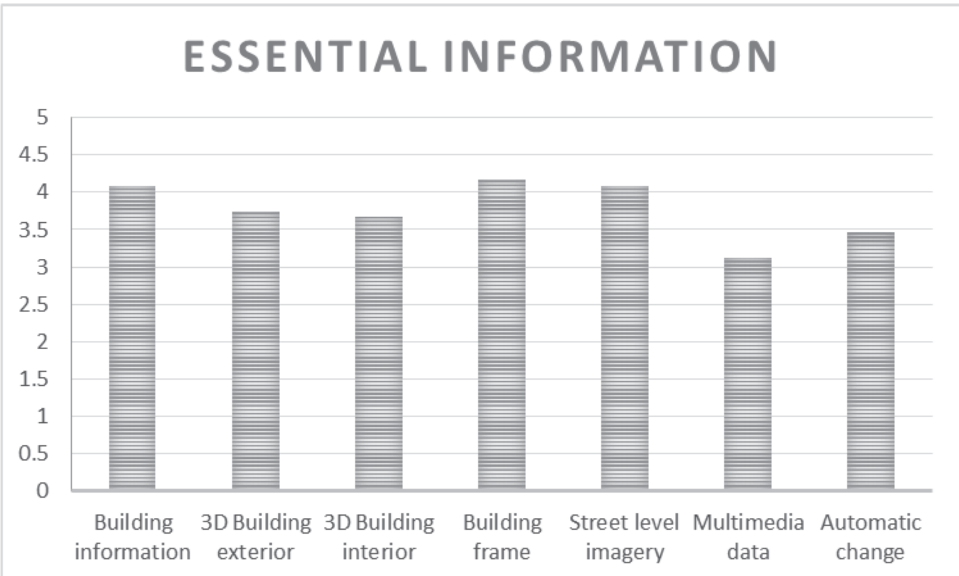


Figure 6-21 Level of importance for each reference data (out of 5)

6.6.5. Summary

In this chapter, system architecture for standalone AR and network-based AR was designed. Then, user interfaces and functions for both Indoor AR and Outdoor AR were defined based on user requirement analysis that was conducted in Section 4.2. With the design of system architecture and user interface, two prototypes (Indoor AR and Outdoor AR) were developed based on android platform. In order to evaluate the prototype, functional evaluation, registration accuracy test and user evaluation were carried out. The result of functional test showed every functions were working correctly according to the system design. The result of user evaluation showed mobile AR can improve limitations of current building damage and safety assessment.

7. CONCLUSION AND RECOMMENDATION

7.1. Review of research objectives and questions.

General objective of this study is to improve efficiency and safety of ground-based building damage and safety assessment in a disaster situation with mobile AR. To achieve the objective, firstly, the procedure and main obstacles of ground-based building damage and safety assessment were identified based on literature review. With the identified limitation of ground-based assessment, mission-critical information and functions that need to be delivered through mobile AR were defined. Then various concept of mobile AR for building damage and safety assessment were defined which comprised of following elements: procedure, data process, AR process and assessment method. Based on this concept, prototype of Indoor (marker-based) AR and Outdoor (sensor-based) AR were developed. The prototype were evaluated with respected to functional test, accuracy test and user evaluation. The answers of the research questions are summarized as follow:

1. How does user perform building damage and safety assessment in the field?

The procedure is various since each country has its own policy and rule for the assessment. However, they commonly have following structure of the ground-based assessment: pre-evaluation, rapid evaluation and detailed evaluation. Pre-evaluation is to gather relevant information and define evaluation method in the field. Then rapid evaluation is conducted by structural engineer, architect and fire fighter. The rapid evaluation mainly focuses on assessment of building exterior, and it only takes around 10 minutes per building. The result of rapid evaluation classifies building safety into three groups: safety, unsafety and limited use. If a building is classified to limited uses, it requires detailed evaluation. It is worthwhile to note that safety assessment is followed by damage assessment. With the result of damage assessment, final decision of building safety is made. This means damage and safety assessment is strongly correlated. Yet, in other cases, the building safety is affected by external parameters not by its own damage. For instance, the collapse of neighbouring buildings can affect the safety of the other buildings. Details are given in section 2.2.

2. What are the main obstacles of the damage and safety assessment in situ?

The main obstacles can be categorized as following: lack of data organization, safety issue, limitation of pre-disaster reference data, lack of familiarity with the disaster area, needs for value-added information, needs for rapid assessment and lack of locational (situational) awareness. Details are given in section 4.2.

3. Which information is valued-added information for the assessment in situ?

The value-added information, mostly provides pre-disaster status, can be categorized as following: building attribute (building classification, date of construction, material, purpose, building height, building story, address), Street level imagery, area-related video clip and photo, 3D building geometry (interior, exterior, frame), , hazardous material (location of nuclear facilities, LPG facilities, chemical storage), essential facilities (hospital, fire station, police station and shelter), Street address (roads map) and landuse (landuse map). According to user feedback of the prototype, the most important data is 3D building frame (4.2 point out of 5) followed by building attribute (4.1 point out of 5) and street level imagery (4.1 point out of 5). Details are given section 4.3 and 6.6.

4. Which functions of AR are required in a disaster situation?

Following functions are defined after user requirement analysis: AR visualization of essential information, map display, address of user's current location, Radar interface that shows location of essential facilities, 3D model handling (rotation, zoom-in/out with touch gesture), reset of 3D model, mapping building location and address, distance and direction of selected object, warning for a hazard area and data on/off. Details are given in section 6.2.

5. How can AR get those information and deliver to user efficiently?

In this study, two types of system architect were proposed according to availability of network connection. External sources that require network connection (e.g. street level imagery) can be obtained and delivered to user directly using API that is provided by service provider. Internal sources that are directly stored in the device can be obtained from various source. Building information can be extracted from cadastral database of local government or emergency response organization. 3D building can be extracted from 3D warehouse of Google earth, or it can be generated from LiDAR, 2D building footprint and sequential images. Offline map of world (e.g. OpenStreetMap) can be easily obtained and stored in the device. Details are given in section 4.3, 4.4 and 5.3.

6. What is the systematic process of AR approach for building damage and safety assessment?

In order to define systematic process of AR approach, six concepts of AR were defined in order of Level of Complexity (LOC): building existence (LOC1), building information (LOC2), building-linked information (LOC3), building geometry (LOC4), change detection (LOC5) and progress of change (LOC6). For each concept, data source, data process, AR process and damage assessment method were defined. Details are given in chapter 5.

7. Does Mobile AR provide usability and functionality that can improve assessment in a disaster situation?

Yes, users who have experience of building damage and safety assessment in the field (70% of them have more than 5 years of experience) answered mobile AR can improve touch handling of mobile device can improve operational performance up to 34%. In addition, they answered practicality of mobile AR in a real disaster situation is 3.6 point out of 5. Details are given in section 6.6.4.

8. How much mobile AR can improve current limitations of ground-based building assessment?

According to user feedback for the prototype, mobile AR can reduce assessment time up to 25%, and can improve assessment accuracy (objectiveness) up to 24%. In addition, Radar and map functions that indicate user's current location, street name and location of target building can improve locational (situational) awareness up to 33% (Radar) and 36% (Map) respectively. Details are given in section 6.6.4.

7.2. Discussion and conclusion

Rapid damage and safety assessment needs to be conducted right after natural disaster occurred. However, current procedure of building assessment still relies on human interpretation which is subjective and time-consuming. The problem mainly comes from lack of reference data in the field. This study proposed mobile AR that delivers various reference data, and superimposes those data directly on real object using mobile device. The result of this study showed following possibility and limitations of mobile AR:

Usability

Current mobile device uses touch screen which lets user manipulates something on the screen interactively with simple touch gesture (e.g. zoom-in/out or rotation of 3D building). The result showed this interaction can improve operational performance in a disaster situation. In addition to touch handling, current mobile device is adopting voice recognition function that can orally manipulate mobile device. Although accuracy of voice recognition is still on verification stage, it has been improved rapidly with improvement of mobile device and wearable PC like Google glass. Thus, voice recognition is also expected to increase usability in a disaster situation. For instance, user might rotate 3D object just by orally ordering "rotate building A to 30 degree".

Efficiency of mobile AR

The result showed that mobile AR can improve the assessment accuracy (objectiveness), also can reduce the assessment time. In addition, its functionality and practicality was demonstrated. Although the results shows positive possibility of mobile AR, following factors need to be considered carefully. First, the result is based on online survey, so that there might be scientific gap between online survey and real user test. If user could get a chance to manipulate the prototype directly, it would lead to different result. Secondly, there is no standard for accuracy and speed of the building assessment. Although the survey asked user how much mobile AR can improve current limitations compared to traditional method, standard accuracy and speed of tradition method itself have variation with respect to individual knowledge and procedure of the assessment that vary according to policy of each country. Thirdly, Indoor AR did not get the expected positive feedback (3.1 out of 5). This is because most tasks are conducted in the field not in the office for the building assessment. Indoor AR might be a solution for the one who manages overall disaster situation. Lastly, level of efficiency of mobile that is variable depending on level of the assessment experience. However, the results do not show enough trends of difference according to different level of experience. This is because the number of sample is small (Overall 34 responses) and most of sample is in experience level of "more than 5 years" (24 responses).

Essential information

This study pre-defined essential information for the building assessment in a disaster situation in section 4.3. Then priority of each information was also defined by author. Interestingly, the priority defined by author and the result of user evaluation show different preference. User evaluation showed that the most important data is building frame followed by building attribute and street level imagery in order. On the other hand, pre-defined list in this study showed that the most important is building attribute followed by building frame, hazardous material and building interior in order. In pre-defined list, street level imagery was given lower priority since the information requires internet connection which is not guaranteed in a disaster situation. This gap is firstly caused by small population of the survey. Secondly, because of shortage of online survey, user only measured practical level of the information without considering external factors while pre-defined list considered factors of safety and availability of network connection. Although there is internet connection problem in a real disaster situation, it is worthwhile to notice that there is strong needs of street level imagery.

Locational (situational) awareness

The user evaluation showed interesting result about location (situational) awareness. The result indicates user want geographic information that can identify user's current location and locations of targets. In addition, it also implies that mobile AR create a more synergy when it is combined with map system (Geographic Information System). The reason user has need of map with locational information is that location awareness decreases especially in a severely damaged area. Furthermore, user is usually dispatched to unfamiliar place with short notice which cause decrease of locational and situational awareness. Accordingly, it is important for user to identify where user is located currently and where the target is located. And this can be done providing GIS. Both platforms (AR and GIS) can be adopted in mobile device, so that it is worthwhile to combines these system to create value for user.

Performance of mobile device

Since mobile AR handles multiple 3D data, it requires comparatively high performance of the device. The more 3D objects are displayed, the more performance of mobile device is required. One of user opinion appealed that mobile AR should be fast and responsive. Thus, it is important to control performance with given resources. The performance can be tuned using following two factors: user interface and data generation. In terms of user interface, display radius and layer concept can be utilized. The display radius sets the maximum distance of object that is display on current screen. Display radius can be adopted programmatically in the code, and it can be provided as a user interface as well that user can adjust freely. Layer concept is also important which controls data group that is displayed on screen at once. As user select data that user is interested, the system can prevent display lag. The other approach is to tune data itself. Since a file size of 3D data is larger than usual 2D data, it is important to adjust file size of 3D data. The file size of 3D data depends on a number of polygons (faces) and texture file (image file). Therefore, to reduce file size, 3D data needs to be generated using less faces and low resolution of texture image. However, the number of faces and resolution of texture file can affect quality of 3D model. Therefore it is necessary to find out appropriate parameters to adjust between quality and performance. It is also worthwhile to mention that performance of mobile device has been improved quickly, so that the limitation of performance is expected to be settled in a near future.

Accuracy of data registration

Registration accuracy test showed sensor-based mobile AR had displacement error (1 to 7 meters) between a real and virtual building. The registration accuracy increased along with the increase of distance between user and the target building. Although the result indicates mobile AR has the registration error, the error needs to be considered carefully in terms of level of tolerance for each Level of Complexity (LOC). For LOC1 (building existence), LOC2 (building attribute), and LOC3 (linked building attribute), the data is based on one point (location). Hence, if the data is within boundary of the building, it is still interpretable. For building exterior and interior of LOC4 (build geometry), if user can match a real and virtual building visually, it is still interpretable. In order to improve visual match, this study proposed the method of user manipulation which lets user select a virtual building, then 2D map shows its location. For building frame of LOC4, the displacement distance needs to be within tolerance that user can find correspondent frame (edge) and corner (point). In case of simple structure of building like the data used in the test, even maximum error (7 meters) allows user to find correspondent frame. Unlike other concepts, LOC5 and LOC6 are for the quantitative analysis, so that they require accuracy less than a meter.

7.3. Reommendations for future work

It is meaningful to recap negative user feedback which is very valuable for the future research. Table 7-1 is categorizing user feedback into five groups: accuracy of reference data, generating database, cost effectiveness, network connection, privacy issue and interruption of visual interpretation. Specific consideration for each problem is described below.

- Accuracy of reference data and generation database
  Most of user concerns are about data and database. Overall database structure for mobile AR of building damage assessment needs to be defined. In addition, the method of acquiring data accuracy should be clarified.

Table 7-1 Recap of user feedback

Classification	User feedback
Accuracy of reference data	• "If that data is virtual that is helpful but only if it is very accurate"
Cost effectiveness	• "Good idea but municipalities typically do damage assessment so it would need to be very cost effective (almost free) or no one would pay for it."
Network connection	• "The mobile connections may be inoperable or jambed"
Privacy issue	• "The building owners will not allow to collect such data."
Interruption of visual interpretation	• "However it takes a real look at the structure that staring at a screen may actually hinder."

- Cost effectiveness
  Although smartphone itself can reduce the cost of hardware, cost and period to build database need to be quantitatively calculated. In addition, the method of reducing cost and period also need to be researched.

- Network connection
  Although this study proposed two system architects for network-connected situation and non-network-connected situation, the future research needs to consider utilization of recent network technology such as mobile ad-hoc that can be constructed in a disaster situation.

- Privacy issue
  Data sharing in a disaster situation is strongly related to the privacy issue. Therefore, data obtaining and sharing of each reference should be considered again in terms of privacy issue.

- Interruption of visual interpretation
  There are some opinions that screen of mobile device itself can be hindrance. Therefore, instead of video see-through AR, possibility of optical see-through AR like Google glass needs to be researched.

In addition to user feedback, following aspects area also recommended for the future research:

- Vision-based (Hybrid) AR
  This study used sensor-based AR for outdoor environment. However it has many limitations in terms of data registration accuracy which is not enough for change detection and 4D concept. Since vision-based (Hybrid) AR has more accuracy than sensor-based AR, it can reduce the limitations that come from low accuracy of sensor-based AR. In addition, vision-based AR allows AR to generate new information from real object such as change detection and 4D (time) change.

- AR-based change detection
  In this study, AR-based change detection is just briefly mentioned because of limited time period. With vision-based AR, AR-based change detection can provide various quantitative information such as volume change, height change and inclination. The technological advancements of 3D reconstruction provides more convenience approaches than traditional method. For instance, nowadays, smartphone-based 3D scanner is on market like "Spike" (http://www.ikegps.com/spike). This small hardware

enhancement smartphone function to directly generate 3D model from live images of smartphone camera.

- Expansion of AR concept
  The concept of mobile AR for building damage and safety assessment can be expanded with various reference and method of data registration. For instance, not only street level imagery but also satellite imagery and oblique imagery can be also good reference. In addition, expansion of "generation of new information" concept is recommend for future work.

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Appendix 1

ATC-20 Rapid evaluation satety assessment form

ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ______________________ Inspection date and time: ______________ ☐ AM ☐ PM

Affiliation: ______________________ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: ______________________

Address: ______________________

____

Building contact/phone: ______________________

Number of stories above ground: ______ below ground: ______

Approx. "Footprint area" (square feet): ______________________

Number of residential units: ______________________

Number of residential units not habitable: ______________________

Type of Construction

☐ Wood frame ☐ Concrete shear wall

☐ Steel frame ☐ Unreinforced masonry

☐ Tilt-up concrete ☐ Reinforced masonry

☐ Concrete frame ☐ Other: ______________

Primary Occupancy

☐ Dwelling ☐ Commercial ☐ Government

☐ Other residential ☐ Offices ☐ Historic

☐ Public assembly ☐ Industrial ☐ School

☐ Emergency services ☐ Other: ______________

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)
				☐ None
Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ 0–1%
Building or story leaning	☐	☐	☐	☐ 1–10%
Racking damage to walls, other structural damage	☐	☐	☐	☐ 10–30%
Chimney, parapet, or other falling hazard	☐	☐	☐	☐ 30–60%
Ground slope movement or cracking	☐	☐	☐	☐ 60–100%
Other (specify) ______________	☐	☐	☐	☐ 100%

Comments: ______________________

____

Posting

Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: ______________________

____

____

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: ______________________

____

☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: ______________

☐ Other recommendations: ______________________

Comments: ______________________

____

Appendix 2

Online questionnaire form for user's evaluation (Introduction)

Questionnaire for Master of Science Thesis / Title: "A building damage and safety assessment with mobile augmented reality"

Title: "A building damage and safety assessment with mobile augmented reality"

The goal of this study is to provide various reference data through mobile augmented reality for building damage and safety assessment. Augmented reality (AR) aims at combining computer-generated data with real objects. Users (first responder) of mobile AR can be structural engineer, architect, and volunteer groups who go to field to conduct building damage assessment right after the occurrence of a natural disaster such as earthquake, flood, tornado and so on. Right after the disaster occurred, first responders are supposed to visit disaster area to check building damage quickly in order to identify building's safety.

In this study, mobile AR provides following reference data that are composed of from simple to complex data: building location, building information (e.g. building classification, material, height, purpose), building-related multimedia (e.g. internet photos, video clip of the building), building geometry (3D building interior, exterior and 3D building frame), Building change(e.g. change detection between pre- and post-disaster building). These reference data can be extracted from cadastral database of local government, building manage company, google earth and internet service.

The purpose of this survey is to ask you about the efficiency of mobile AR and its reference data. Through this survey, we are expecting to find out how much the mobile AR can contribute building damage and safety assessment in disaster situation. The following videos show a demonstration of a prototype of mobile AR. The prototype comprised of two types of system: Indoor AR and Outdoor AR based on an android smartphone. Indoor AR shows 3D buildings and building information around the damaged area, so that user can figure out overall status of damaged area. Outdoor AR is intended for field operations, and superimposes various reference datasets on real buildings in the disaster area. With outdoor AR users can figure out the initial structure of pre-disaster buildings, so that user can directly compare pre-disaster datasets with the real buildings in the field.

This survey takes about 10 minutes. Thank you in advance for your support.

Online questionnaire form for user's evaluation (Demonstration)

Augmented Reality (Indoor)

Above video shows demonstration of Indoor AR that shows 3D models and building information of pre-disaster. With indoor AR, user can check overall status of disaster area in office. User can zoom-in, out and rotate of building. When user touch model, it gives building information also

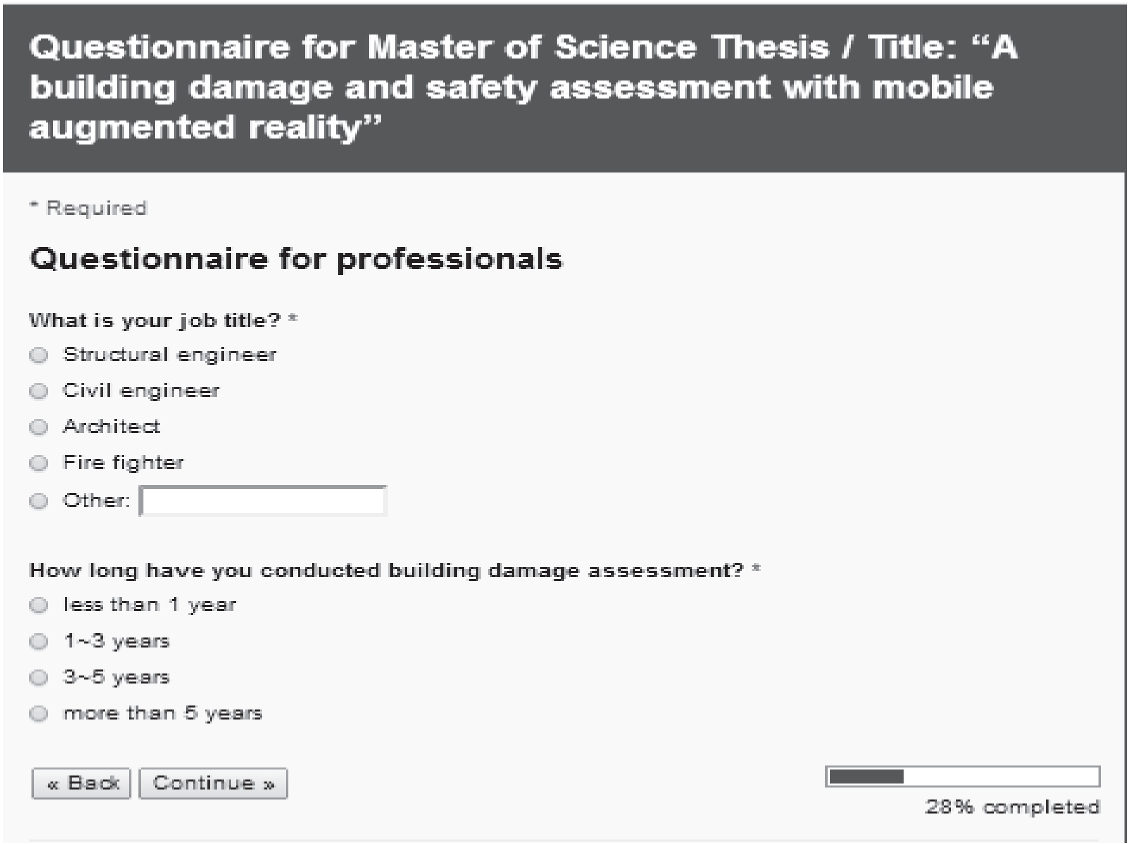
Augmented Reality (Outdoor)

Above video shows demonstration of Outdoor AR that superimposes various reference datasets on real building in disaster situation. With outdoor AR users can figure out initial structure of pre-disaster building, so that user can directly compare pre-disaster datasets with real building in the field.

Do you have any experience of building damage(or safety) assessment? *

- Yes
- No

Online questionnaire form for user's evaluation (user information)



Questionnaire for Master of Science Thesis / Title: "A building damage and safety assessment with mobile augmented reality"

* Required

Questionnaire for professionals

What is your job title? *

- Structural engineer
- Civil engineer
- Architect
- Fire fighter
- Other:

How long have you conducted building damage assessment? *

- less than 1 year
- 1~3 years
- 3~5 years
- more than 5 years

« Back | Continue »

28% completed

Online questionnaire form for user's evaluation (Efficiency of mobile AR)

* Required

Efficiency of mobile AR

Do you have any experience with mobile Augmented Reality? *

- Yes
- No

What purpose did you use AR? (If you answered Yes above question)

- For scientific purpose (Hazard and disaster domain)
- For scientific purpose (Other domain)
- For study
- For work
- For entertainment
- Other:

How much do you think Indoor AR can improve understanding a disaster situation? *

	1	2	3	4	5	
Not at all						A lot

How much do you think mobile AR can reduce assessment time compared to traditional method of building damage assessment? *

Traditional method means visual interpretation by inspector without any support of mobile system

- 10%
- 20%
- 30%
- 40%
- more than 50%

How much do you think mobile AR can improve assessment accuracy (or objectiveness) compared to traditional method of building damage assessment? *

Traditional method means visual interpretation by inspector without any support of mobile system

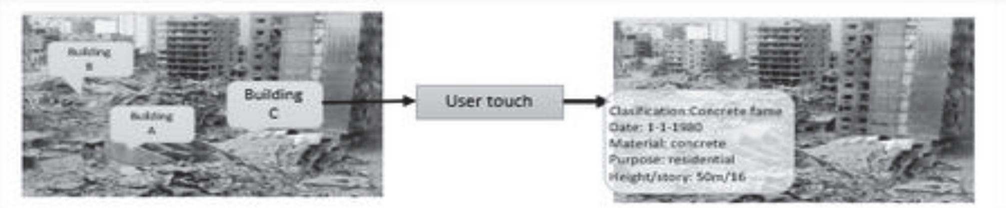
- 10%
- 20%
- 30%
- 40%
- more than 50%

Online questionnaire form for user's evaluation (Essential information 1)

Essential information(reference data)

We show some example of reference data below. We would like to know which reference data are essential for building damage and safety assessment. You can choose scale from 1 to 5 according to its level of importance.

Building information

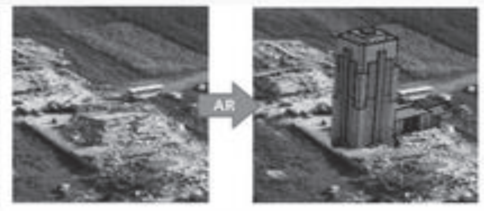


Reference data 1: Building information (Building classification, material, Number of floor, Height etc.). *

This reference data shows building existence and its attribute.

	1	2	3	4	5	
not necessary	○	○	○	○	○	very important

3D building exterior

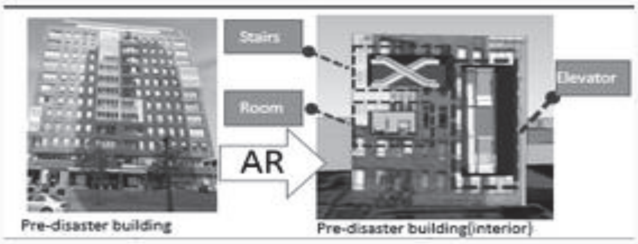


Reference data 2: 3D building exterior of Pre-disaster(initial) building *

This reference data shows initial shape of building.

	1	2	3	4	5	
not necessary	○	○	○	○	○	very important

3D building interior



Reference data 3: 3D building Interior of Pre-disaster (initial) building *

This reference data shows location of inner structures such as stairs, rooms and elevators.

1 2 3 4 5

Online questionnaire form for user's evaluation (Essential information 2)

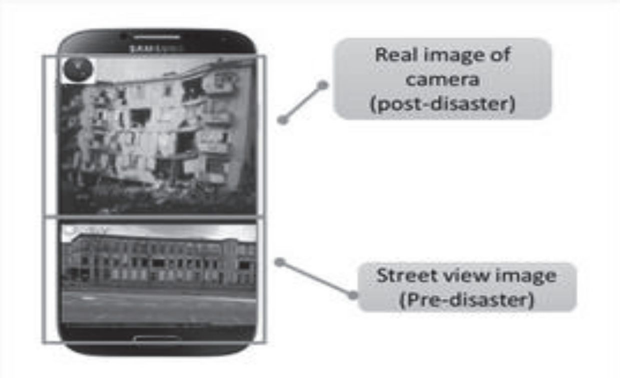
3D building frame

Reference data 4: 3D building frame *

1 2 3 4 5

not necessary ○ ○ ○ ○ ○ very important

Street level imagery



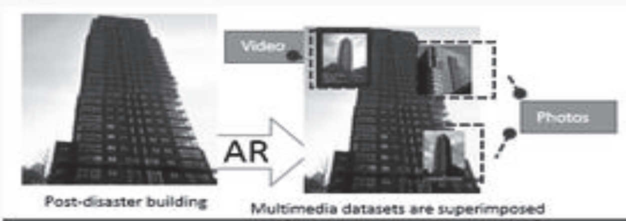
Reference data 5: Street level imagery *

This reference data shows street level imagery(e.g. google street view) of pre-disaster building around damaged building.

1 2 3 4 5

not necessary ○ ○ ○ ○ ○ very important

Building-related information



Reference data 6: building-related information *

This reference data shows photos or video clips that have building-related information. The data can be extracted from internet service such as youtube, Flickr and so on.

1 2 3 4 5

not necessary ○ ○ ○ ○ ○ very important

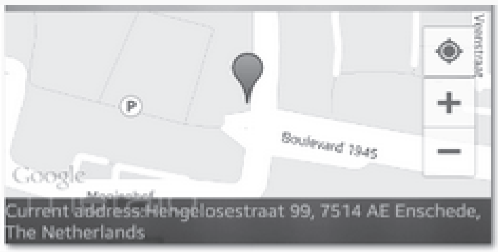
Online questionnaire form for user's evaluation (Locational awareness)

Locational awareness

If you can identify the current street name of your position in the disaster area, do you think it can improve your locational awareness? *

Address and map of your current location is displayed on AR(refer to below image)

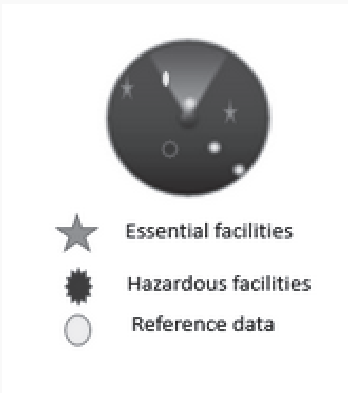
- ○ 10%
- ○ 20%
- ○ 30%
- ○ 40%
- ○ more than 50%



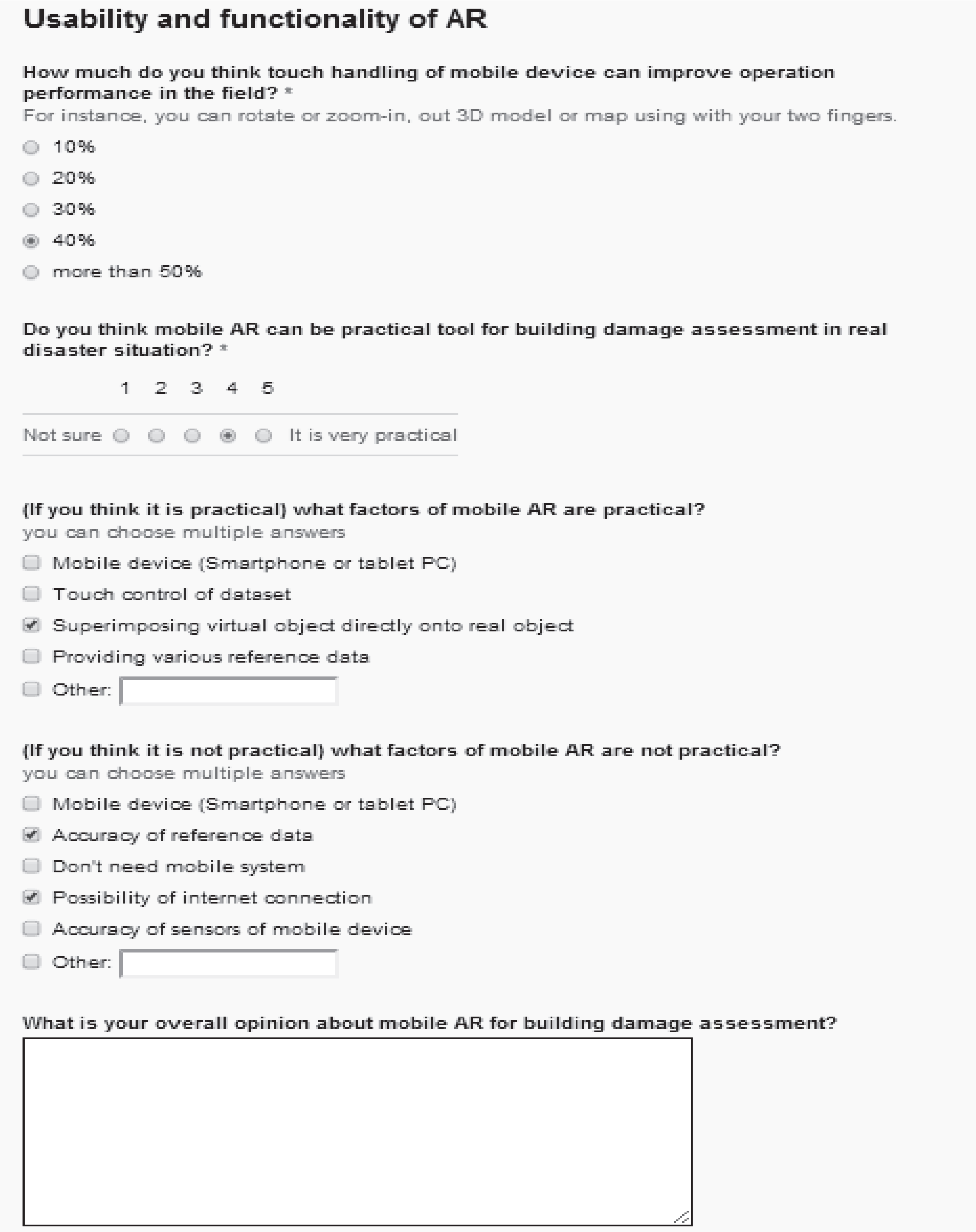
If you know the location of a target building in the disaster situation, do you think it can improve your locational awareness? *

Radar shows location of essential facilities(e.g. hospital, power station), hazardous facilities(e.g. chemistry plant) and target buildings(refer to below image)

- ○ 10%
- ○ 20%
- ○ 30%
- ○ 40%
- ○ more than 50%



Online questionnaire form for user's evaluation (Usability and functionality)



Usability and functionality of AR

How much do you think touch handling of mobile device can improve operation performance in the field? *

For instance, you can rotate or zoom-in, out 3D model or map using with your two fingers.

- ○ 10%
- ○ 20%
- ○ 30%
- ◉ 40%
- ○ more than 50%

Do you think mobile AR can be practical tool for building damage assessment in real disaster situation? *

	1	2	3	4	5	
Not sure	○	○	○	◉	○	It is very practical

(If you think it is practical) what factors of mobile AR are practical?

you can choose multiple answers

- ☐ Mobile device (Smartphone or tablet PC)
- ☐ Touch control of dataset
- ☑ Superimposing virtual object directly onto real object
- ☐ Providing various reference data
- ☐ Other:

(If you think it is not practical) what factors of mobile AR are not practical?

you can choose multiple answers

- ☐ Mobile device (Smartphone or tablet PC)
- ☑ Accuracy of reference data
- ☐ Don't need mobile system
- ☑ Possibility of internet connection
- ☐ Accuracy of sensors of mobile device
- ☐ Other:

What is your overall opinion about mobile AR for building damage assessment?