Remote Sensing for Seismic Vulnerability Assessment of Built Environments

Christian Geiß, Joachim Post, Hannes Taubenböck et al.
Motivation

- Rapid urbanization

Taubenböck et al. 2012
Motivation

Conventional approaches to assess the seismic vulnerability of buildings face a challenging situation

„First Assessment - Street Surveying“
Istanbul: 75 engineers 1 year

„Smith rebound hammer test“, Padang 2008
Research Questions

- *Which features* can be derived from satellite remote sensing data that *best explain* seismic building vulnerability?

- *How suitable* are features derived from satellite remote sensing data for *estimating seismic building vulnerability* levels?
Evaluation Scheme

DATA
- Optical (VHR)
- nDSM
- Multitemporal optical (MR)
- IN SITU
  - assessed vulnerability
  - Scoring Value (SV)
  - EMS-98

FEATURE CALCULATION
- Spatial Level
  - Building Level (B)
  - Block Level (S)
  - Features
    - Extent
    - Shape
    - Color
    - Texture
    - Spatial Context
  - 3D Characteristics
  - Period of construction

EVALUATION
- Feature Selection
  - $X_1$, $X_2$, ..., $X_n$
- Regression Analysis
  - $X_1$, $X_2$, ..., $X_n$
  - Results
  - Identify best features for building robust models
  - Identify features with highest explanatory content
  - Build Regression Models
  - Build Classification Models
  - Results
  - Accuracy Assessment
Experiment Setting and Data

Detailed assessment by civil engineers *in situ*

Scoring Value (SV)

**EMS-98**

<table>
<thead>
<tr>
<th>Initial classification</th>
<th>Number</th>
<th>Aggregated classification</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
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<td>A-B</td>
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<td>B</td>
<td>235</td>
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<tr>
<td>B-C</td>
<td>26</td>
<td>B-C</td>
<td>149</td>
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<td>C</td>
<td>123</td>
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<tr>
<td>C-D</td>
<td>32</td>
<td>C-D-E</td>
<td>43</td>
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<tr>
<td>D-E</td>
<td>3</td>
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<td>E</td>
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</table>

Motivation | Seismic Vulnerability Assessment of Buildings | Large-Area Assessment of Urban Structures | Conclusions
Evaluation Scheme
METHODS
Feature Calculation

Spatial Level

Building Level

Block Level

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Methods
Feature Calculation

132-dimensional feature vector, whereby 73 features are related to individual buildings, and 59 provide block level information.

a) features that went into the calculation of the \textit{in situ} values when they can be quantified by means of remote sensing data

b) features frequently utilized in previous studies on remote sensing based building vulnerability assessment

c) features that were used to discriminate urban built-up structures by means of remote sensing previously
METHODS

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- Regression Analysis
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### RESULTS

Regression Analysis

**SCORING VALUE (SV)**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heightb</td>
<td>3.01487***</td>
<td>3.13441***</td>
<td>5.07357***</td>
<td>5.08306***</td>
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<tr>
<td>Roof Type</td>
<td>.98291</td>
<td>.6640369</td>
<td>1.081441</td>
<td>1.063173</td>
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<tr>
<td>GLCM Homogeneity</td>
<td>.2558058</td>
<td>.2544025</td>
<td>.2649701</td>
<td>.2515001</td>
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<tr>
<td>GLCM Homogeneity</td>
<td>1.07571</td>
<td>1.315121</td>
<td>.4871516</td>
<td>1.336938</td>
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<tr>
<td>M(3):M(4)</td>
<td>1.350518***</td>
<td>5738469</td>
<td>.7967434</td>
<td>651387</td>
</tr>
<tr>
<td>M(2)/(M(1)+M(2)+M(3)+M(4))</td>
<td>170.6297</td>
<td>190.7972</td>
<td>217.2341</td>
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<tr>
<td>M(2):M(4)</td>
<td>9.150705</td>
<td>-1.461638</td>
<td>10.16238</td>
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<tr>
<td>Number of observations</td>
<td>434</td>
<td>434</td>
<td>434</td>
<td>434</td>
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<tr>
<td>R²</td>
<td>0.167</td>
<td>0.262</td>
<td>0.288</td>
<td>0.320</td>
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</tbody>
</table>

Height and geometry are the most important determinants (significant at 99.9% level)

R² of 0.262;

Additional features raise the model’s R² value to 0.32

Spectral features enhance model performance but are rarely significant

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# RESULTS

**Supervised Regression**

## SCORING VALUE (SV)

### Multi-linear Regression

<table>
<thead>
<tr>
<th>Used features</th>
<th>MAE</th>
<th>MAPE</th>
<th>ME</th>
<th>MPE</th>
<th>StDev</th>
<th>RStDev</th>
<th>R</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>All features</td>
<td>2.33</td>
<td>13.32</td>
<td>-0.56</td>
<td>-3.02</td>
<td>2.56</td>
<td>14.32</td>
<td>0.43</td>
<td>2.98</td>
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<tr>
<td>Relief-F W(A)&gt;0</td>
<td>2.02</td>
<td>11.84</td>
<td>-0.11</td>
<td>-0.58</td>
<td>2.07</td>
<td>11.29</td>
<td>0.48</td>
<td>2.62</td>
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<tr>
<td>CFS subset</td>
<td>1.84</td>
<td>10.99</td>
<td>-0.17</td>
<td>-0.91</td>
<td>1.52</td>
<td>8.33</td>
<td>0.56</td>
<td>2.41</td>
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<tr>
<td>CFS subset (R&lt;0.8)</td>
<td>1.80</td>
<td>10.81</td>
<td>-0.20</td>
<td>-1.10</td>
<td>1.45</td>
<td>7.96</td>
<td>0.58</td>
<td>2.37</td>
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</tbody>
</table>

### Support Vector Regression

<table>
<thead>
<tr>
<th>Used features</th>
<th>MAE</th>
<th>MAPE</th>
<th>ME</th>
<th>MPE</th>
<th>StDev</th>
<th>RStDev</th>
<th>R</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>All features</td>
<td>1.88</td>
<td>11.26</td>
<td>0.02</td>
<td>0.13</td>
<td>1.91</td>
<td>10.37</td>
<td>0.53</td>
<td>2.48</td>
</tr>
<tr>
<td>Relief-F W(A)&gt;0</td>
<td>1.79</td>
<td>11.07</td>
<td>0.43</td>
<td>2.31</td>
<td>1.72</td>
<td>9.13</td>
<td>0.57</td>
<td>2.42</td>
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<tr>
<td><strong>CFS subset</strong></td>
<td><strong>1.72</strong></td>
<td><strong>10.61</strong></td>
<td><strong>0.23</strong></td>
<td><strong>1.25</strong></td>
<td><strong>1.54</strong></td>
<td><strong>8.28</strong></td>
<td><strong>0.59</strong></td>
<td><strong>2.36</strong></td>
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<tr>
<td>CFS subset (R&lt;0.8)</td>
<td>1.73</td>
<td>10.67</td>
<td>0.24</td>
<td>1.31</td>
<td>1.63</td>
<td>8.73</td>
<td>0.59</td>
<td>2.36</td>
</tr>
</tbody>
</table>

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## RESULTS

Supervised Regression and Classification

EMS-98

**Overall Accuracy:** 65.4%

**Kappa statistic:** 0.36

<table>
<thead>
<tr>
<th>Class</th>
<th>User’s Accuracy (Precision)</th>
<th>Producer’s Accuracy (Recall)</th>
<th>ROC Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>0.696</td>
<td>0.793</td>
<td>0.666</td>
</tr>
<tr>
<td>B-C</td>
<td>0.661</td>
<td>0.554</td>
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<tr>
<td>C-D-E</td>
<td>0.294</td>
<td>0.227</td>
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<tr>
<td>Weighted Average</td>
<td>0.643</td>
<td>0.654</td>
<td>0.645</td>
</tr>
</tbody>
</table>
Large-area Assessment

data with coarser spatial resolution but larger spatial coverage (TanDEM-X, RapidEye)

Polygon()

$X_1$
$X_2$
$X_3$
...

urban structures determined by large industrial/commercial buildings (highly vulnerable)

urban structures determined by tall detached residential buildings (slightly vulnerable)
Large-area Assessment

Overall Accuracy: 85.6%
Kappa statistic: 0.77
Conclusions & Outlook

- relation between urban morphology drawn from remote sensing and seismic building vulnerability exists

- estimations feature accuracies that may allow for a valuable support with respect to seismic vulnerability assessment

- define common scales and benchmark accuracies that need to be met

User: Can I make decisions based on the results?
Scientist: What accuracies do you need in order to make decisions?
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