Classification of collapsed buildings during earthquakes from stereo aerial photographs using multiple features

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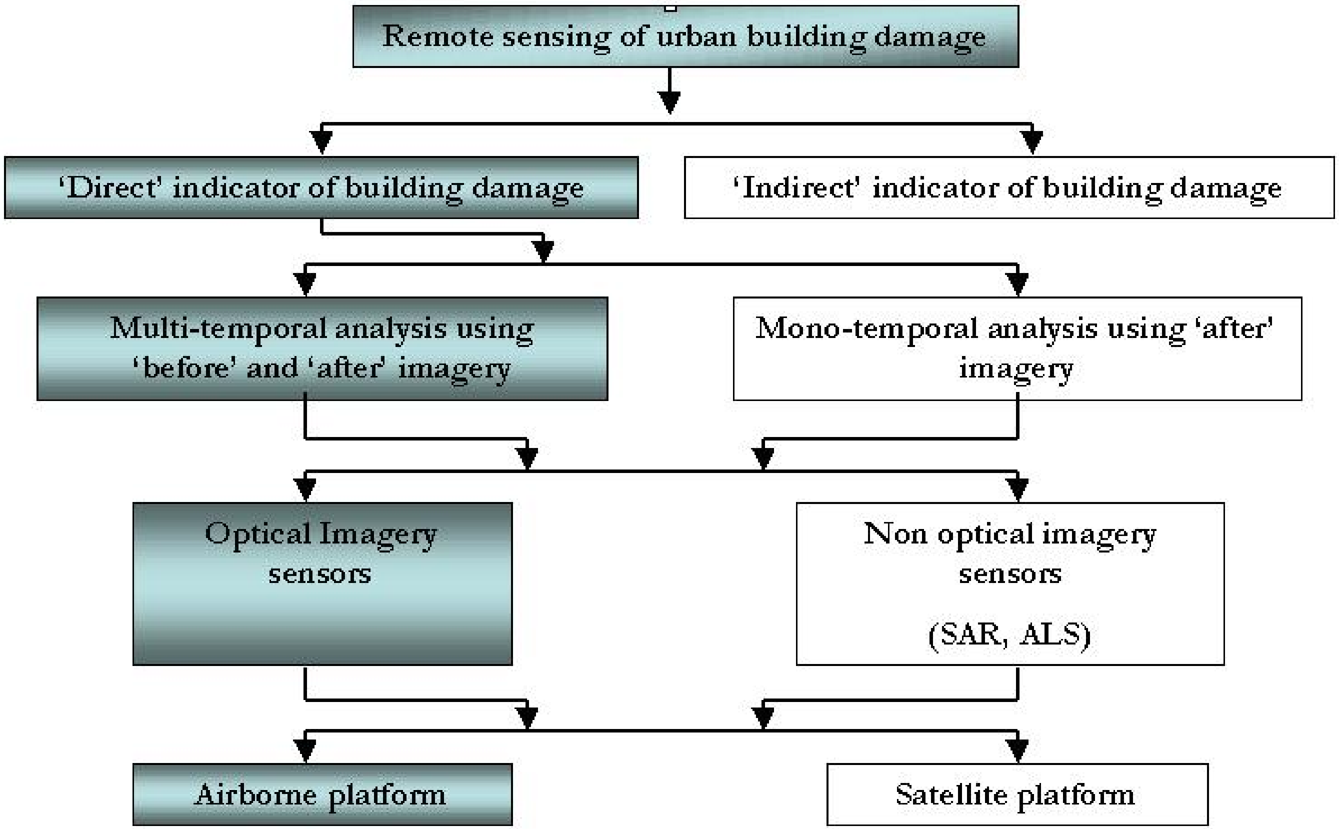
General methodology



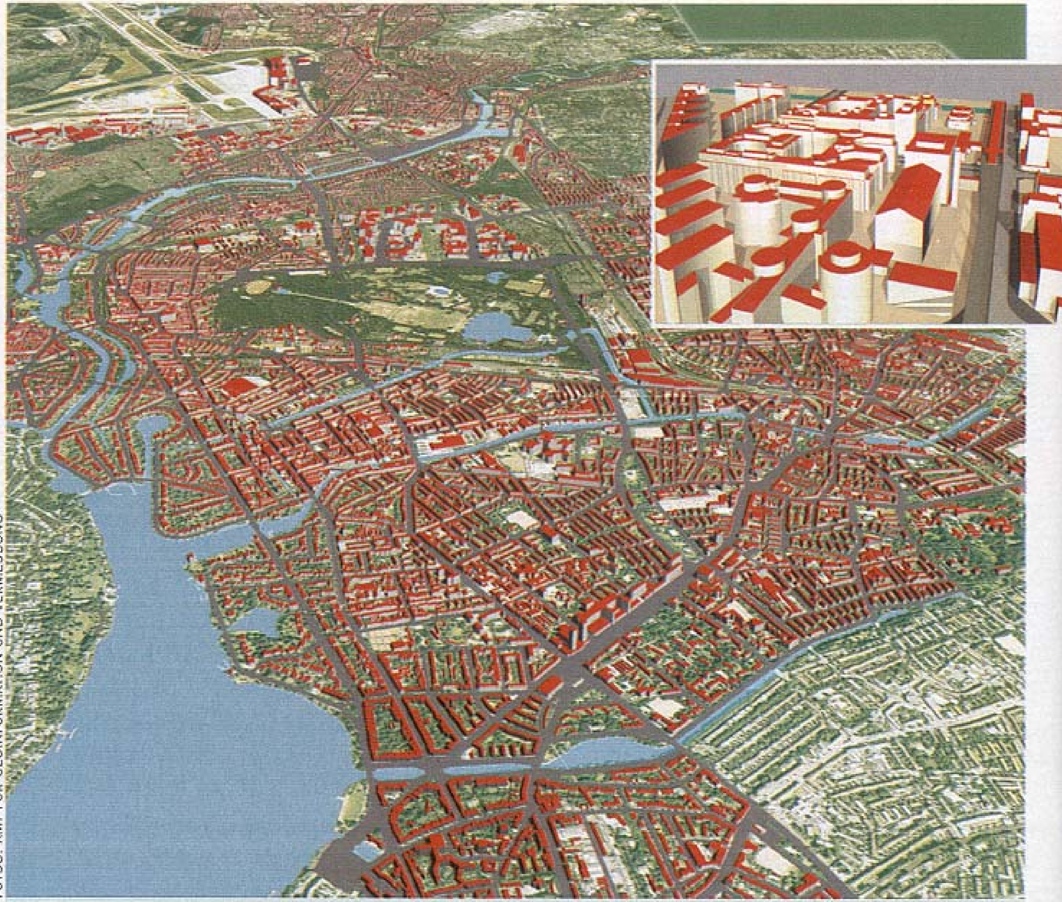
Aim:

Develop methodologies to create damage map using automatic photogrammetric techniques

DEFINITION OF 3D CITY MODELS

A 3D city model describes all objects of interest in an urban area in computer compatible form

- buildings,
- terrain,
- vegetation,
- traffic networks (road, railway)
- public utilities (energy, sewage),
- telecommunication,
- etc.



FOTOS: AMT FÜR GEOINFORMATION UND VERMESSUNG

Hamburg im 3-D-Computermodell (Blick nach Norden über die Außenalster)

KARTOGRAFIE

Modellstadt Hamburg

Hamburger Baubehörde hat ihre ganze Millionenstadt im Computer nach-baut, detailgetreu bis zu den letzten Hafensilos, Eigenheimen und Kiosk-en: 320 000 Gebäude insgesamt, und es ging ziemlich flott. Zum Glück hatte …nt für Geoinformation schon vor Jahren seine hergebrachten Flächenkarten …t den Umrissen aller Bauten digitalisiert. Auf dieser Basis ließen die Vermesser …n jedes Haus im Rechner emporwachsen bis zu der Geschosszahl, die in der …chen Kataster-Datenbank verzeichnet ist, und fertig war das Rohmodell – eine …henstadt, noch ohne Dächer. Im nächsten Schritt fügt nun ein Computer die vielgiebelige Dachlandschaft hinzu, gewonnen aus Luftbildern. Für jeden Sektor nimmt er je zwei Aufnahmen aus schräg versetzten Winkeln. Das ergibt eine Art Stereobild, aus dem sich von jedem Dach die räumliche Gestalt bis auf 20 Zentimeter genau errechnen lässt. Den Nutzen haben am Ende Stadtplaner und Architekten, die im Modell herumfliegen oder ganze Stadtviertel gegen Gebühr auf ihre Rechner kopieren dürfen. Das Amt denkt auch an die Mobilfunkfirmen, die bald neue UMTS-Antennen in großer Dichte aufstellen müssen. In der Modellstadt können sie ihre Gerätschaften so verteilen, dass möglichst jeder Winkel bestrahlt wird.

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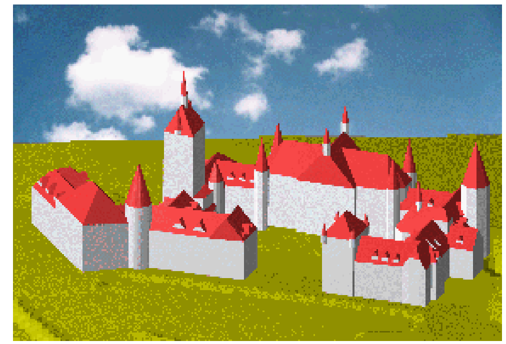
Conversion of aerial or satellite image data into 3D models

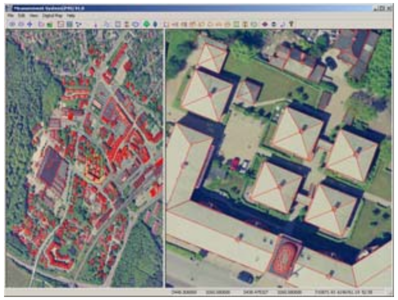
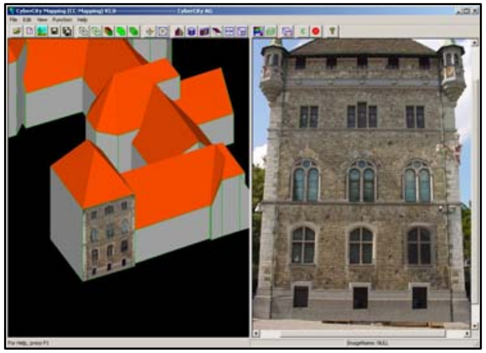
Geometry
Texture



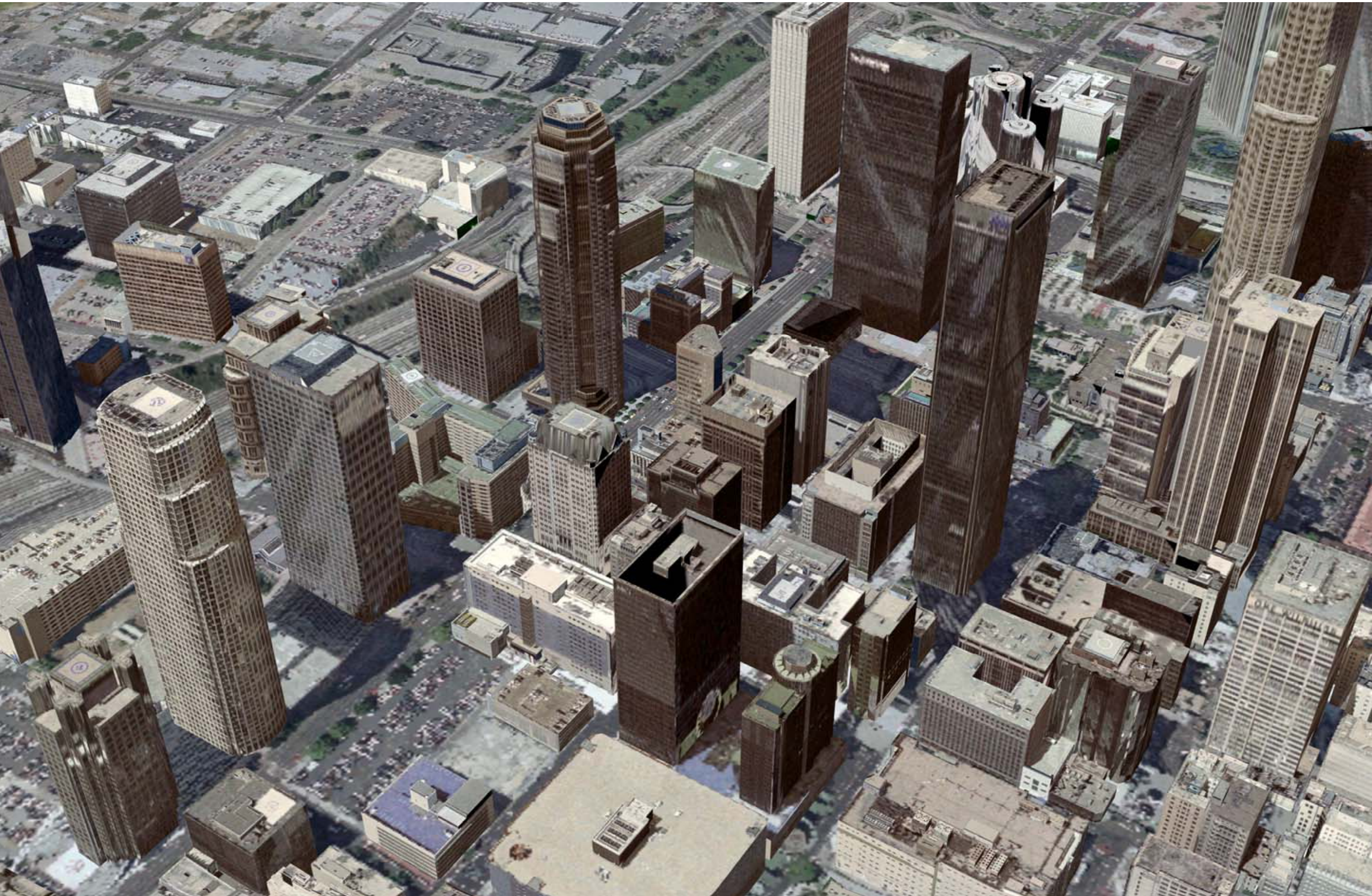
Facade
Texture

CC-Modeler software (typical workflow)
CyberCity Inc., Zurich

Salzburg

1 	2 	3 
Aerial or satellite images (CC-VisualStar)	**Measurement in stereo model** (CC-VisualStar)	**Raw model** (CC-Modeler)
4 	5 	6 
Refined model (CC-Edit)	**Texture mapping** (CC-Mapping)	**Visualization** (e.g. ArcGIS, VRML)

Los Angeles



Landmarks

Reference Projects 3D City Models, CyberCity Inc.

CH: Zurich, Zurich Airport, Berne, Geneva, Chur
D: Hamburg, Giessen, Bonn, Munich, Aventis, Hoechst, BASF, Bad Tölz, Weilheim, Reutlingen, Aalen, Karlsruhe, Audi, HarmanBecker
AU: Vienna, Linz, Salzburg, Hard, Obertauern
GB: London, Pfizer
Dan: Kopenhagen, Karlsberg,Silkeborg, Alborg, Arhus, ...
F: Paris
I: Firenze, Parma
USA: Los Angeles, Santa Monica, Westwood, San Diego, Las Vegas, Chicago, Long Beach Harbour, Port of LA, LittleTokyo, COS, Phoenix, LAX Airport,San Bernardino Airport, etc

Objectives in this research

Case study: **Kobe earthquake**
Data: **A pair of aerial photo before and after**
Method: **using DSM generated automatically (before and after)**
Feature**:** **Difference between DSMs**

→ Map of demolished area Globally

Case study: **Bam earthquake**
Data: **A pair of aerial photo before and after and 2D map of city (before earthquake)**
Method: **using DSM generated automatically (before and after)**
Feature: **Rate of Volume reduction for each building**
Classification: **Thresholding - (optimum value ?)**

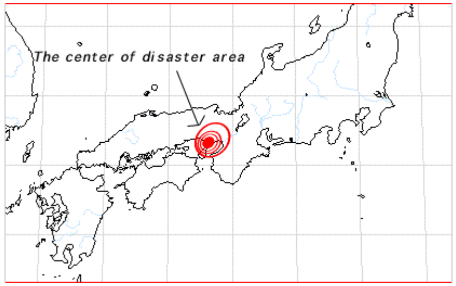
→ Collapsed & Uncollapsed buildings map

Case study: **Bam earthquake**
Data: **A pair of aerial photo before and after and 2D map of city (before earthquake)**
Method: **using DSM (before and after) generated automatically + Edge detection by Canny operator (after)**
Feature: **Rate of Volume reduction for each building + Edge fitness of each building**
Classification: **k-nearest neighbor**

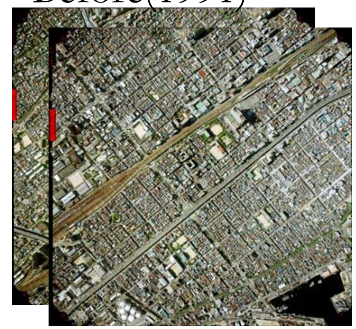
→ Collapsed & partial collapse & no damage buildings map

Study area: Kobe earthquake & Bam earthquake

Kobe Earthquake – Japan
17 January 1995,
7.2 Richter scale



Before(1991)

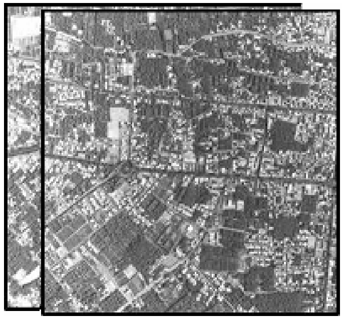


After (1995)

Image scale: **1:6000**	Image scale: **1:5000**
Image resolution: 3**0 micron**	Image resolution: 2**0 micron**
Ground Pixel size: **ca. 20 cm**	Ground Pixel size: **ca. 10 cm**

Bam Earthquake - Iran
26 December 2003,
6.6 Richter scale

Before (1994)



After(2003)

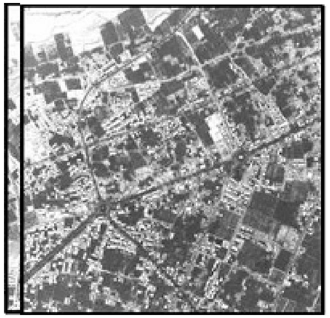


Image scale: **1:10000**

Image resolution: **20 micron**

Ground Pixel size: **ca. 20 cm**

2D map before earthquake

Provided by National Cartography Center of Iran

MERCI

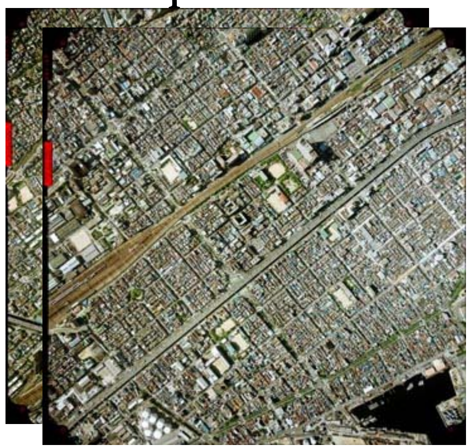
Criteria of aerial photo interpretation

Stereoscopic photo-interpretation	
Damage classification	Criterion of interpretation
Collapse	Totally collapsed, Buildings which reduced to rubble
Partial collapse (Severely damaged)	Partially collapsed, deformed, or severely leaning buildings
No Damage	Without visible damage or buildings whose damage state is difficult to identify from aerial photographs

Regarding to the elapsed time between pre- and post event images, those buildings that existed in both pre and post-earthquake photos were used in the assessments.

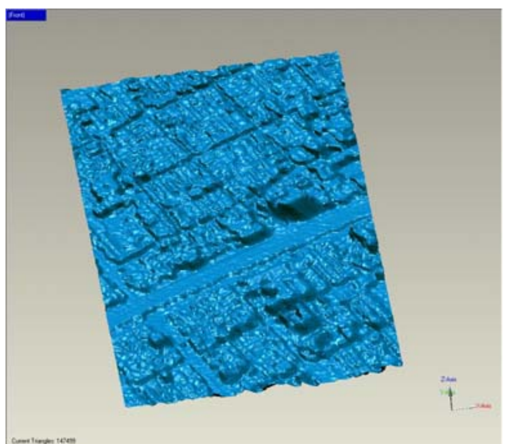
Automatic DSM generation before and after Kobe earthquake

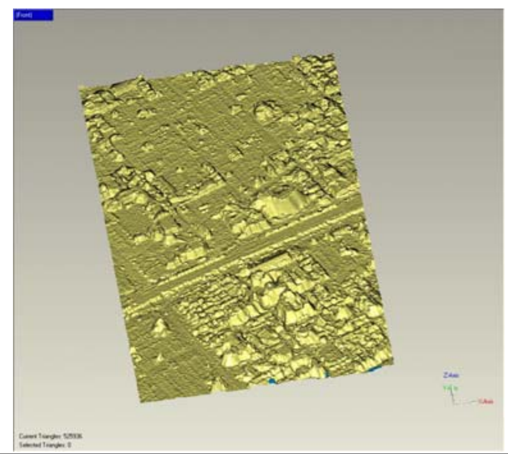
Before earthquake
Aerial photos - 1991



After earthquake
Aerial photos - 1995

Digital Surface Model (DSM) generated by VirtuoZo software automatically



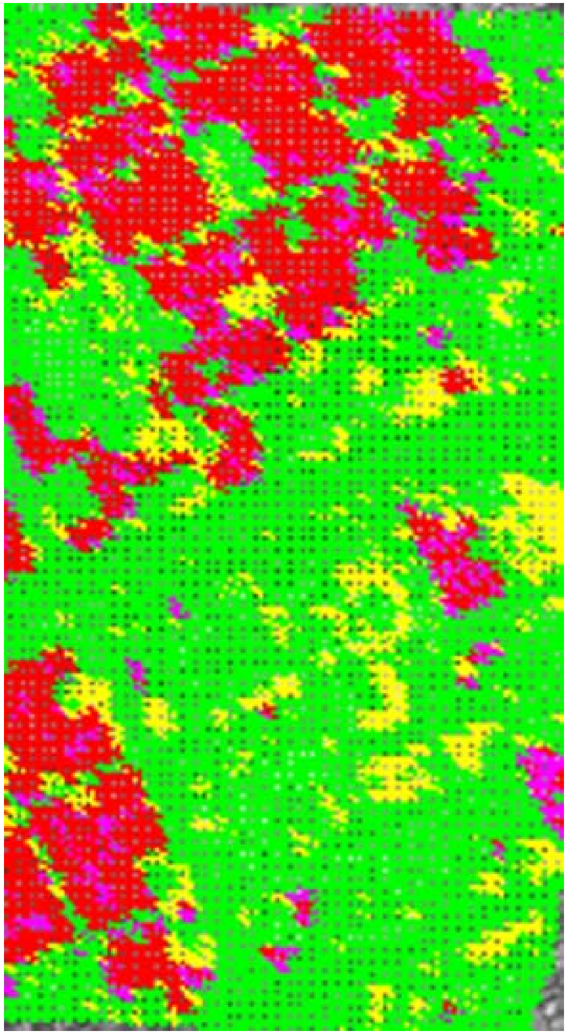


Statistics of height differences with checkpoints - 500 check points			
	Max. absolute (m)	*Mean (m)*	*RMSE (m)*
Before	**27.85**	**-1.00**	**3.11**
After	**18.79**	**-0.29**	**2.69**

Experimental results - Kobe city

If *DSM(before) – DSM(after)* > *'threshold'* then *'collapsed'*

Actual collapsed area



Estimated collapsed area

threshold = 4m

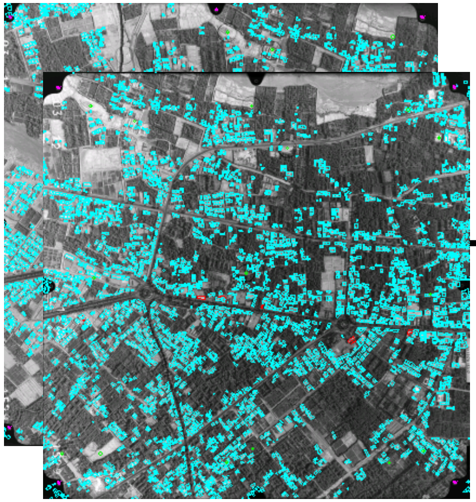
Collapsed – really collapsed

Uncollapsed – really uncollapsed

Uncollapsed but really collapsed

Collapsed but really uncollapsed

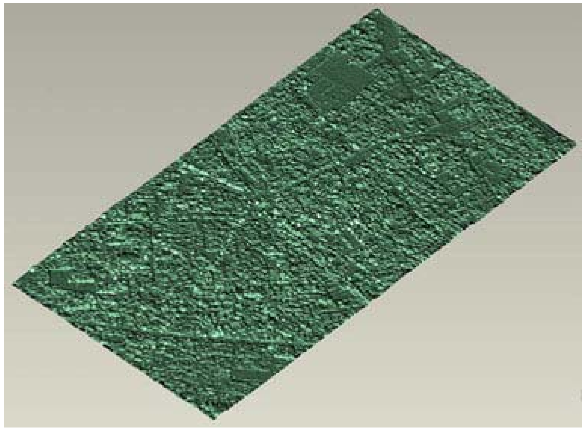
Overall accuracy (correct area / total area) : 75%



Pre-Process :

- Interior Orientation
- Relative Orientation
- Absolute Orientation

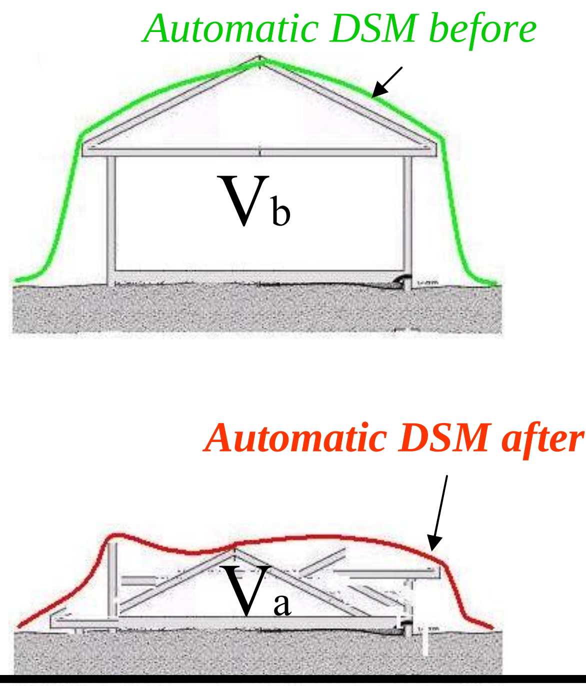
Automatic Digital Surface Model Generation

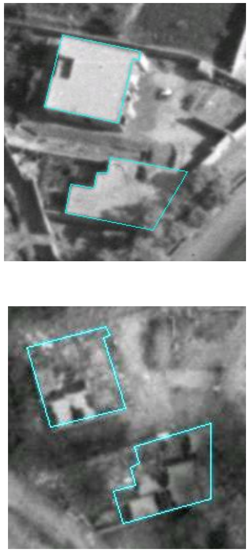


ADSM generated by VirtuoZo
Statistics of height differences with checkpoints (Bam City)

	Number of points	Maximum absolute (m)	Mean (m)	RMSE (m)
Before	4944	11.64	1.24	1.86
After	4530	10.51	1.18	1.66

Feature 1: Rate of Volume Reduction





if :

$$\frac{(V_b - V_a)}{V_b} \times 100 > \text{threshold}$$

then "Collapsed"

else "Uncollapsed"

- To determine **optimum threshold** boundary a method proposed by Fung & LeDrew (1988) was used
- In this method "error matrices" were produced and analyzed for each threshold iteratively

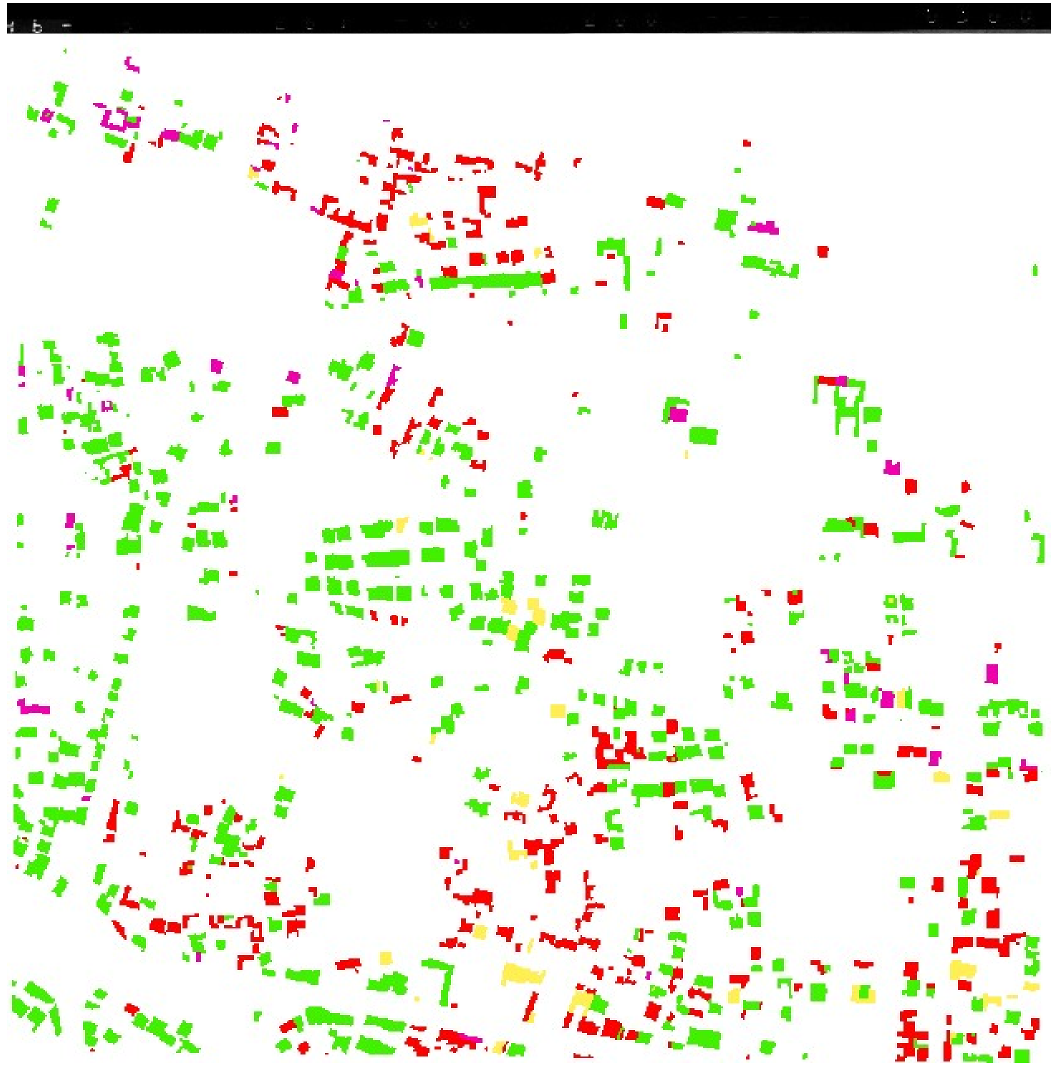
Optimum threshold: $(V_b - V_a)/V_b = 0.65$		Reference		
Rate of volume reduction		Collapsed	Uncollapsed	Total
	Collapsed	240	30	270
	Uncollapsed	35	408	443
	Total	275	438	713
Overall accuracy	**90.85%**			

Experimental results – Bam city

The Accuracy indices computed from Thresholding

Threshold [%]	*Collapsed*		*Un-collapsed*		*Overall accuracy [%]*	*Average accuracy*		*Combined accuracy*		*Kappa (× 100) [%]*
	P [%]	*U [%]*	*P [%]*	*U [%]*		*P [%]*	*U [%]*	*P [%]*	*U [%]*	
40 %	98.54	52.53	44.04	97.96	65.07	71.29	75.24	68.18	70.16	36.62
…										
61 %	90.88	83.00	88.30	93.90	89.30	89.59	88.45	89.44	88.87	77.81
62 %	90.51	84.07	89.22	93.73	89.72	89.87	88.90	89.79	89.31	78.61
63 %	89.05	85.31	90.37	92.92	89.86	89.71	89.12	89.78	89.49	78.78
64 %	88.69	87.41	91.98	92.82	90.70	**90.33**	90.12	90.52	90.41	80.44
65 %	87.23	88.85	93.12	92.06	**90.85**	90.17	90.46	90.51	90.65	**80.62**
66 %	86.13	89.06	93.35	91.46	90.56	89.74	90.26	90.15	90.41	79.97
67 %	83.94	90.55	94.50	90.35	90.42	89.22	90.45	89.82	90.44	79.52
68 %	81.39	90.65	94.72	89.01	89.58	88.06	89.83	88.82	89.70	77.58
69 %	79.93	92.02	95.64	88.35	89.58	87.79	90.18	88.68	89.88	77.46
70 %	77.01	92.55	96.10	86.93	88.73	86.55	89.74	87.64	89.23	75.46
…										
84 %	38.69	100.00	100.00	72.19	76.34	69.34	86.09	72.84	81.22	43.66

Experimental results – Bam earthquake, *using only feature 1*

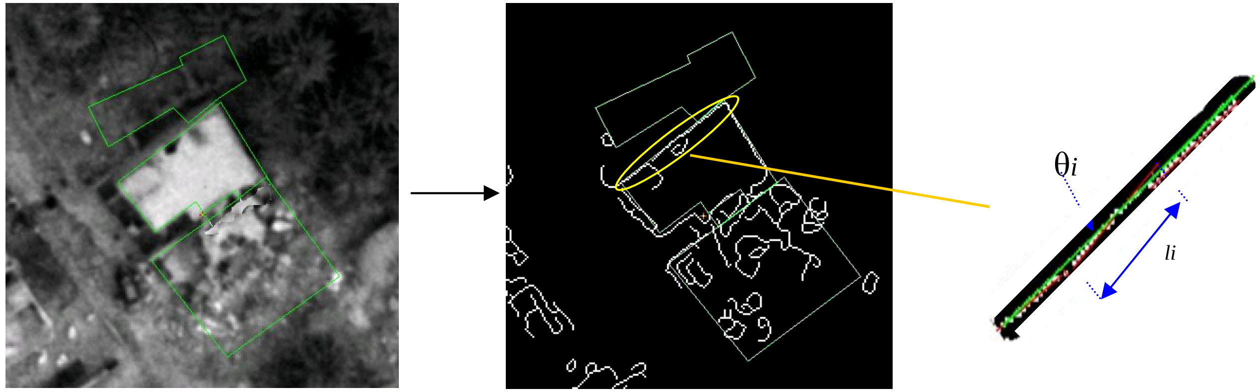


Collapsed- really Collapsed = 240	Uncollapsed-really Uncollapsed = 408
Uncollapsed but really Collapsed = 35	Collapsed but really Uncollapsed = 30

Optimum threshold = 65%, **Overall accuracy= %91**

Feature 2: Rate of edges fitness with actual polygon lines

Canny edge detector



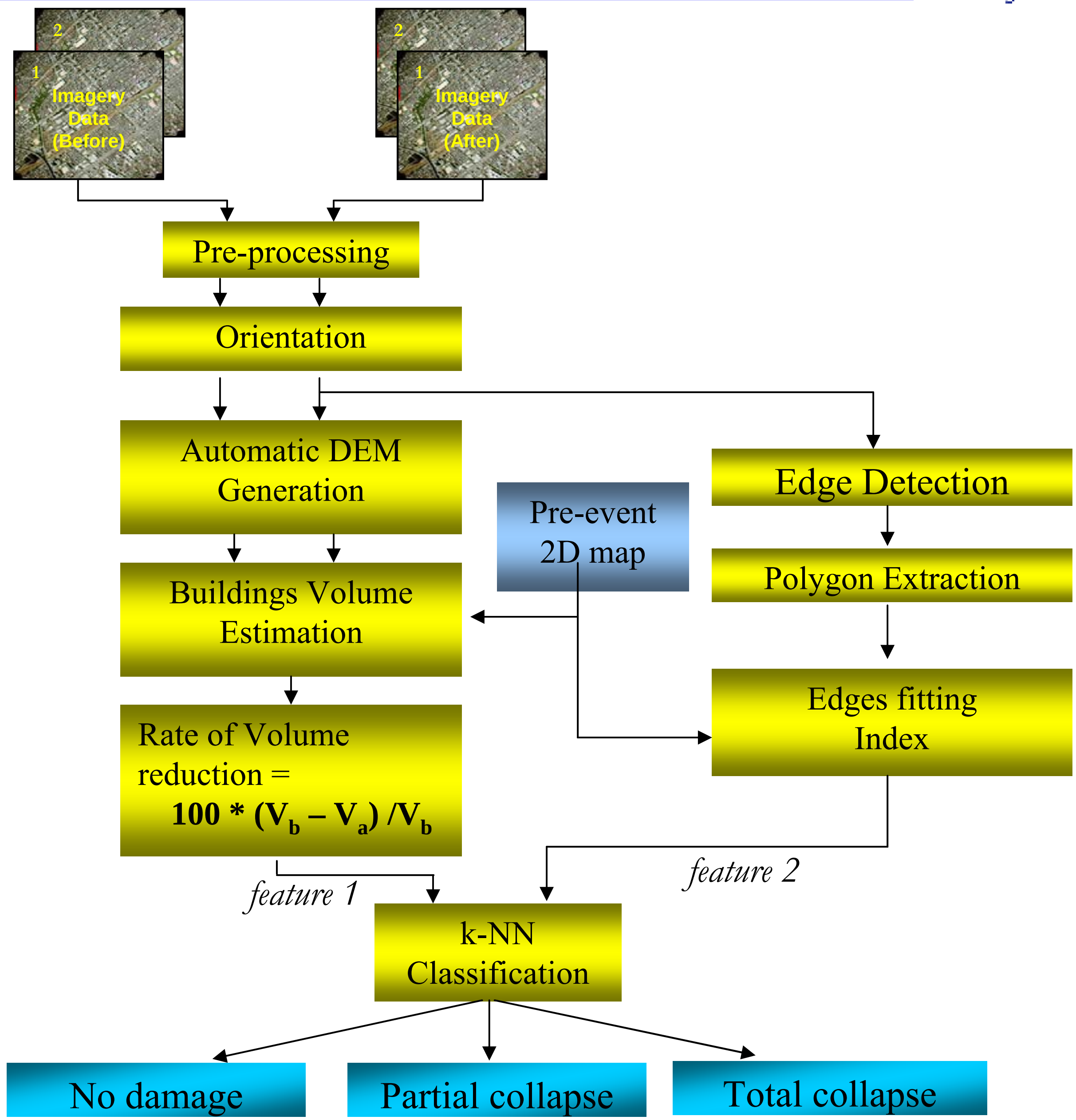
- Regression factor of segmented lines (*r*)
- Angle between segmented lines and actual polygon lines (θ)
- Length of segmented lines (*l*)

$$f_j\left(\frac{\sum l_i r_i \cos\theta_i}{\sum l_i}\right) \propto$$

Rate of demolition for each side of polygon

$$\text{Collapsed} \approx 0 \leq \text{Edge fitting Index} = \sum f_j \leq 1 \approx \text{Uncollapsed}$$

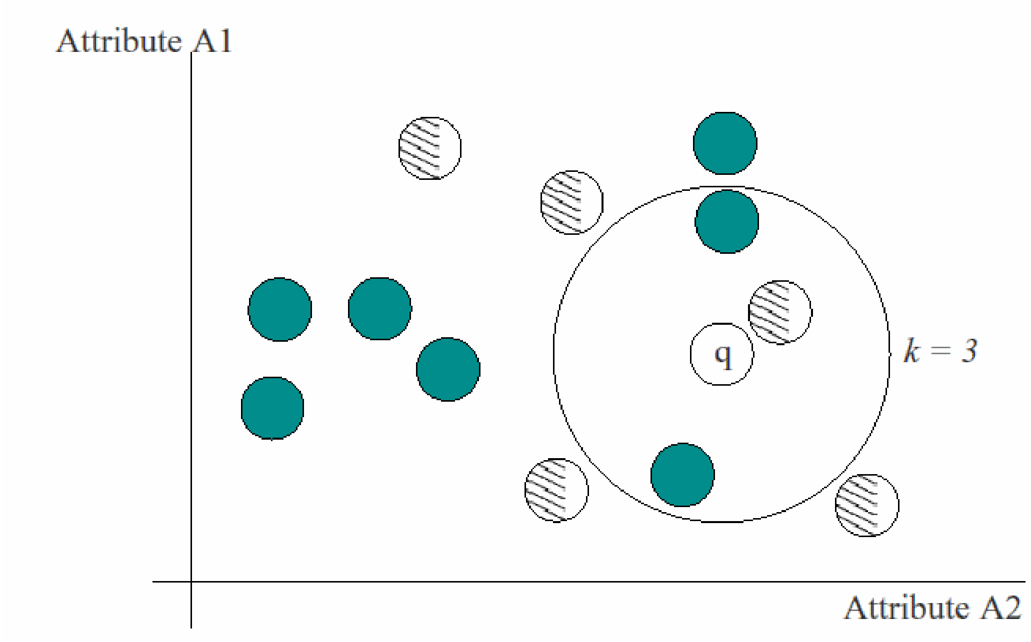
Damage classification flowchart



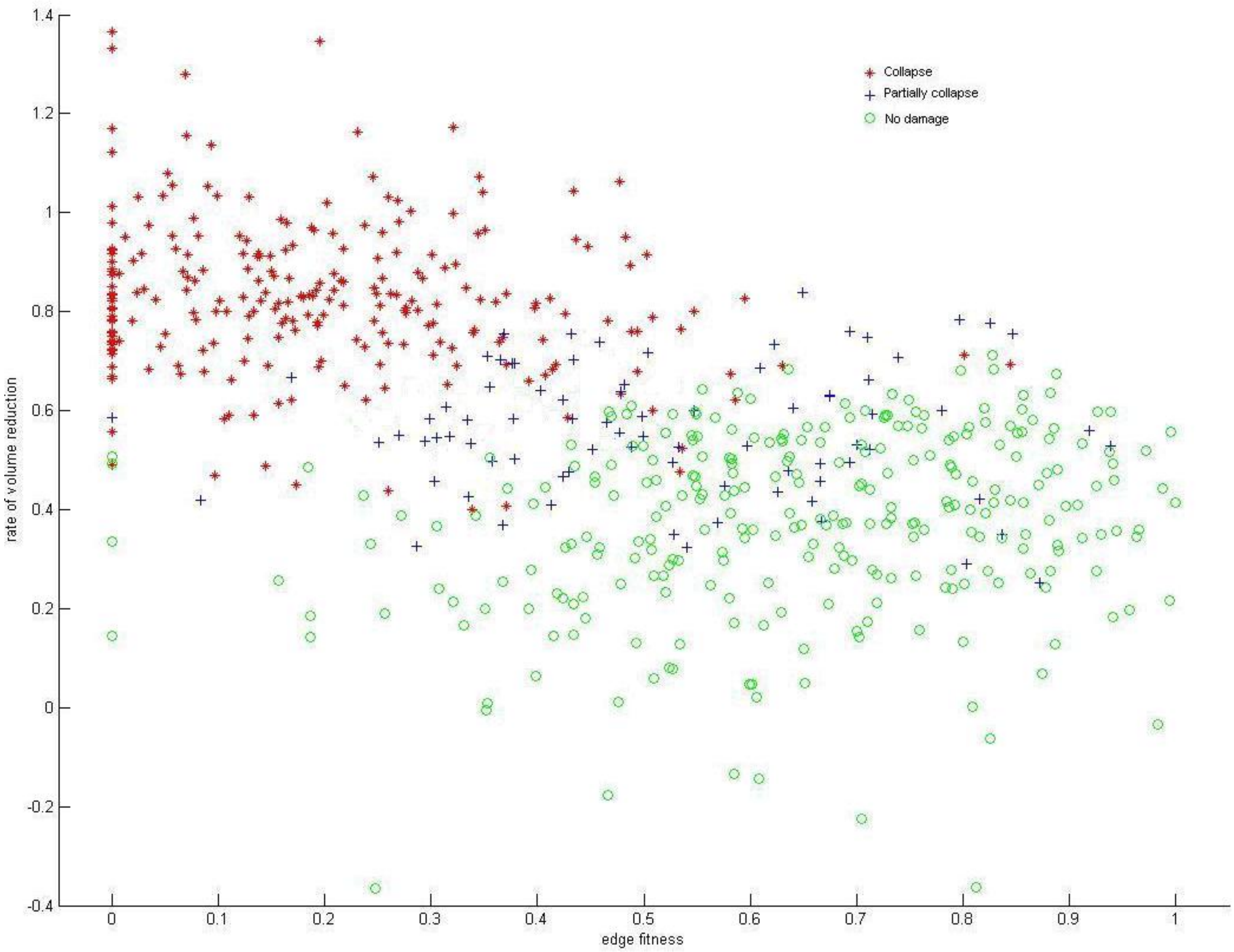
K-Nearest Neighbor classification method

• It is one of a class of methods known as *instance-based* methods.
• In the classification step, we are given an instance q (the query), whose attributes we will refer to as q.Ai and we wish to know its class.
• In k-NN, the class of q is found as follows:
1. Find the k instances in the dataset that are closest to q.
2. These k instances then vote to determine the class of q.

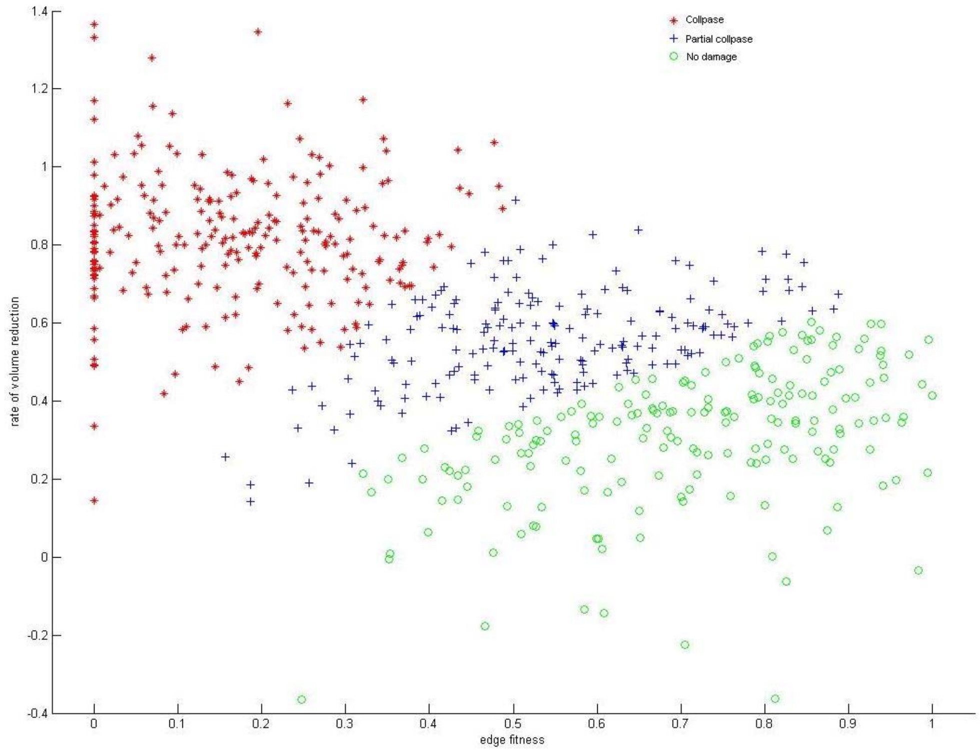
• In the basic nearest neighbor classifier, each training sample is used as a prototype and a test sample is assigned to the closest prototype



Experimental results: Feature space and actual distribution of labeled buildings



Experimental results: output of k-nearest neighbor classification



Training sample, n = 30 (collapse = 10, partial collapse = 10, no damage = 10) , k = 30

Visual interpretation / k-NN classification	**Collapsed**	**Partial Collapsed**	**No Damage**	**Total**
Collapsed	217	12	11	240
Partial Collapsed	34	51	107	192
No Damage	0	13	174	187
Total	251	76	292	619

Conclusions & Discussion

• The accuracy of DSMs directly affects the reliability of automatic detection of the damaged buildings

• Thresholding based on optimum threshold value could successfully reveal the location of collapsed buildings (overall accuracy: 91%). This threshold value must be used in an adaptive manner.

•With k-NN classification a high degree of agreement is evident between the assessment results and the reference data in the 'collapse' state (producer accuracy: 86.5%, user's accuracy: 90.4%, overall acc. 71.4%) None of the collapsed building is labeled as 'no damage' !

• The main reason for 107 'no damage' buildings to be wrongly categorized as 'partial damage' is the mismatching due to image elements like shadows and vegetation, which produce errors in DSM generation.

• The absence of the features on the buildings (hidden in the shadows) caused mismatching between left and right images. Therefore volume estimation has no sufficient accuracy in this area and causes an overlap between 'partial damage' and 'no damage' in feature space. Also, the lack of edges on the boundaries of the adjacent buildings is another problem.

Thank you

- The following accuracy indices were generated from error matrix:

Error matrix

		Reference		
DEM difference		Collapsed	Uncollapsed	Total
	Collapsed	**218**	**31**	**249**
	Uncollapsed	**58**	**406**	**464**
	Total	**276**	**437**	**713**
Producer Accuracy		78.99 % = (218÷276)×100	92.91 % = (406÷437) ×100	
User Accuracy		87.55 % =(218÷249) ×100	87.50 % = (406÷464) ×100	
Average Accuracy (producer's)				**85.95 %**
Average Accuracy (user's)				87.53 %
Overall accuracy ***(is the total number of correctly classified samples - diagonal cells of the matrix - divided by the total number of samples)*** → ***(218 + 406) ÷ 713***				**87. 52 %**
Combined accuracy (producer's) (average of the overall accuracy and producer's average accuracy)				86.73 %
Combined accuracy (user's) (average of the overall accuracy and user's average accuracy)				87.52 %
Kappa (×100) ***(It measures how the classification performs as compared to the reference data – Congalton & Mead (1983) used it to compare the result of several classification methods)*** → *for formula please refer to Fung & LeDrew paper 1988*				**73.21 %**

Kappa: coefficient of agreement (K), by Cohen (1960)

It is a measure of the actual agreement (indicated by the diagonal elements of the matrix) minus chance agreement (indicated by the product of row and column marginals):

$$K = \frac{M \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+} x_{+i}}{M^2 - \sum_{i=1}^{r} x_{i+} x_{+i}}$$

r = the number of rows in the error matrix

x_{ii} = the number of observations in row i and column i (diagonal elements)

$+$ = summation over the index

M = the total number of observations