Damage Assessment with Very-High Resolution Optical Imagery Following the December 26, 2003 Bam, Iran Earthquake

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This paper presents a methodology for quantifying the number of buildings that collapsed following the Bam earthquake. The approach is 'object' rather than 'pixel'-oriented, commencing with the inventory of buildings as objects within high-resolution Quickbird satellite imagery captured before the event. The number of collapsed structures is computed based on the unique statistical characteristics of these objects/buildings within the 'after' scene. A total of 18,872 structures were identified within Bam, of which the results suggest that 34% collapsed - a total of 6,473. Preliminary assessments indicate an overall accuracy for the damage classification of 70.5%.

INTRODUCTION

Over the past decade, the value of optical remote sensing technology for city-wide damage assessment has been increasingly recognized (see Matsuoka and Yamazaki, 2000; Eguchi *et al.*, 2000, 2003; Estrada *et al.*, 2001; Yamazaki, 2001; Adams, 2004, Huyck *et al.*, 2004). As very high-resolution commercial imagery has become available from sensors such as Quickbird and IKONOS, it is now possible to identify damage to individual structures (Chiroiu *et al.*, 2002; Adams *et al.*, 2003, 2004; Saito *et al.*, 2004). This paper summarizes an "object-oriented" methodology for counting the number of buildings that collapsed in Bam - a valuable statistic that was unavailable in the aftermath of the event[a]. Analytically, this approach differs from traditional "pixel-based" optical analyses used to develop damage maps following the 1995 Kobe, Japan (Matsuoka and Yamazaki, 1998), 1999 Marmara, Turkey (Eguchi *et al.*, 2002; Huyck *et al.*, 2004), and 2001 Boumerdes, Algeria (Adams *et al.*, 2003; Yamazaki *et al.*, 2003) earthquakes. The paper commences with an outline of the methodology and goes on a summary of conclusions and directions for future work

METHODOLOGY

An object-oriented methodology (De Kok *et al*., 1999, Benz *et al*., 2004, Bitelli *et al*., 2004) is used here to quantify the number of collapsed buildings in Bam[i]. In theoretical terms, this approach focuses on the analysis of "objects" within the imagery (in this case buildings), rather than individual pixels. For traditional pixel-based studies, each pixel is treated as an analytical unit characterized by reflectance (DN), thematic and processed (e.g. texture) values (Schowengerdt, 1983). In contrast, objects are vector (line/polygon) units encompassing a group of related pixels. They are characterized by the intrinsic properties of the constituent pixels, together with additional relational features that operate in a multi-level hierarchy with respect to their neighbors (Baatz and Schape, 2000). From Table 1, the present study employs high-resolution standard product Quickbird imagery, collected before and in the immediate

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aftermath of the Bam earthquake. These city-wide scenes were pre-processed using techniques of true-color IHS pan-sharpening and contrast enhancement (Carper *et al.,* 1991; Gonzalez *et al.,* 2002). To maximize spatial correspondence between the multi-temporal scenes the “after” event image was registered to the “before” image, using a series of 49 spatially distributed ground control points with a first order polynomial transformation.

Table 1. High-resolution Quickbird imagery of Bam and pre-processing procedures.

Acquisition Date	**Summary True Color Image**	**Spatial Resolution**	**Pre-processing steps**
“Before”: 09/30/2003		0.60 m panchromatic 2.40 m multispectral	IHS pan sharpening (RGB channels), contrast enhancement (linear with 2% saturation)
“After”: 03/01/2004			IHS pan sharpening (RGB channels), contrast enhancement (linear with 2% saturation), registration to “before” using 49 control points (1.8 RMS), first order polynomial mapping function and nearest neighbor re-sampling

The flow diagram in Figure 1a outlines the methodological stages involved in counting the number of collapsed buildings in Bam. In summary, the inventory of intact pre-earthquake buildings is identified through segmentation and classification of the pre-processed ‘before” image. These footprints are superimposed on the “after” image, which visibly distinguishes damaged from non-damaged structures. Footprints throughout the city are then categorized as either collapsed or non-collapsed, based on the unique statistical characteristics of these respective damage states within the post-earthquake scene. Notably, this approach to damage classification differs from the “change detection” analyses previously employed by Adams *et al.* (2004) and Huyck *et al.* (2004). It identifies building collapse in terms of the unique statistical characteristics of intact versus damaged structures within the “after” scene, rather than the degree of change between pre- and post-event images. Finally, the number of collapsed buildings is estimated. The following section describes each of these processing steps, together with accuracy assessments that were conducted for the image segmentation, building classification and damage count. In Figure 1b, each step of this workflow is shown for an illustrative set of buildings in south-east Bam.

The object-oriented components of the analysis (Step 1 through Step 4 in Figure 1) were conducted using eCognition image processing software. Although alternative segmentation algorithms (see, for example, Meinel and Nubert, 2004) and feature extraction software (Feature Analyst, Visual Learning System, Inc.) are currently available, a comparative analysis is beyond the remit of this paper, and as such is reserved as a topic for future work.

a) Methodology

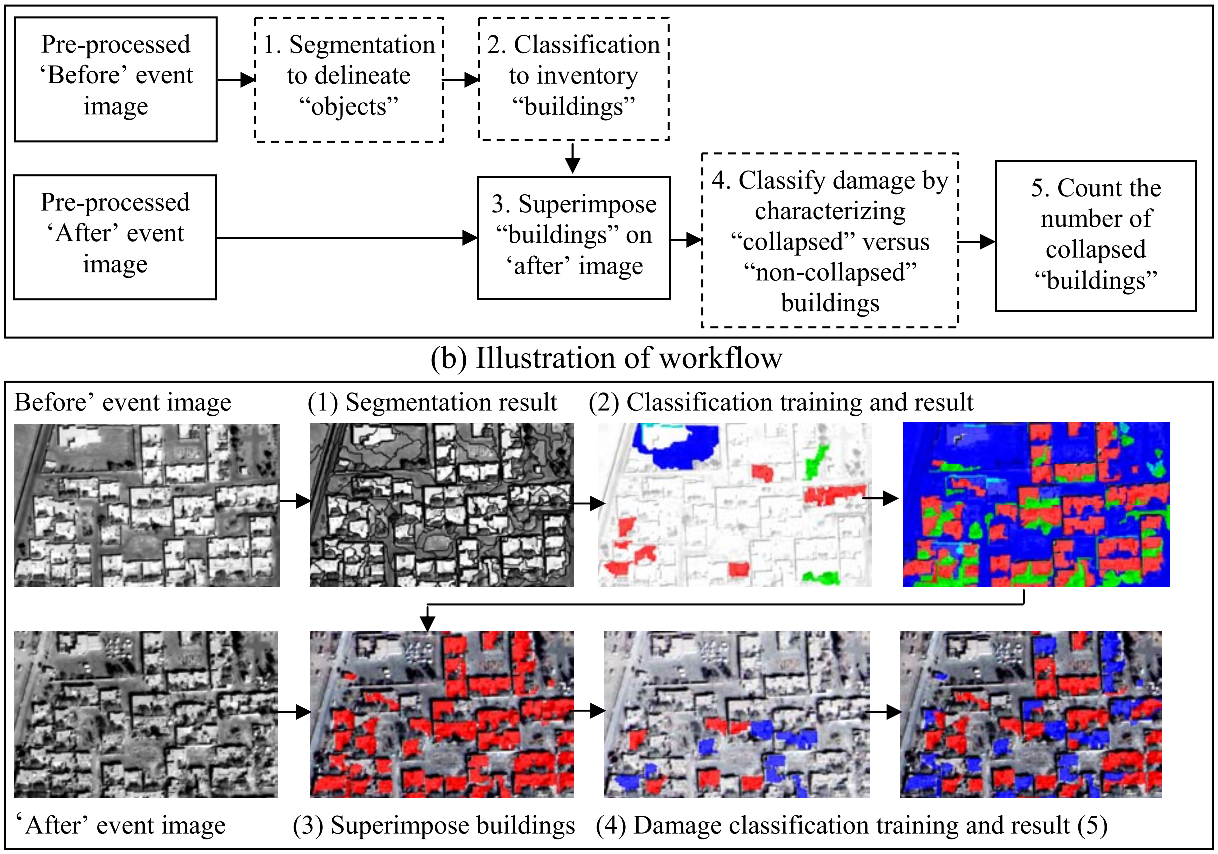

Figure 1. (a) Object-oriented methodology used to count the number of collapsed buildings in Bam. Dashed boxes demarcate processing steps at which an accuracy assessment was performed. (b) Illustration of workflow for a neighborhood in south-east Bam

RESULTS

When superimposing the 'before' image building outlines with the 'after' image, visual inspection of buildings that remained standing suggests that the registration process (see Table 1) generally achieved a close correspondence between their footprints on the pre- and post-event coverage. A small margin of offset (on the order of 2-3 pixels) was evident between the location of some outer walls, apparently due to multi-temporal variability in shadowing and sensor look angle.

Figure 6 shows results for the city-wide re-classification, where a nominal 40% of objects were classified as collapsed. The confusion matrix in Table 2 shows results for the accuracy assessment, which was conducted using 136 samples from the Step 2 building class. A total of 24 objects were rejected from the confusion matrix, because they were misclassified from building to 'other'. For the remaining samples, the re-classification achieved an accuracy of 70.5%. Finally, the proportion of objects classified as collapsed buildings was adjusted to 34.3% according to the marginal probability approach employed by Czaplewski (1992). Accordingly, the final count of collapsed buildings was calculated as 6,473.

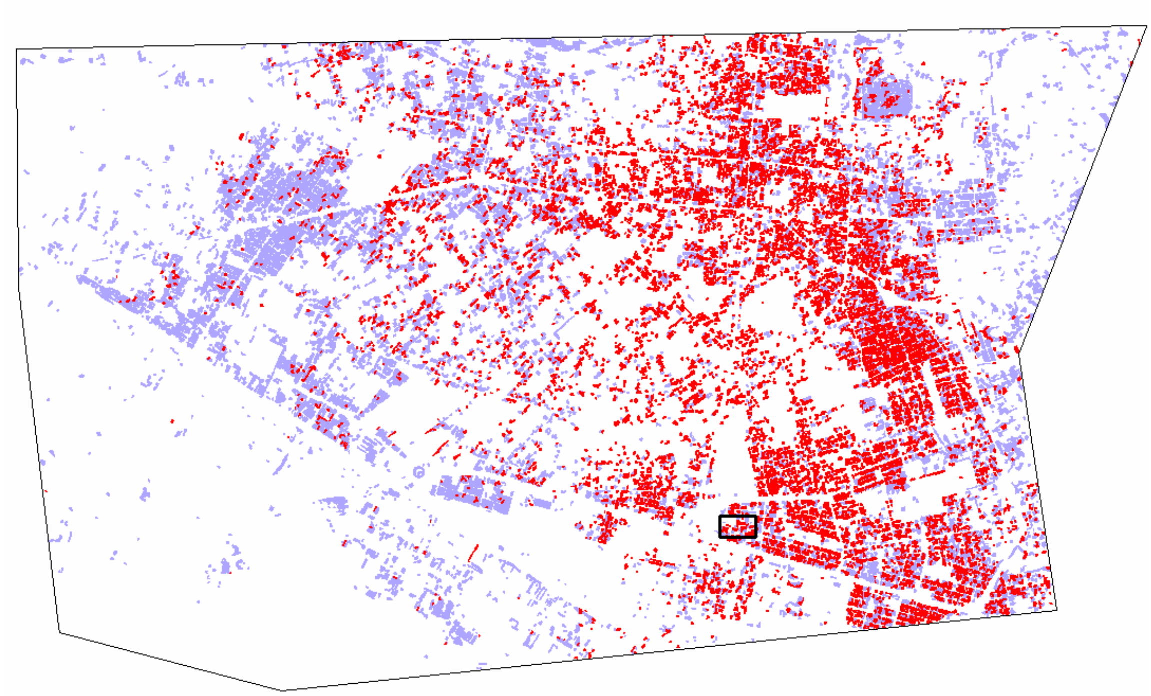

Figure 2. Building damage map for the city of Bam, based on object-oriented analysis of Quickbird imagery captured before and after the event. Collapsed structures are shown in red and non-collapsed in blue. The black box represents the illustrative subset in Figure 1b.

Table 3. Results for the damage re-classification and count of collapsed buildings. The confusion matrix for the accompanying accuracy assessment shows the "Producer" classification accuracy (Congalton, 1982) used to compute the final count.

Damage Detection						**Accuracy assessment**			
	Training Sample	Objects classified	%	Buildings classified	Final count (eq [1])	Collapsed	Not damaged	Total	User Accuracy
Collapsed	174	8,458	40	7,549	6,473 (34.3%)	44	12	56	78.5%
Not damaged	206	12,686	60	11,323	12,399 (65.7%)	21	35	56	62.5%
Total		21,144	100	18,872	18,872	65	47	112	
					Producer accuracy	67.4%	74.4%		

The preliminary results obtained here using e-Cognition object-oriented image processing software suggest that of the 18,872 buildings identified in Bam, 6,473 collapsed. While a comparative analysis of the performance of alternative object-oriented analytical techniques is a subject for further work, it is anticipated that this general theoretical approach has enormous potential to yield rapid urban damage estimates in future disasters.

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