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# PHOTOGRAMMETRY TECHNIQUES FOR OBJECT-BASED BUILDING CRACK DETECTION AND CHARACTERIZATION

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## ABSTRACT

Last decade, the occurrence of natural and man-made disasters is increasing significantly. Those hazardous events have tremendous impact on the society with effects like considerable loss of lives and heavy damage on building infrastructure. The integrity of the infrastructure is mostly evaluated with visual interpretation surveys performed by certified experts who aim to identify visible damage signs on the exterior part of the structure. In addition, the latter is time consuming and subjective on experts' perspective. Thus, the elements that are visible after an event as initial signs of structural deterioration are cracks. The research attempts to develop an image-based framework to identify cracking features and provide reliable information about their geometrical properties. The information constitutes an additional tool for detail damage characterization. In addition, with the cracking features, holes on the damaged façade were highlighted since those elements constitute initial points for crack propagation. First, the DSM was analyzed to identify depressions on the elevation model that constitute potential damage. Second, the orthorectified image of the damaged façade where the damaged features can be identified based on brightness values compared with the background. The results suggest that the proposed methodology from the initial step of image acquisition till the OBIA proved reliable. From damage areas with "simple" damage pattern the accuracy classification result was high in contrary with problematic areas were the results look pessimistic. These results seem significant interesting for stakeholders and institutions that are looking for efficient damage mapping and monitoring of infrastructure based on VHR imagery.


*Keywords: close range photogrammetry; object-based; crack detection; building damage mapping; OBIA*

## 1. INTRODUCTION

### *1.1 Background*

Damage identification has long played a fundamental role in various domains in order to detect and assess the structural damage on early stage and proceed to appropriate actions for the maintenance and monitoring of civil infrastructure Burland, Broms, & De Mello, (1977). In order to characterize the damaged features rapidly after a disaster first their geometrical properties need to be identified and characterized. Organizations such as BAT (2014) and EEFIT (2014) are responsible for executing the procedure of Structural Damage Assessment (SDA) in order to assess the structural stability and safety. SDA constitutes an essential procedure to evaluate the structural integrity and functionality of infrastructure after a disastrous event. The predominant method that has been used for many years in SDA is visual inspection during ground-based surveys. This type of method provides important structural information for the affected areas, but it faces serious drawbacks like subjectivity from the visual inspectors and no rapid response. Thus, for the case that rapid results are required it can be too expensive.

Nowadays, there is need for a more robust, repeatable, image based approach for detailed damage mapping Kerle & Hoffman, (2013) and characterization. Remote sensing techniques try to solve the issue of robustness and automation but they are not so far that much developed in order to provide a

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definite benchmark which will replace the in situ assessment that experts do Lemoine, Corbane, Louvrier, & Kauffmann, (2013). Moreover, on the ground, experts map different aspects like damage or safety depending on the procedure and the rules they will follow. The fact that there is no unique approach makes it more difficult to establish this definite truth benchmark. Organizations like United Nations Institute for Training and Research UNITAR, (2014) have been using remote sensing information and image-based processing methods to identify damaged areas Kerle & Hoffman, (2013) and provide a characterization of their geometric properties. The use of Unmanned Aerial Systems (UASs) to acquire Very High Resolution (VHR) images in order to extract significant damage information seems to bridge the gap between the traditional ground surveys and remote sensing techniques. Hence, it is less error prone and cost effective compared with the traditional ground-based methods. Nonami, Kendoul, Suzuki, Wang, & Nakazawa, (2010)

### *1.2 The role of remote sensing in damage assessment*

Remote sensing has contributed a lot to the development of damage mapping. However, it is since the last decade that it has been proved as a reliable tool for damage assessment after natural or man-made disasters. An example is the case of Dell'Acqua & Gamba (2012), who presented a holistic review of various remote sensing techniques to evaluate earthquake related damage. Many other scientists have performed a large number of experiments based on change detection techniques on pre- and post-imagery to identify damaged areas after a disaster. A large number of space-borne platforms were used to collect imagery to proceed to SDA. Specifically, Zhang & Kerle (2008) demonstrate a detailed review of the available space-borne sensors for damage assessment procedures. They pointed out the potential limitations such as that the data acquisition after an event is weather dependent (cloud cover). Radar and optical datasets were examined with pre- and post-event datasets while change detection techniques were applied on the imagery. In addition, Tian & Zhang, (2004) applied pre-processing methods such as edge enhancement and change detection techniques on different datasets, from SPOT and airborne images to SAR images in order to identify damaged areas. Also, Kerle (2010) in his paper presented an underestimation of the structural damage in terms of damage severity and spatial extent in the damage maps that have been produced by UNITAR after an earthquake event in Indonesia. As the need for more detailed information is unavoidable for the specialists to evaluate the disaster and its consequences, the need for higher spatial resolution is significant. Nowadays, the spatial resolution has been increased up to the level of mm and that gives further possibilities for more efficient solutions.

### *1.3 Building damage assessment*

In order to execute a comprehensive per building damage assessment, information for the roof and the facades is needed, as it is stated clear in Galarreta's research (2014). Most of the conventional sensors are capturing imagery close to nadir perspective that makes it difficult to collect damage information after an event, related with the building facades. In the early 2000s when Pictometry was founded a solution to this drawback could has been given by the use of the images that this new system could acquire EagleView, (2014). The latter offers aerial image acquisition from five different viewing directions, simultaneously. One image close to nadir perspective and four oblique images at 40º viewing angle which makes the current method efficient for reliable building damage assessment (Gerke & Kerle (2011), Saito & Spence (2010)). Nowadays, large firms in Netherlands like TNO are looking to develop an image-based framework capable to lead to a detailed characterization of the visible damage signs on façade level. This will enable cost effective solutions as the structural experts will be able to inspect the infrastructure from a safe distance and rapidly.

As mentioned above, the spatial resolution is increasing tremendously with data acquired from new sensors and new airborne platforms that have been introduced with the pace of time. Today, the so-called Unmanned Aerial Vehicles (UAVs) or drones, such as the one from Aibotix , are capable of hovering over sites and collect imagery that will be used for several purposes. Disastrous sites can be one of these cases that images are captured for damage assessment which usually is conducted by surveyors. These platforms are capable to combine advantages of close range photogrammetry with airborne acquisition. For instance, they can perform low altitude flights and even hover over a predefined location and collect imagery simultaneously. The small height in combination with VHR sensor mounted on the platform constitutes them efficient for post-disaster damage assessments cases. For instance, they are able to capture imagery with cracks less than 1cm in width with the VHR sensors mounted Chen, Rice, Boyle & Hauser, (2011). However, a serious limitation of UAVs is that they can cover small areas due to the limited flight time. Nowadays, both in private and public sector UAVs are used increasingly for infrastructure monitoring that many times includes building inspection (e.g. SKEYE BV, (2014)).

### *1.4 From pixel towards object*

Since the first days of remote sensing, the traditional way for information extraction was based completely on a pixel level. The last two decades the evolution of remote sensing and close-range photogrammetry, with the Very High Resolution (VHR) imagery, has given much more possibilities for analysis. Object-Based Image Analysis (OBIA) that will be used in the current thesis is an approach that takes advantage of the information that can be extracted from these VHR images. Today both terms Object Based Image Analysis (OBIA) and/or Object-Oriented Analysis (OOA) are used but for this study the term OBIA has been adopted. The main task of image analysis is to extract real word objects based on some parameters which pixel based approaches are not able to do Trimble, 2014b). As the spatial resolution is becoming higher, the pixel size is decreasing and the objects are represented better by clusters of pixels Blaschke, (2010). The traditional pixel-based methods for information extraction are not so reliable to be applied on VHR imagery (Joshi, 2010). Many researchers such as Yamazaki, Suzuki, & Maruyama, (2008), Blaschke & Strobl, (2001) and Haiyang, Gang, & Xiaosan, (2010) have agreed on the reliability of object based image analysis techniques on VHR imagery and they have pointed out that the latter can many times provide more accurate and reliable results than the pixel based approach. Another asset of OBIA is that it can combine spatial, spectral and contextual information of the image to extract the features of interest, while the pixel approach is based on the reflectance statistics of the pixel.

## 2. METHODOLOGY

### *2.1 General*

Nowadays, the technological developments give many possibilities for automated ways of damage feature extraction and classification in terms of severity. However, only semi-automated ways have been adapted so far. Here the proposed approach will take advantage of the information that can be extracted from very high-resolution images via OBIA techniques to extract geometrical properties of these features that can further be used for assessment in terms of severity. For assessing the severity of damage, information about its geometrical properties need to be known. The damage features here are a) the cracks and b) the holes and the “surface unit” is part of the building façade without other structural elements like windows and doors. If the geometric properties of the damage are known per façade then this information can be composed for making conclusions for the damage severity per building. Thus, the focus is on how to characterize the damage features per façade and not on how to assess them in terms of severity. The first step was the site selection. For a real case scenario, the site will be located were the disastrous event will happen but for this study already damaged buildings were found to simulate the disaster site. These images will be used for photogrammetric analysis. Consequently, there was need to establish an arbitrary local coordinate reference system on the façade’s plane. Four Ground Control Points (GCPs) were measured per façade and their coordinates were used for the sensor orientation. The latter gave the exterior orientation parameters of the images which in combination with the acquired imagery and the image matching algorithm were used to generate the digital surface model (DSM). The DSM layer is a 2.5D which represents the elevated features of the façade and it is later assessed for its quality. After that, the orthorectification of the images is done for geometrical corrections such as uniform scale. Again, the resulted product will be assessed for its quality directly after the generation. If the quality condition is acceptable then the two products will be used as input data in OBIA to segment and extract the damage feature of cracks and

holes. At this stage the information that VHR images could provide (DSM & orthorectified image) will be further used for the OBIA. A hybrid approach for the segmentation process will follow. That means that the information of both orthorectified image and DSM was combined for the segmentation stage. For the current thesis this hybrid approach is the stage where the additional information from the DSM is expected to give more reliable and accurate information. The latter enabled the use of the elevation and colour information to identify and extract the damage features based on the two products but at the same time for the segmentation, it was also combined with the information from the RGB orthorectified image. This way the parameters of the segmentation algorithms were adjusted for each material and a final value for each case was selected. Thus, if a comprehensive segmentation is produced then the aim of the classification process is to assign in the segmented objects a respective class based on the predefined set of properties. The classification result will demonstrate the façade as a unique homogenous object and the potential damage in the classes as cracks or holes which then are used for the accuracy assessment. The final quality assessment of the classification is done based on a number of statistical measurement factors. In the end, the structural expert or civil engineer will derive a classification result on an interface showing the highlighted damage feature in accordance with its geometrical properties such as the maximum width, length and area but also its location. Based on this information, the specialist will be able to add an essential quantitative characterization analysis tool for the SDA procedure. In addition, the time to generate SDA after the event will be decreased substantial and the danger of in situ inspections will be eliminated (
Figure 1).

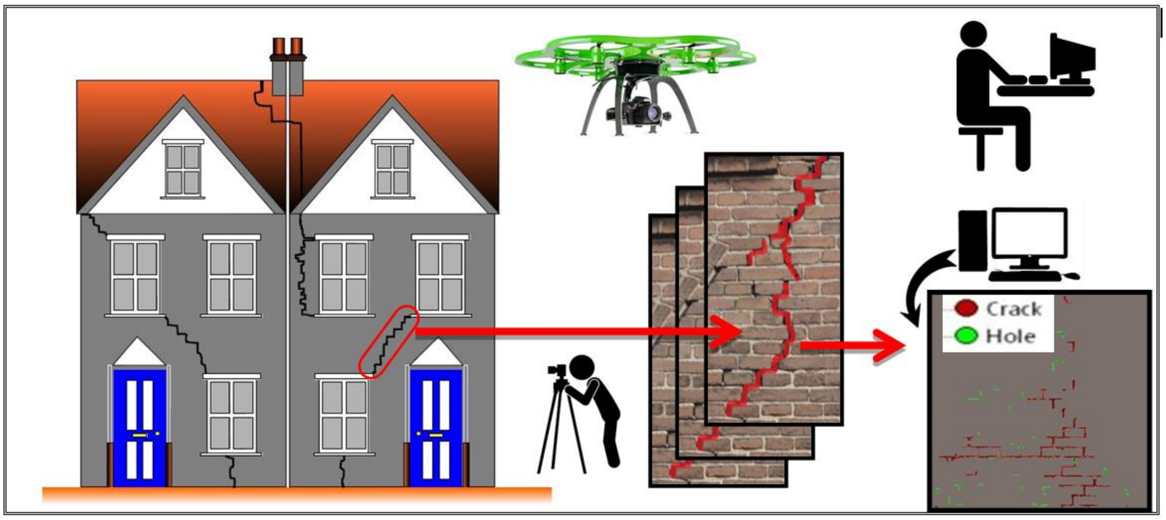


Figure 1.Damage identification and classification procedure

### *2.2 Image acquisition*

The process of data collection for surface damage features such as the cracks and the holes on buildings was implemented in three distinct stages, during daytime. Each stage represents a different damaged location for data acquisition. At the beginning of the experiment the following decisions for the following elements had to be taken:

- Site selection
- Platform
- Sensor.

For the site selection as it has already been mentioned already damaged buildings were selected to stimulate the post-disaster geometries. To find such building in the Netherlands was a challenge as most of the times the restoration of the damage takes place immediately after that. The construction materials of the places where the images captured are a) brick and b) concrete. This is because; the two cases constitute the mostly used in building constructions and such were considered as the most representative. Concrete is defined as a mixture of cement, aggregate and water (American Concrete Institute, 2011). Brick is a traditional structural building material that is used extensively in the building construction in the north part of Europe for individual residential accommodation. Its ingredients are usually fine clay, brick and cement. (National Authority on Clay Brick Construction, 2014). The criteria for the platform were a) the availability, b) the cost and c) the accessibility possibilities that were provided. At the beginning the aim was to use a UAV that could easily and safely reach a disastrous site for VHR image acquisition. However, time and platform availability did not allow that. Instead, a terrestrial platform with a VHR sensor mounted on it was used. The sensor should be capable to acquire images of very high spatial resolution, at the level of few mm. This requirement derives from the geometrical characteristics of the object that is under the focus of the current study. Consequently, the sensor that was used is the consumer digital camera NIKON D3200 DSLR with AF-S DX NIKKOR 18-105mm lens. All the experiments conducted with the same terrestrial platform and the same sensor. For the image acquisition two different illumination conditions were tested. The photos were captured once with flash and then the same scene was capture without flash. This is because at the analysis stage the different result of the two cases should be examined in order to assess if the "with flash" images can provide more detailed information. Specifically, for each sample areas (e.g. Brick I) 2 distinct datasets (M1a-M1b) are available after the image acquisition step, a) photos with the use of a flash light and b) photos under the ambient lightning solely.

### *2.3 Experimental setup*

The data acquisition was a crucial part in the current research (Figure 2). At first, an extensive work at the office was carried out to identify damaged areas that could be investigated to collect the damage information. The aim was to find facades that will constitute the base data of the study of the representative materials. When the damaged facades were selected the image acquisition was conducted. Artificial targets were created and printed in advance. These targets were attached on the façades to be used as GCPs for the sensor orientation. These points could not have been randomly placed on the façade but should shape an orthogonal as they were also used for the definition of the local coordinate reference system. The targets were removed after the image acquisition. Due to inaccessibility in some areas the image acquisition met some limitations such as difficulties to establish the GCPs on the building.

In the following step, multiple images were captured with an approximate baseline of 10-20cm to generate the 3D products that are going to be used in the image processing step. As a result, the image overlap exceeded the 80% which is sufficient for this case. If the disaster site is inaccessible from human experts for instance after a disaster in a nuclear plant, then an airborne platform will take the place of the specialists. The use of a UAV platform to perform a predefined flight path to capture damage features on high elevated infrastructure such as power plants tubes or installations will be time and cost efficient plus it does not put in danger the experts.

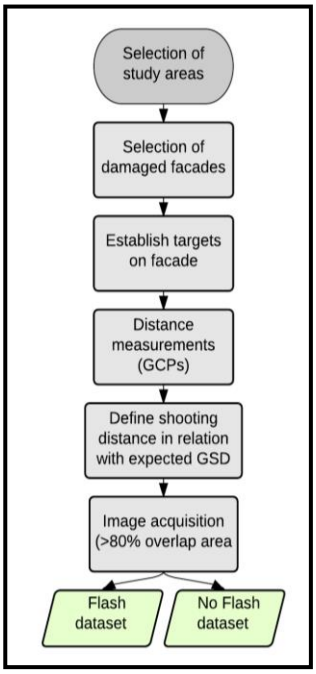


Figure 2. Flowchart of the image acquisition stage

## 3. OBJECT-BASED IMAGE ANALYSIS (OBIA)

OBIA procedure includes two major steps, the segmentation and the classification process. The tool that was carried out the image analysis step is eCognition Developer software package developed by Trimble (2014). The latter is the most used software package for OBIA techniques as more than half of the published papers in the domain of OBIA are making use of this software (Blaschke, 2010). Moreover, it offers a wide variety of segmentation algorithms from knowledge driven methods (top-down) to data driven methods (bottom up). In our experiments the multiresolution segmentation (MLS) was applied which is a bottom-up, region merging technique based on homogeneity criteria between adjacent pixels.

In addition, in our case the objects of interest are appearing in different scales in the imagery. As a result, MLS is capable of taking into account its variety and adapt the scale to fit the scale of the given task. Thus, it produces large homogenous segments in an arbitrary resolution in different type of datasets. In MLS, three factors have to be determined the scale, the colour and the shape. The colour can be weighted between 0-1 and the shape factor follows the same weight range between smoothness and compactness. Also, a weight assignment between the used spectral bands or layers of the imagery is possible. The scale defines the maximum size of the object as a result, the process ends when the scale factor exceeds this value. The segmentation process was followed by a spectral difference segmentation to merge neighbouring objects based on their mean layer intensity values (Trimble, 2014a). In the current step a set of rulesets were designed to capture the damage features of interest on a façade level and classify them accordingly. For the purpose of damage classification two damage classes were created after careful consideration based on literature and extensive discussions with the experts, a) holes and b) cracks. The aim of this step was to develop a set of rulesets capable to capture the location of damage features, classify the segmented objects in the predefined damage classes and extract the damage information. The developed ruleset had to be able to be transferred and applicable for different damage scenarios.

We follow a hybrid approach to segment the imagery by using the 2.5D DSM and the orthophoto of the damaged facades. First, the image-based DSM was the first input and it includes all the damaged artefacts of the façade which are visible as degraded cavities. The orthorectified image was the second input of the hybrid approach where the damaged features are visible and appear with low brightness value. This is because there are shadows in the damaged area. Based on this assumption for the damage features the rulesets were designed to fulfil the segmentation process in order to highlight the cracks and holes and keep as a homogeneous intact object the "healthy" façade.

The classification process which followed the segmentation has the aim of assigning the objects in meaningful damage classes. A set of rules were designed to fulfil the classification requirement based on careful selection of the object's characteristics like the ratio length to width, the rectangular fit and the area. The approach of parameter selection was motivated from previous works on building damage assessment in OBIA such as from Galarreta, (2014), Blaschke, Lang & Hay, (2008) and Mavrantza & Argialas, (2008). However, the major difference between the current approach and the previous study that was done by Galarreta is that the hybrid approach that was adapted takes full advantage of the 2.5D information that the DSM provides.

## 4. ACCURACY ASSESSMENT

The accuracy assessment is a procedure for quantifying the quality of the extracted damage features in terms of completeness and correctness and it constitutes a critical part of the post-classification stage. It is usually done by comparing the classification result with reference data that is considered as the most accurate. Sources of reference data can for example be ground truth measurements, images of higher resolution, maps or laser scanning data. For the current case the orthorectified images and the point cloud data from a laser scan were used as reference data.

***Area based approach***

The first accuracy assessment approach was area-based (Joshi, 2010). Every image was examined to check the quality of the identification and classification of damage features. Statistical measurements took place between the extracted area from OBIA and a reference data that was previously created by manual digitization of the selected damage features on the orthophotos in ArcGIS (ESRI, 2014) after their generation.

In Figure 2, an assumption is made; the rectangular ABCD is the reference data and the rectangular SROP is the extracted damage features area from the OBIA methods. Then three types of measurement factors could be defined. The green area or True Positives (TP) is the area which is present in the reference data but also in the extracted one from OBIA. Next, the blue area or False Positives (FP) is the area that is present in the reference dataset but not in the OBIA result. For instance, cracks that were identified as cracks in the manual digitization is not present in the post-classification stage. The red area or False Negatives (FN) is the area that was extracted as damage feature from the classification step, but it was not present in the reference.

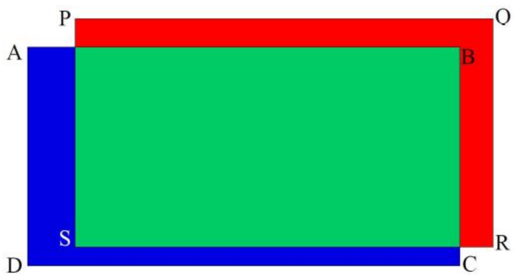


Figure 3. Illustration of the accuracy assessment (Joshi, 2010) Green: TP, Red: FN and Blue: FP

**Split factor** = TP / FP

**Missing factor** = FN / TP

**Correctness** = TP / (TP + FP)

**Completeness** = TP / (TP + FN)

Figure 4. Factors for performing the accuracy assessment (Joshi, 2010)

Based on the previous three factors, four quality measurements could be obtained (Figure3) to represent the quantitative quality analysis of the classification. First, the split factor represents the number of true positives compared with the number of false positives. Second, the missing factor represents the number of false negatives compared with the number of true positives. The latter is a measurement factor to indicate the amount of missing information after the classification. Third, the correctness is a measure factor which represents the correct detection rate against the reference damage features. It ranges from 0-1 and it is represented in percentage (%). It is a factor which indicates if the reference damage information was correlated accurate with the classified damage features. Completeness is a factor which indicates how complete the extracted damage features are and it ranges from 0-1 like correctness factor.
As it was time consuming to run the spatial queries in ArcGIS every time for each set of data, a script was developed in R-project to automate the procedure of accuracy assessment. As an alternative accuracy assessment method and in order to automate the procedure, a script was designed in R environment Bell Laboratories, (2014). R-project is a programming language based on a variety of scripts and environment for statistical computing and graphics R Core Team, (2014). The developed script in R first calculates the area of the reference data and the difference between this and the ArcGIS approach is the generation of a buffer zone of 0.05cm around the objects. The buffer zone is created to eliminate errors because of small areas near the feature's boundaries that had to be included as damage feature areas during the manual digitization. The digitizing process was done in order to define the truth crack on the orthophoto (reference data). The reference area with the buffer is calculated and the intersection with the area of the objects resulted from OBIA is computed. Following this approach, the accuracy assessment of the classification could be done in a more automated way that allows more tests for the quality assessment. This script used to assess the accuracy for the damaged cases in insulating material and brick. The main reason of the current script development was that the latter is less time consuming to implement the accuracy assessment.

## 5. ANALYSIS

The damage features like holes and cracks which were extracted by OBIA techniques were found reliable and representative of the damage that was identified on the sample areas as initial signs of deterioration. It is important to notice that a more detailed damage catalogue could be more effective. From the selected features, the main focus of this research was initially focused only on the cracking features but after careful consideration features such as holes were included in the features that had to be extracted. The latter was based on the assumption that holes could be the initial point where a crack could propagate from.

**Damage feature extraction**

At first, it has to be noticed that there are a lot of different segmentation and classification approaches which a user can apply to proceed with the damage extraction from building facades. In the current thesis a coherent image-based approach was developed based on extended literature review and discussions with experts. The OBIA methodology was based in the assumptions posed in methodology chapter where the damage features are represented in the data from pixels of low brightness and less elevated captivities.
Three distinct rulesets were developed in the initial stage to capture the damage features for the three different materials that were under investigation (concrete, brick and insulating material). Different materials have different spectral properties and because of that, parameters like the threshold of brightness had to be adjusted. Apart from that, the three materials because of the different texture gave different segmentation results; especially, for the case of the brick. There, an additional rule should be added in the set-in order to refine the result. First, the image of each case was segmented in homogenous objects based on a combination of segmentation algorithms followed by the classification process. In addition, the selected damage classes have proved to be sufficient for the appropriate classification process under the experiments that carried out in this thesis. The damage samples did not include any non-structural features such as windows or doors and such no semantics were included in the rulesets.

Figure 5. In the green area the actual cracks "concrete I". In the red areas objects that were wrongly highlighted as independent objects after the segmentation process.

**a) Segmentation**

All the damaged samples were analyzed with the same segmentation approach. First, a multiresolution segmentation process was applied in the samples to highlight the damage features of interest, followed by a spectral difference segmentation process where similar objects were merged based on their mean layer intensity values. Despite that the selected approach captured damage features of cracks and holes in the imagery, in some cases the background elements were wrongly highlighted as objects of interest. Especially, in the case of concrete where the sample area was complex many features such as decorations on the wall or plaster removal that were categorized as damage. In order to be able to include even the small thin cracks on the façade, the developed segmentation ruleset included also features that had dark color due to the illumination conditions and the produced occluded areas. Later

with the designed classification parameters the segmented artefacts were included as façade objects.
In Figure 4, the result of the segmentation process in the sample “concrete I” is illustrated. In red rectangular boxes are presented the areas that are wrongly segmented as objects and are distinguished from the rest of the background due to their brightness values. In the green box the actual cracking feature that was identified during the field visit.

**b) Classification**

The aim of the classification step was to assign meaningful classes at the objects that were resulted from the segmentation process. The developed rulesets were able to identify a significant part of the damage features in most of the samples with high reliability. However, in some complex cases the resulted classification failed to detect even the visible damages with the current set of rulesets. The classification process was based on two major assumptions in the current thesis. The 2.5D DSM would provide elevation information of the damaged façade and the orthorectified image should provide the brightness information. As a result, in some cases where the obtained DSM had noise, the results from the image analysis step showed errors. For instance, in the sample of “Concrete II” one extra classification rulesets had to be designed in order to fulfil the requirement of a comprehensive classification. In addition, the DSM had different values between the flash and the no flash especially for the concrete and the brick. The latter is due to the fact that the flash light is augmenting the brightness values of the projected layers. This results in errors in OBIA process due to the modified parameters of the objects. Consequently, the developed set of classification rules on the flash dataset was not capable to be applied directly on the no flash dataset. Moreover, in the sample of “brick I” where a small hairline crack was present the developed ruleset for brick materials was not capable to extract the cracking feature due to its small size and also the current crack was not visible on the DSM as damage element. Due to high complexity in some of the damage samples, the classification process had been included some background objects wrongly. In Figure the result of the classification in the damage sample of “concrete II” is illustrated. As it can be seen the crack that exists in the upper left part of the image was identified reliably in the classification process. However, there are multiple small objects that were classified as holes. As it can be seen in the real photo, the current façade includes a rectangular box where the two targets are also attached. The rectangular box is window which was used to allow the transition of the air in the interior of the building. As a result, the small holes that it is constituted the box are classified as potential damage features and more specific as holes. In reality the current box is constituted from small holes, but they are not signs of damage. Also, a small part of the attached GCPs is classified with the rest artefacts as holes.

Figure 6. In the green area the actual cracks on the damage sample “concrete II”. In the red areas objects that were wrongly highlighted as independent objects after the segmentation process. At the down left part, the façade as it is in reality.

## 6. CONCLUSION

This study aimed to produce a methodological framework that can be used for comprehensive damage characterization of surface cracking features using image-based techniques on VHR imagery. The

current approach was explored by using a terrestrial platform with a VHR sensor mounted on it for the image acquisition step. The same workflow for damage characterization could be carried out with the use of an airborne platform and specifically a UAV to proceed with the data acquisition efficiently in a manner of time and cost. The conclusion of the study is that based on the literature review there was need for a new framework to provide accurate and reliable information for the damage feature on constructions. Thus, it was decided to explore if the image-based analysis in OBIA on VHR imagery could provide any such possibility. For that different materials were tested to assess how same objects behave in different material. Also, per material the case of ambient illumination and enhance from additional source were explored.
It must be concluded that the several types of crack in terms of geometrical characteristics and environment (material) need different ruleset to be characterised. There were cases that the crack was successfully identified and characterised but that was only there were the texture of the material was simple and smooth, the geometry was also planar. The more complicated like the brick did give the same level of high accuracy. For these cases further study is required. The overall outcome after all is based on the assumption that the damage features have lower brightness values in the orthorectified image and are located in lower height than the mean height of the façade contributed at a high level. Also, the images with the additional illumination did not give the expected results. The accuracy from these images were much lower for the more complex cases (e.g. brick).

## 7. REFERENCES

American Concrete Institute. (2011). *ACI 318-11: Building Code Requirements for Structural Concrete and Commentary* (First Edit).

Bell Laboratories. (2014). R Studio software.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(1), 2–16. http://doi.org/10.1016/j.isprsjprs.2009.06.004

Blaschke, T., Lang, S., & Hay, G. (2008). *Object-Based Image Analysis: Spatial Concepts for Knowledge-Driven Remote Sensing Applications* (2008th ed.). Springer; 2008 edition.

Blaschke, T., & Strobl, J. (2001). What’s wrong with pixels? Some recent developments interfacing remote sensing and GIS. *GeoBIT/GIS*.

Burland, J. B., Broms, B. B., & De Mello, V. F. B. (1977). Behaviour of foundations and structures: State of the Art Report. In *Proceedings 9th International Conference on Soil Mechanic and Foundoution Engineering Session II*. Tokyo.

Chen, S.-E., Rice, C., Boyle, C., & Hauser, E. (2011). Small-Format Aerial Photography for Highway-Bridge Monitoring. *Journal of Performance of Constructed Facilities*, *25*(2), 105–112. http://doi.org/10.1061/(ASCE)CF.1943-5509.0000145

Dell’Acqua, F., & Gamba, P. (2012). Remote Sensing and Earthquake Damage Assessment: Experiences, Limits, and Perspectives. *Proceedings of the IEEE*, *100*(10), 2876–2890. http://doi.org/10.1109/JPROC.2012.2196404

EagleView, T. (2014). Pictometry.

EEFIT. (2014). The Earthquake Engineering Field Investigation Team.

ESRI. (2014). ArcGIS.

Galarreta, J. F. (2014). *Urban structural damage assessment using object-oriented analysis and semantic reasoning*. University of Twente, Faculty of ITC.

Gerke, M., & Kerle, N. (2011). Automatic Structural Seismic Damage Assessment with Airborne Oblique Pictometry© Imagery. *Photogrammetric Engineering & Remote Sensing*, *77*(9), 885–898. http://doi.org/10.14358/PERS.77.9.885

Haiyang, Y., Gang, C., & Xiaosan, G. (2010). Earthquake-collapsed building extraction from LiDAR and aerophotograph based on OBIA. In *The 2nd International Conference on Information Science and Engineering* (pp. 2034–2037). IEEE. http://doi.org/10.1109/ICISE.2010.5691203

Joshi, J. R. (2010). *Improving the quality of digital surface model generated from very high resolution satellite stereo imagery by using Object Oriented Image Analysis technique*. ITC, University of Twente.

Kerle, N. (2010). Satellite-based damage mapping following the 2006 Indonesia earthquake—How accurate was it? *International Journal of Applied Earth Observation and Geoinformation*, *12*(6), 466–476. http://doi.org/10.1016/j.jag.2010.07.004

Kerle, N., & Hoffman, R. R. (2013). Collaborative damage mapping for emergency response: the role of Cognitive Systems Engineering. *Natural Hazards and Earth System Science*, *13*(1), 97–113. http://doi.org/10.5194/nhess-13-97-2013

Lemoine, G., Corbane, C., Louvrier, C., & Kauffmann, M. (2013). Intercomparison and validation of building damage assessments based on post-Haiti 2010 earthquake imagery using multi-source reference data. *Natural Hazards and Earth System Sciences Discussions*, *1*(2), 1445–1486. http://doi.org/10.5194/nhessd-1-1445-2013

Mavrantza, O., & Argialas, D. (2008). An object-oriented image analysis approach for the identification of geologic lineaments in a sedimentary geotectonic environment. *Object-Based Image Analysis*, 383–398.

National Authority on Clay Brick Construction. (2014). Brick Industry Association.

Nonami, K., Kendoul, F., Suzuki, S., Wang, W., & Nakazawa, D. (2010). *Autonomous Flying Robots*. Tokyo: Springer Japan. http://doi.org/10.1007/978-4-431-53856-1

R Core Team. (2014). R studio - Manual.

Saito, K., & Spence, R. (2010). Damage assessment of Port-au-Prince using Pictometry. *Proceedings of the …*, (October).

SKEYE BV. (2014). Skeye.

Stanford University. (2014). Building Assessment Team (BAT).

Tian, Y., & Zhang, J. (2004). Techniques for seismic damages assessment by using remotely sensed images. ... *2004. IGARSS'04. Proceedings. 2004 IEEE …*, *0*(Icd), 1422–1425.

Trimble. (2014a). eCognition.

Trimble. (2014b). *eCognition User Guide*.

UNITAR. (2014). United Nations Institute for Training and Research: Operational Satellite Applications Programme.

Yamazaki, F., Suzuki, D., & Maruyama, Y. (2008). Detection of damages due to earthquakes using digital aerial images. *Proceedings of 6th International …*, *2007*.

Zhang, Y., & Kerle, N. (2008). Satellite remote sensing for near-real time data collection (p. 75). Taylor & Francis Group.