ESC 2012 Moscow

Exposure and Vulnerability Estimation from satellite and ground-based remote sensing

for seismic risk assessment in Bishkek, Kyrgyzstan

Massimiliano Pittore, M. Wieland, S. Parolai, J. Zschau
GFZ Potsdam, Section 2.1 Earthquake Risk and Early Warning
GFZ Potsdam, Centre for Early Warning

GFZ Helmholtz-Zentrum Potsdam

HELMHOLTZ ASSOCIATION

Introduction

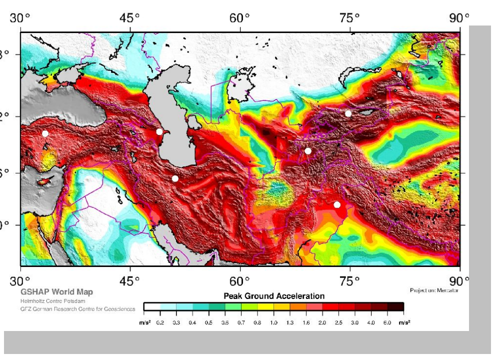
EMCA EARTHQUAKE MODEL CENTRAL ASIA
http://www.emca-gem.org

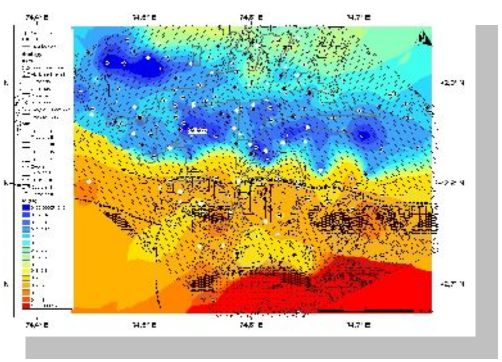
Seismic Risk

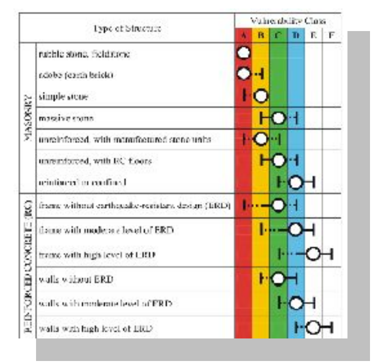
Seismic Hazard
- Probability
- Intensity
- Location

Exposure
- Buildings
- People

Vulnerability
- Physical
- Social

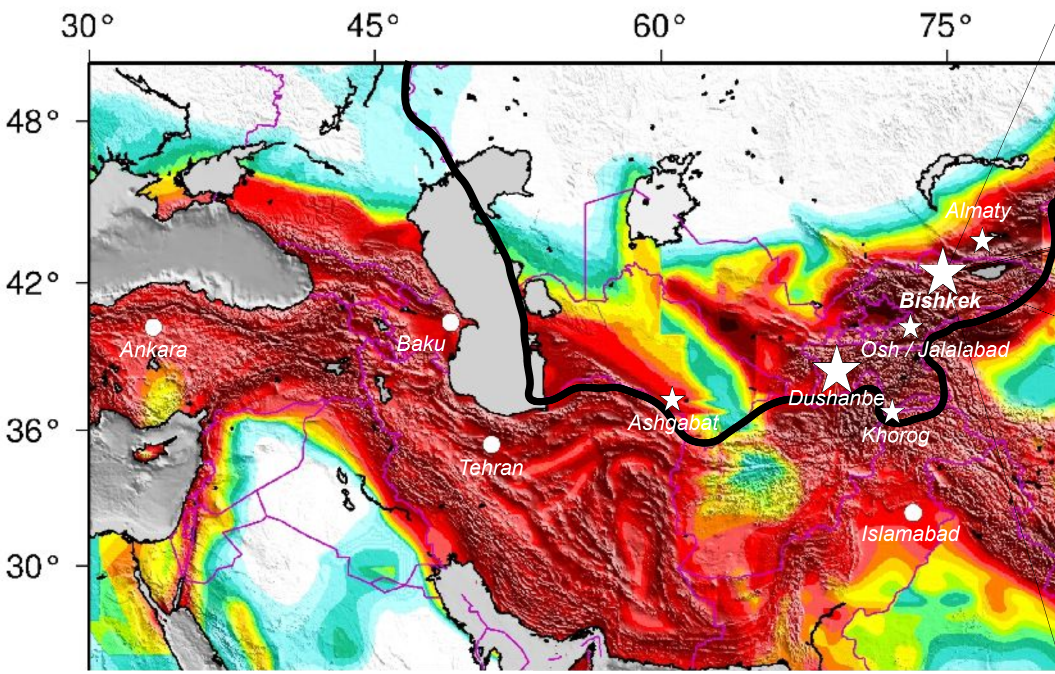


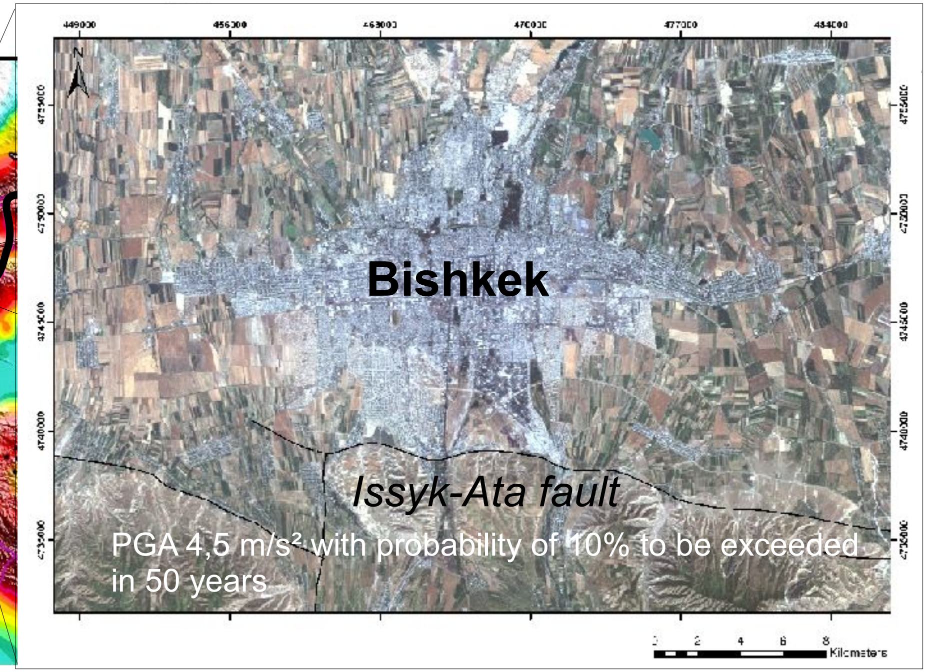


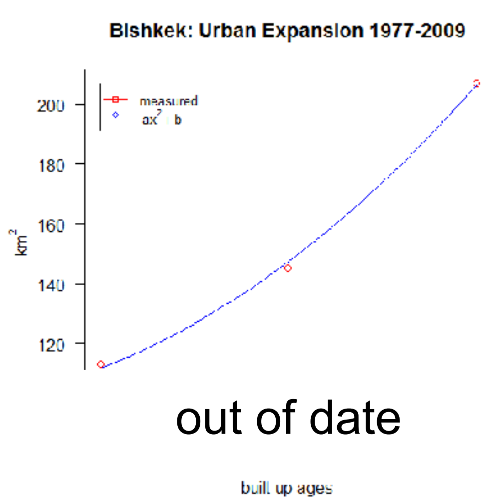


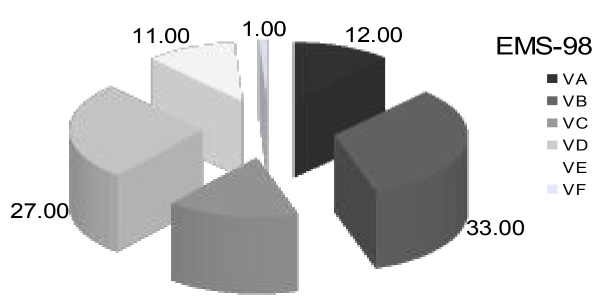
Motivation

EMCA
EARTHQUAKE MODEL CENTRAL ASIA
http://www.emca-gem.org









ID	Building floor	The constructive decision	EMS-98
1	Three- floor building with a ground floor	Building with bearing brick walls and ferro-concrete overlappings	B
2	Nine-floor building with a ground floor	Ferro-concrete frame with brick filling of walls and ferro-concrete overlappings	D
3	Five-floor building with a ground floor	Ferro-concrete frame with brick filling of walls and ferro-concrete overlappings	C

out of date — highly aggregated — spatially fragmented

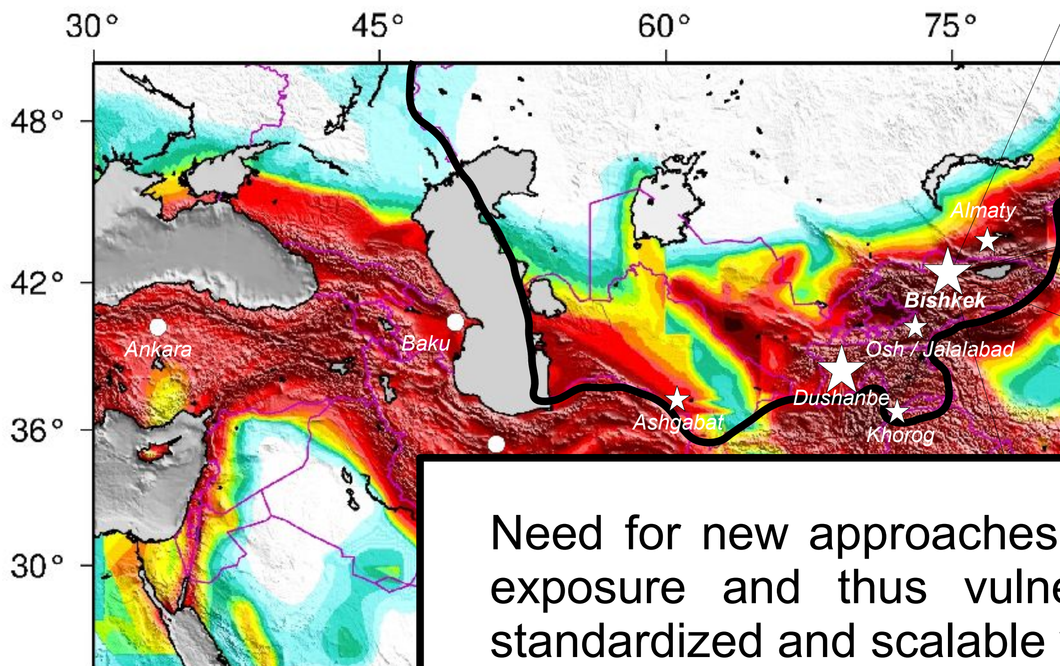
GFZ Helmholtz-Zentrum Potsdam

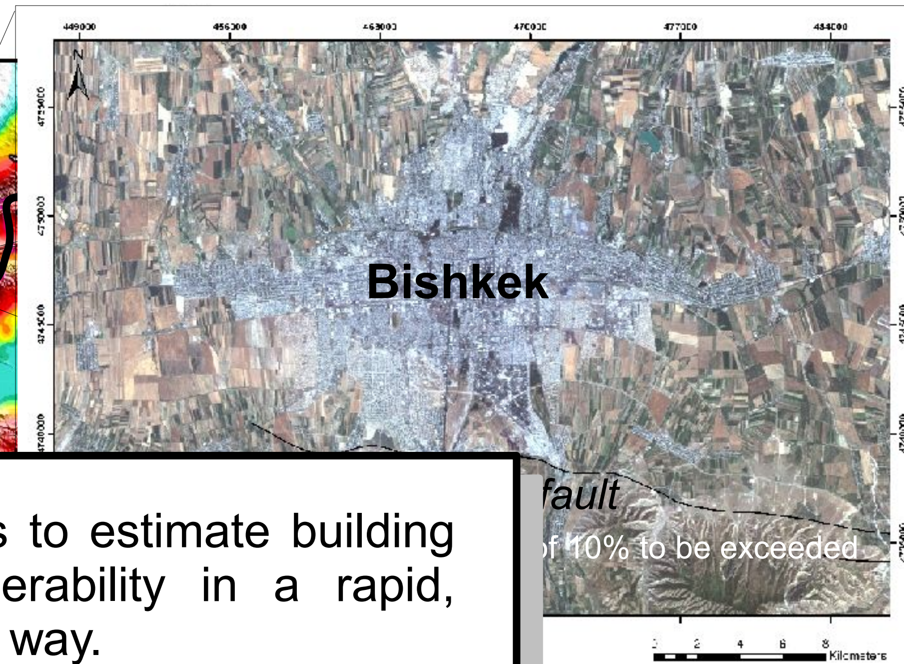
HELMHOLTZ ASSOCIATION

EMCA EARTHQUAKE MODEL CENTRAL ASIA

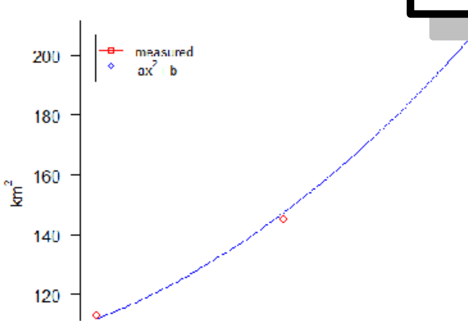
http://www.emca-gem.org

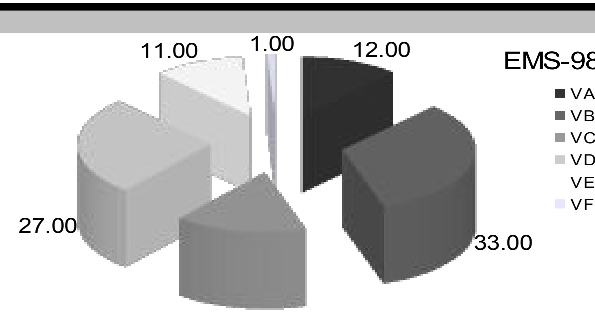
Motivation





Need for new approaches to estimate building exposure and thus vulnerability in a rapid, standardized and scalable way.





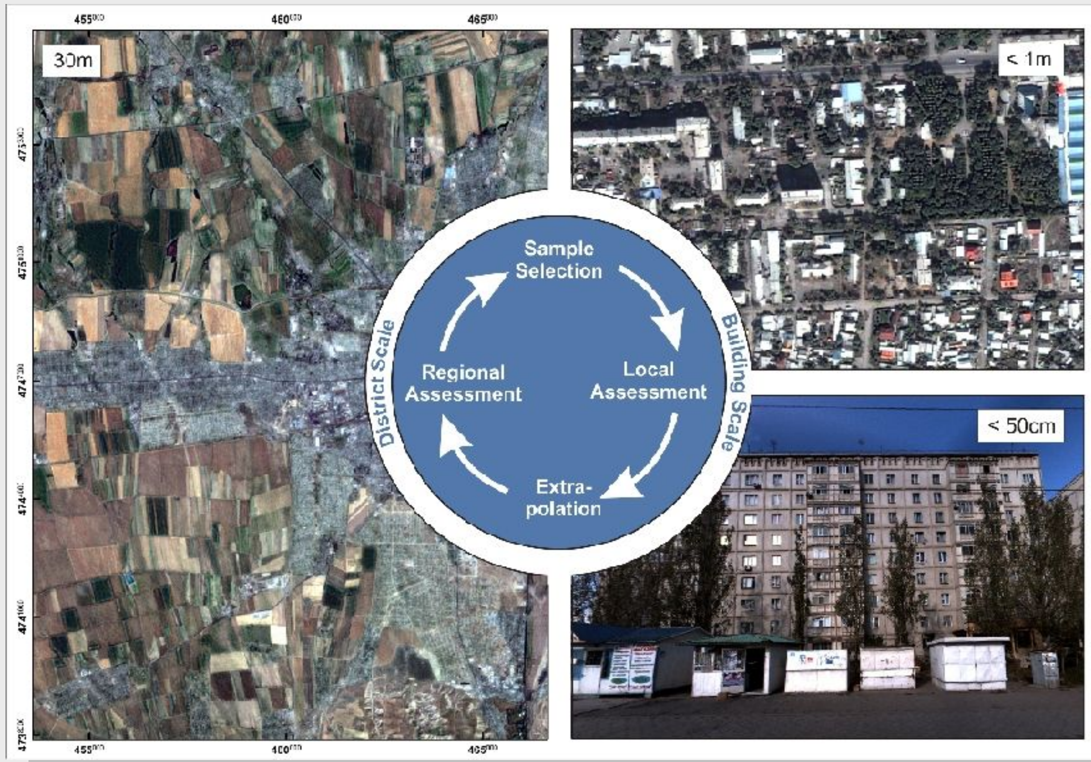
		The constructive decision	EMS-98
	with a ground floor	uilding with bearing brick walls and ferro-concrete overlappings	B
2	Nine-floor building with a ground floor	Ferro-concrete frame with brick filling of walls and ferro-concrete overlappings	D
3	Five-floor building with a ground floor	Ferro-concrete frame with brick filling of walls and ferro-concrete overlappings	C

out of date — highly aggregated — spatially fragmented

Overview of the approach

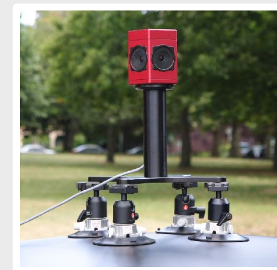
Multi-scale Exposure Estimation

remote



rapid visual survey (RVS) allows for a reasonable first assessment

Coupling **remote sensing** with **in-situ imaging** RVS can be optimized over broad areas.



in-situ

Exposure / Vulnerability model

Stratification (remote) → Sampling (in-situ) → Integration

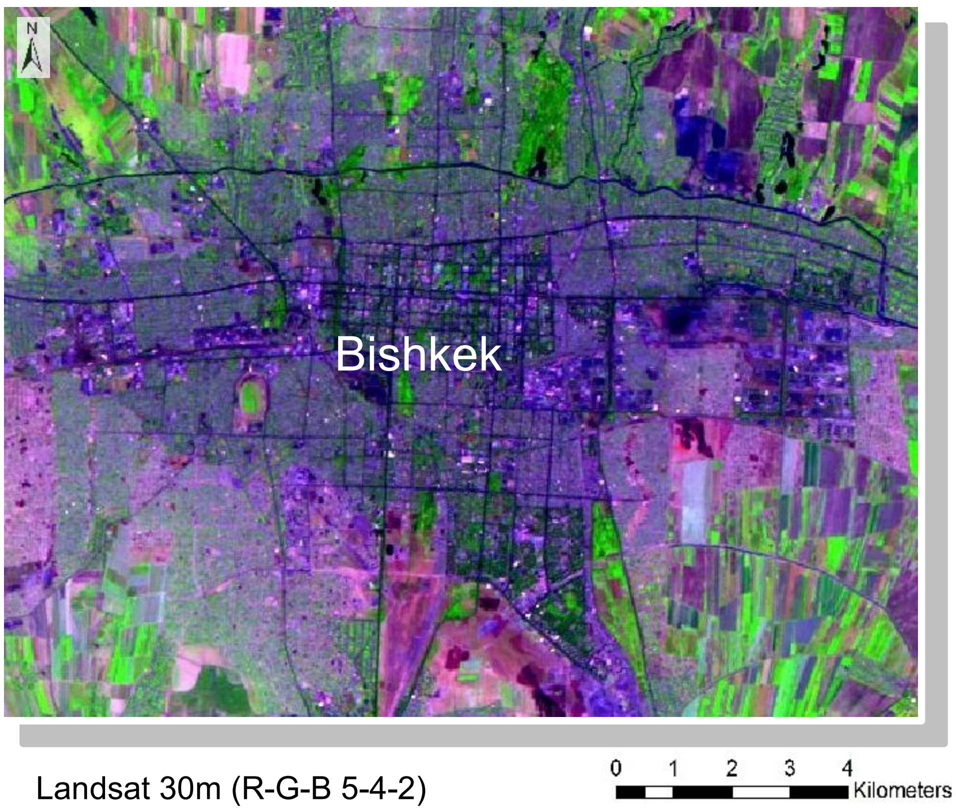
Probabilistic Risk Framework

Analysis of medium-resolution satellite images

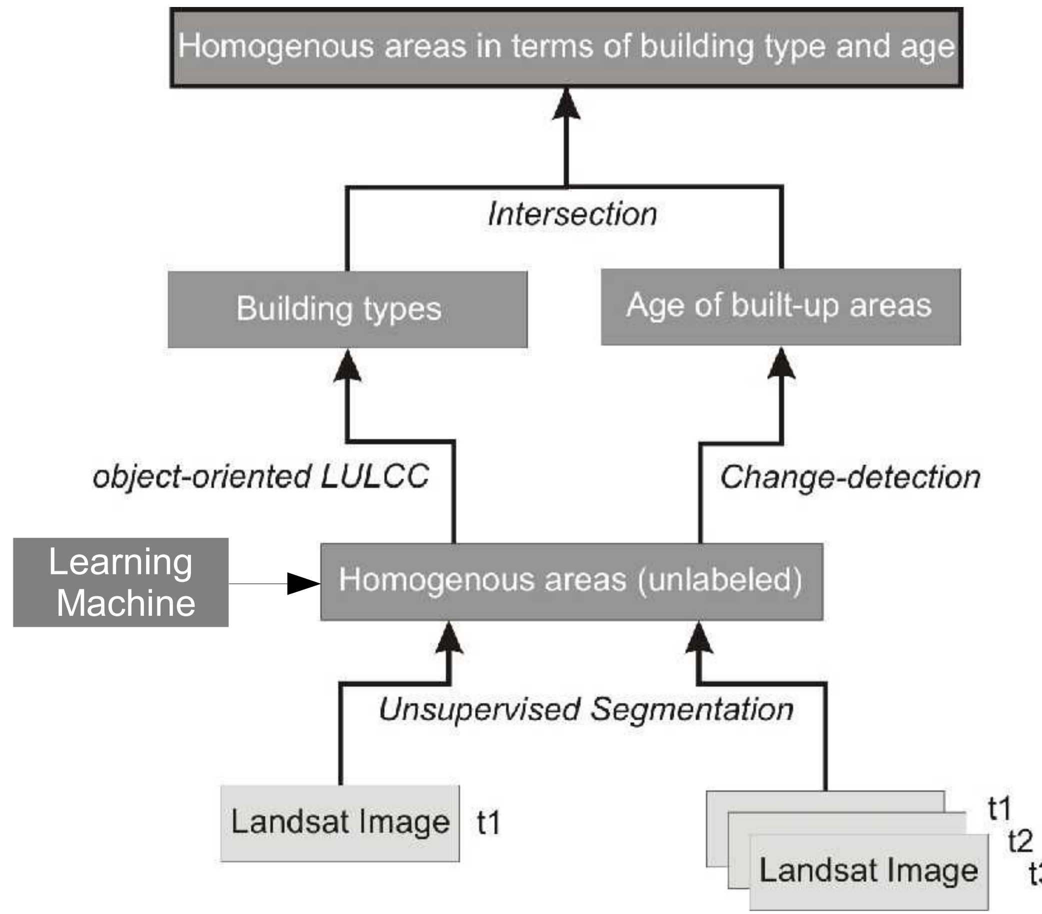
Stage of Stratification

Workflow / Results

Pixels



Landsat 30m (R-G-B 5-4-2)

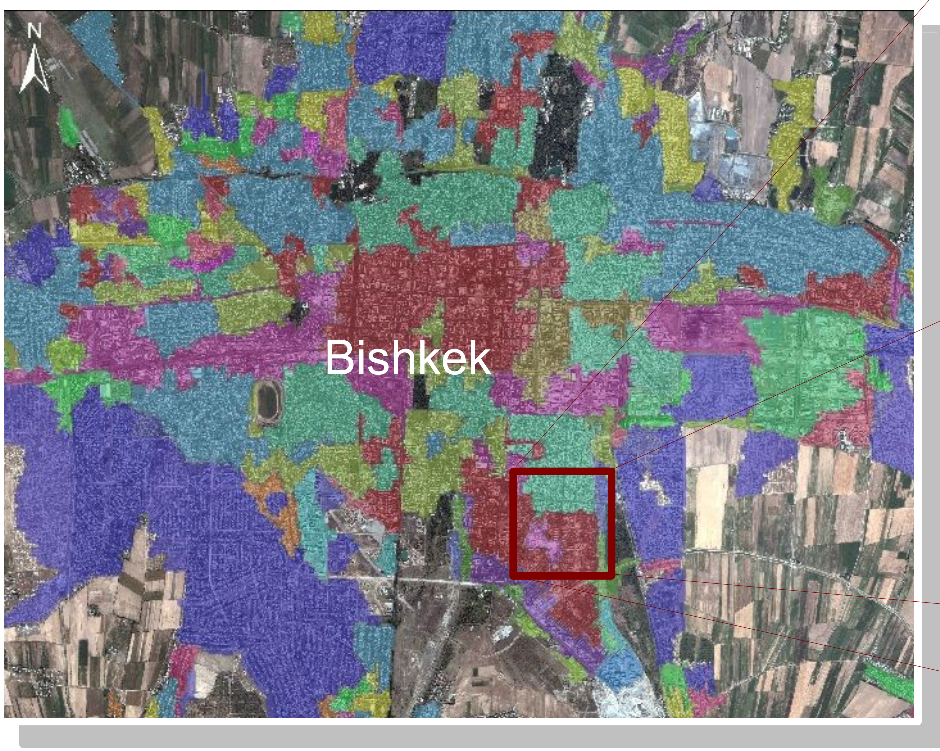


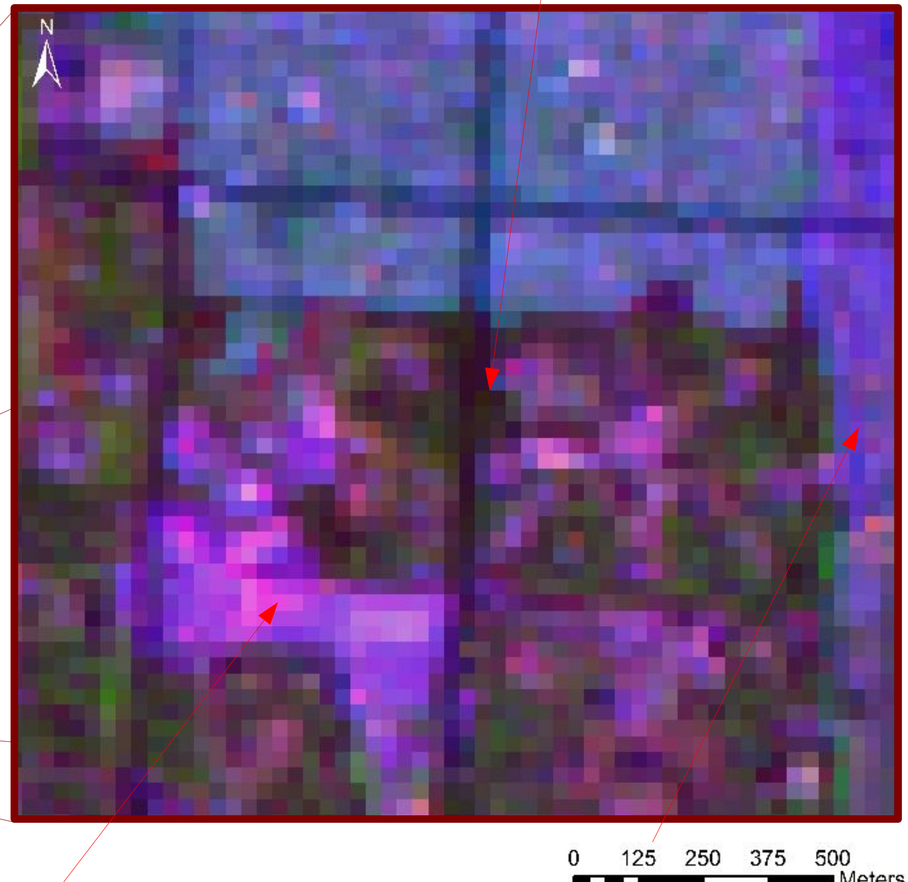
Pixels → Segments → Thematic classes → Urban Structure Types

Analysis of medium-resolution satellite images

Stage of Stratification

Urban Structure Types





Urban Structure Type: 10
Type: 3-6 storey brick, concrete, panel
Age: built before 1977

Urban Structure Type: 16
Type: industrial, commercial
Age: built before 1977

Urban Structure Type: 8
Type: 1-2 storey masonry, brick
Age: built between 1994 and 2009

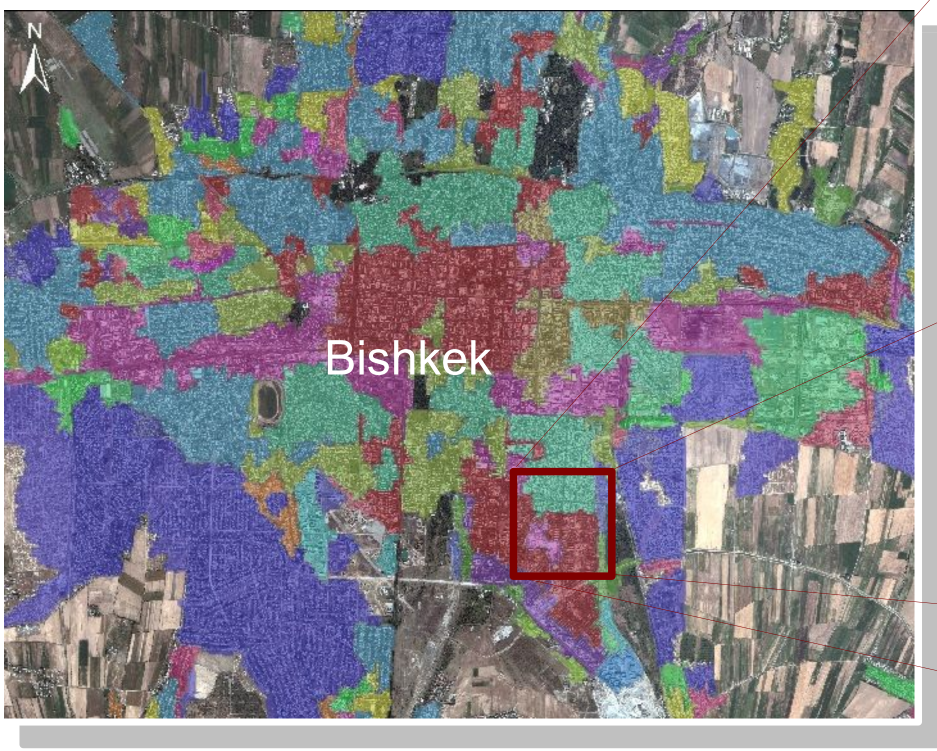
Product	Overall Accuracy	Cohen's Kappa
MR built-up mask (1977)	88.33%	0.66
MR built-up mask (1994)	87.67%	0.67
MR built-up mask (2009)	90.00%	0.78
MR LULC (2009)	81.00%	0.79

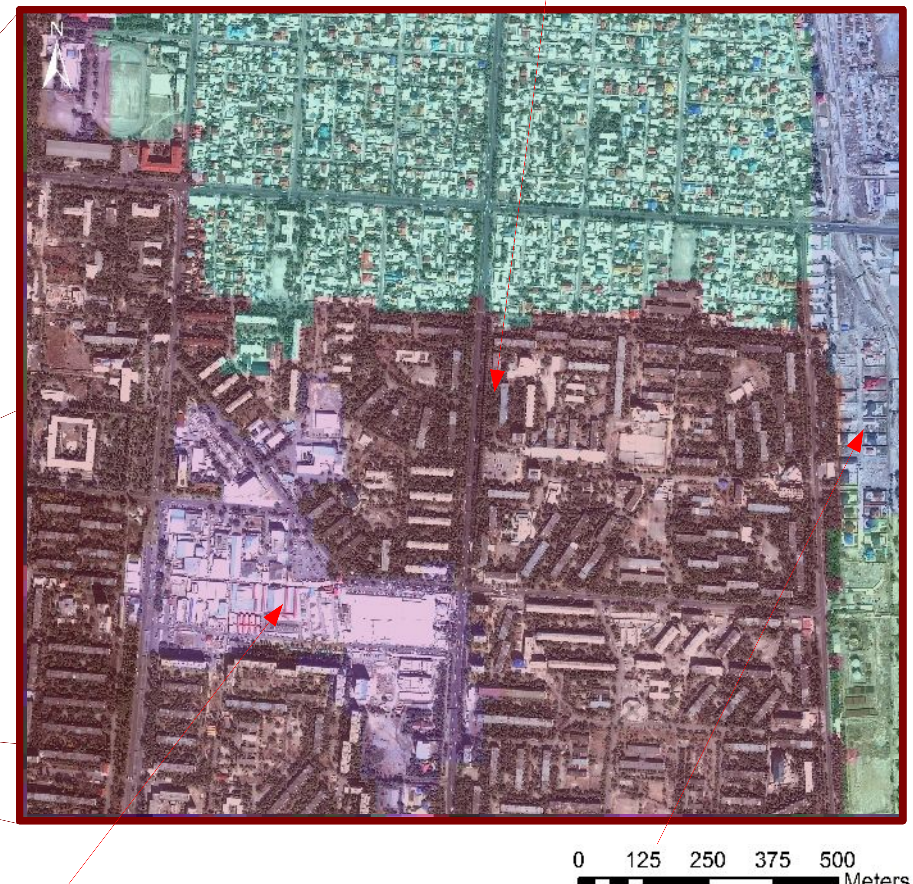
Next: sampling!

Analysis of medium-resolution satellite images

Stage of Stratification

Urban Structure Types





Urban Structure Type: 10
Type: 3-6 storey brick, concrete, panel
Age: built before 1977

Urban Structure Type: 16
Type: industrial, commercial
Age: built before 1977

Urban Structure Type: 8
Type: 1-2 storey masonry, brick
Age: built between 1994 and 2009

Product	Overall Accuracy	Cohen's Kappa
MR built-up mask (1977)	88.33%	0.66
MR built-up mask (1994)	87.67%	0.67
MR built-up mask (2009)	90.00%	0.78
MR LULC (2009)	81.00%	0.79

Next: sampling!

Acquisition and analysis of high-resolution omnidirectional images

GFZ Mobile Mapping System

Image capturing and storing unit

- Omnidirectional camera
- GPS receiver and antenna
- Digital compass with accelerometric sensors
- Customized PC
- Mounting system with sucking cups

Omnidirectional camera

Navigation unit

- Laptop with QGIS, streetmaps, pre-calculated sample areas and routes
- GPS receiver and antenna
- Real-time GPS-tracking

Navigation unit

System mounted on car

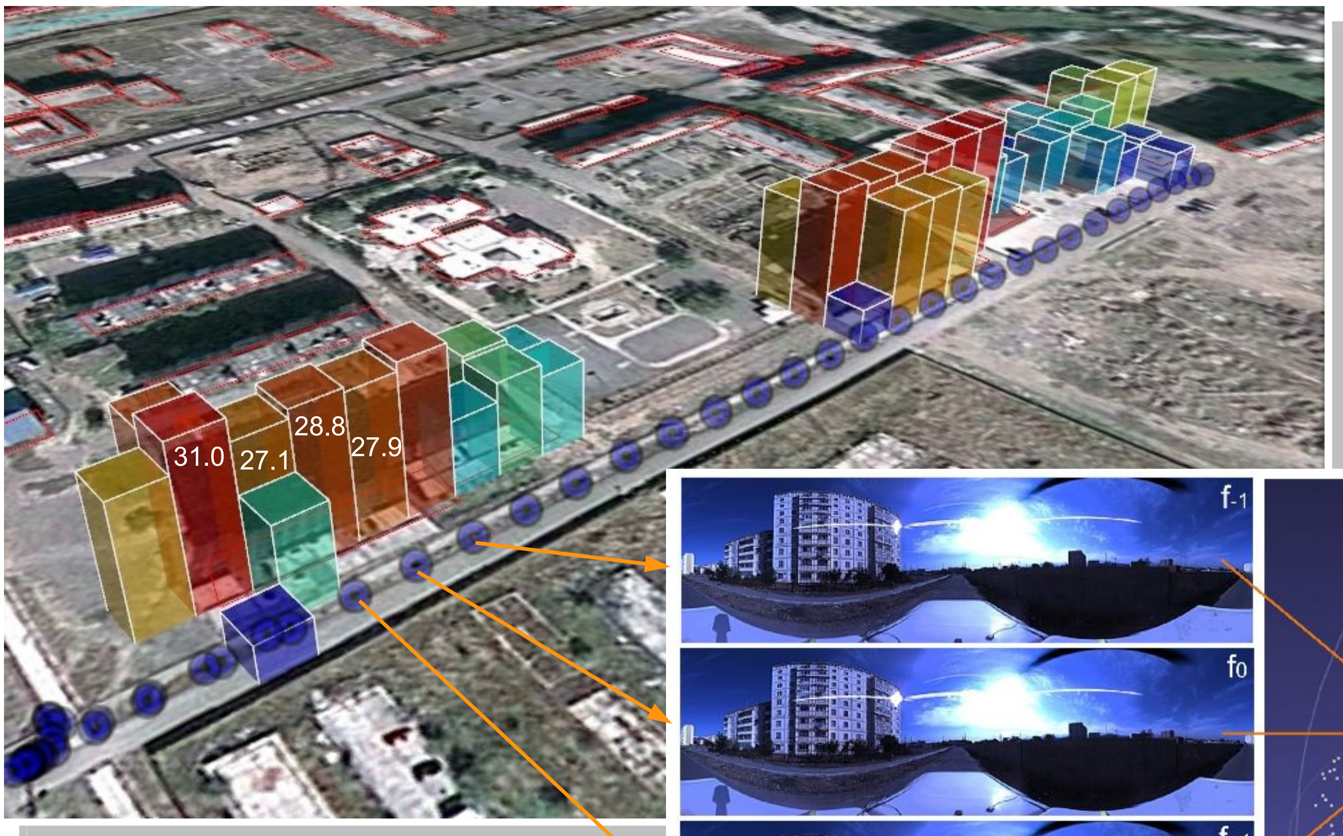
Acquisition and analysis of high-resolution omnidirectional images

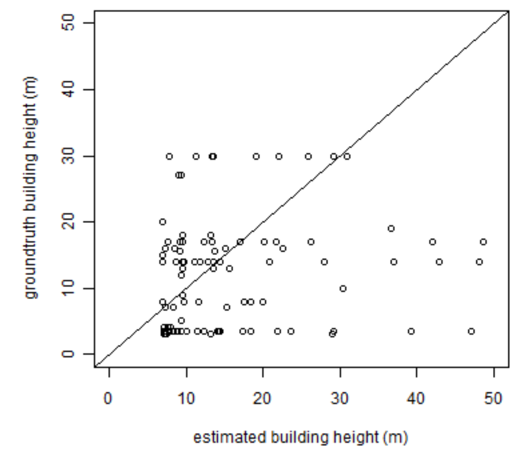
Omnidirectional image
In equirectangular
projection

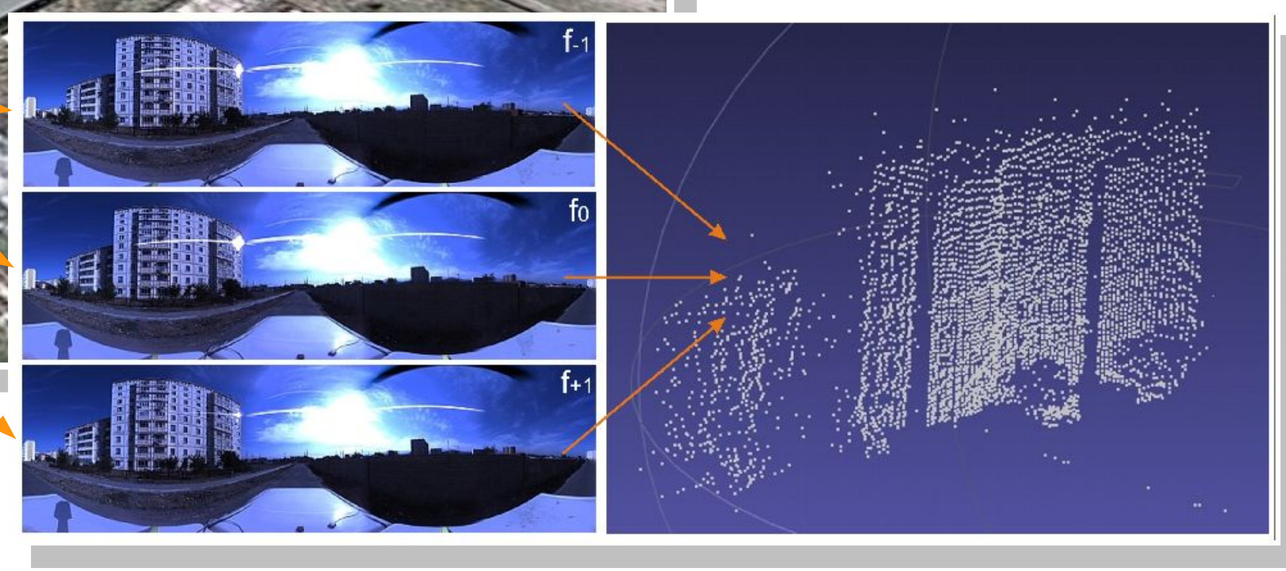
- **Fast**, **unbiased**, **dense** collection of visual content
- No need for skilled operators, just drive it.
- **Intuitive** and **efficient** visual interpretation, e.g. by engineers.

Acquisition and analysis of high-resolution omnidirectional images

Example: Automated height measurement from 3D Dense reconstruction



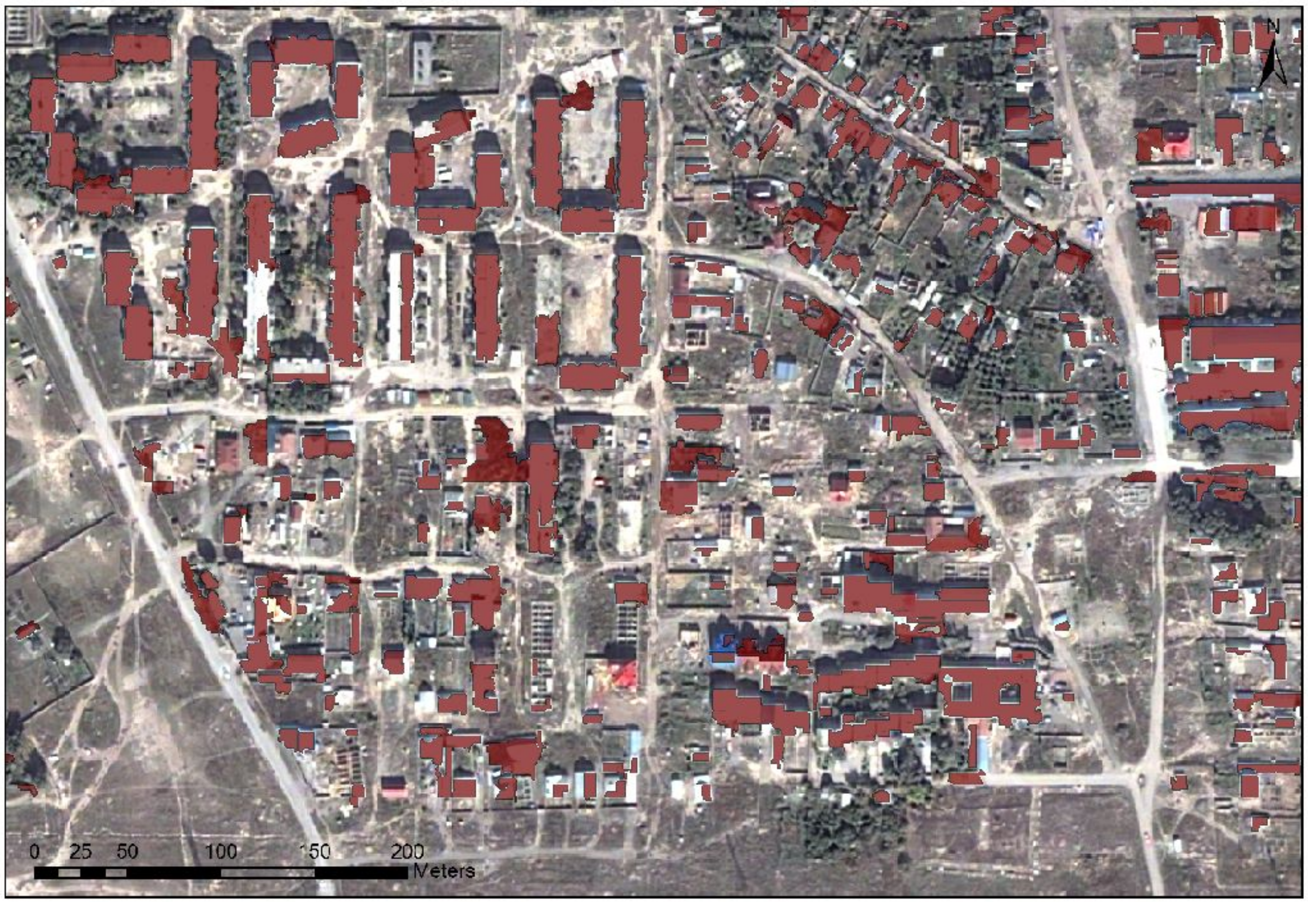




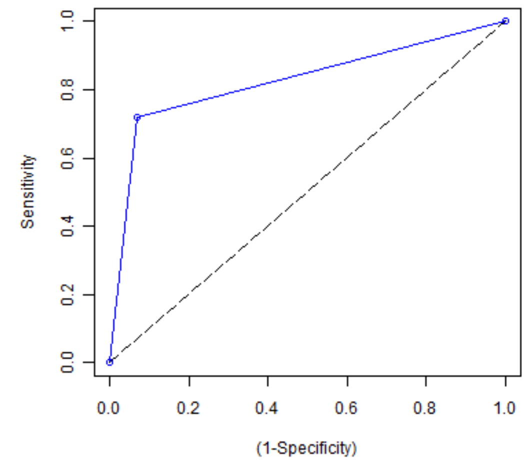
Other possible features:
Set-backs,
Soft-storeys,
No. of openings, ...

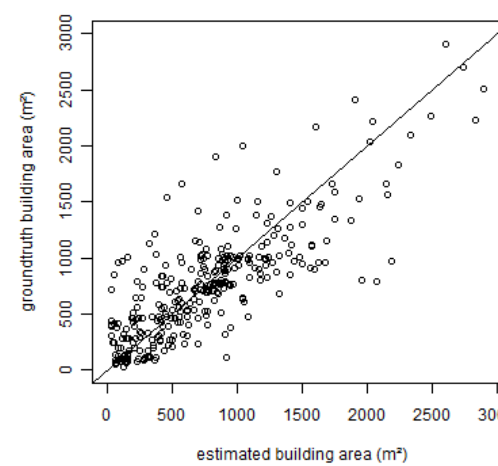
Analysis of high-resolution satellite images

Automated building footprint extraction



Quickbird image (Bishkek 2010)





Building location, footprint area, roof-color/-material, disaggregation of census data, etc.

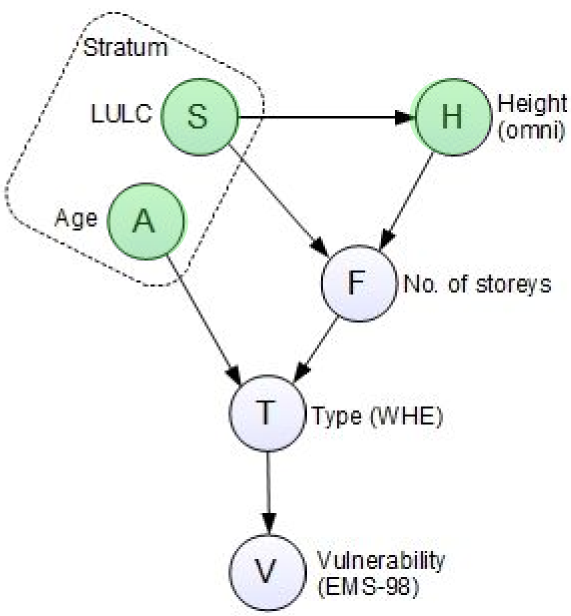
Data integration and vulnerability estimation

- ***Priors*** **from medium-resolution satellite images:**
  - Estimated building age
  - Landuse / Landcover
- ***Information*** **from high-resolution satellite images:**
  - Buildings footprint, location
  - ...
- ***Information*** **from omnidirectional images:**
  - Buildings height
  - ...
- ***Priors and information*** **from manual data entry:**
  - Expert knowledge
  - Ancillary data (e.g. already existing building inventory data)

VULNERABILITY

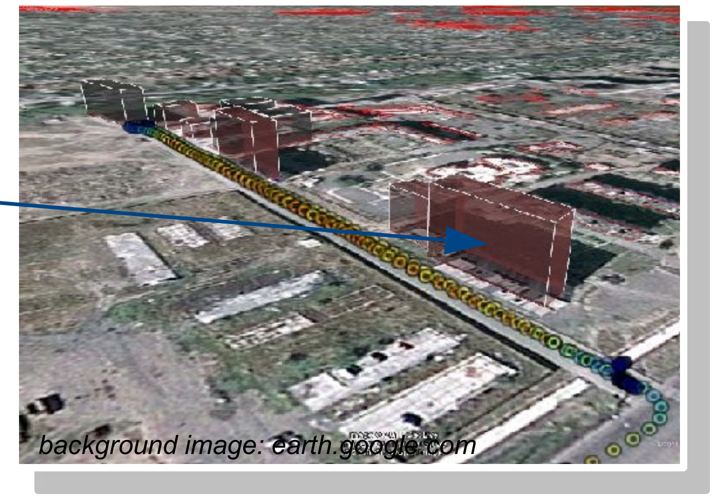
Data integration and vulnerability estimation

Bayesian networks



Evidences:

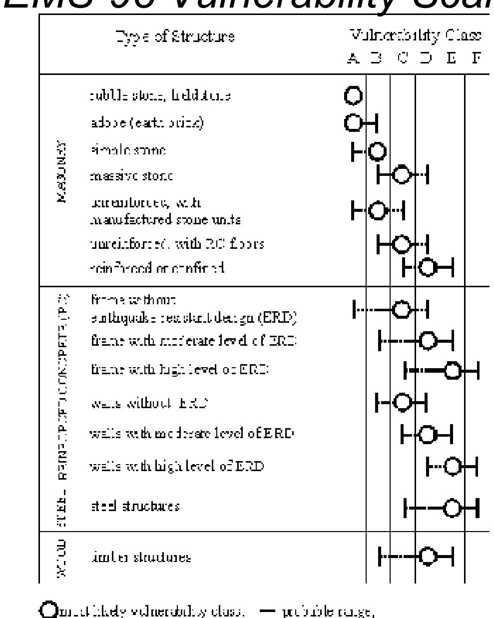
LULC: residential - panel, concrete,frame
Age: 1994-2009
Height: 29 m



type	P(A)	P(B)	P(C)	P(D)	P(E)	P(F)
0	0.9334	0.04757	0.01903	0	0	0
1	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
2	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
3	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
4	0.0181	0.215	0.427	0.2964	0.0435	0
5	0.0181	0.215	0.427	0.2964	0.0435	0
6	0	0.0303	0.06061	0.22	0.43911	0.24998
7	0	0.0303	0.06061	0.22	0.43911	0.24998

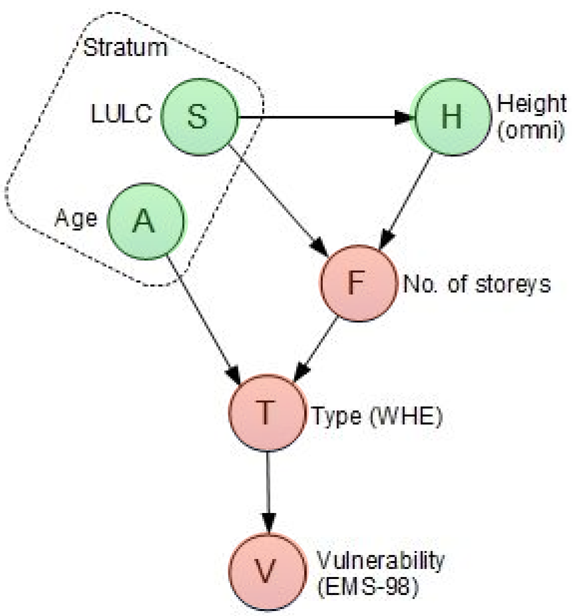
conditional probability table (V)

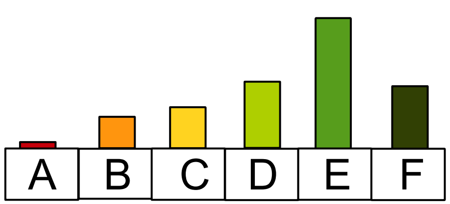
EMS-98 Vulnerability Scale



Data integration and vulnerability estimation

Bayesian networks





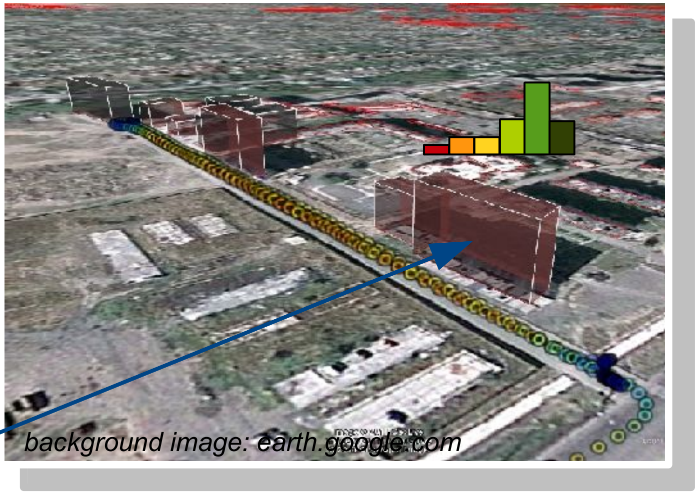
posterior probabilities

Evidences:

LULC: residential - panel, concrete,frame
Age: 1994-2009
Height: 29 m

Posteriors:

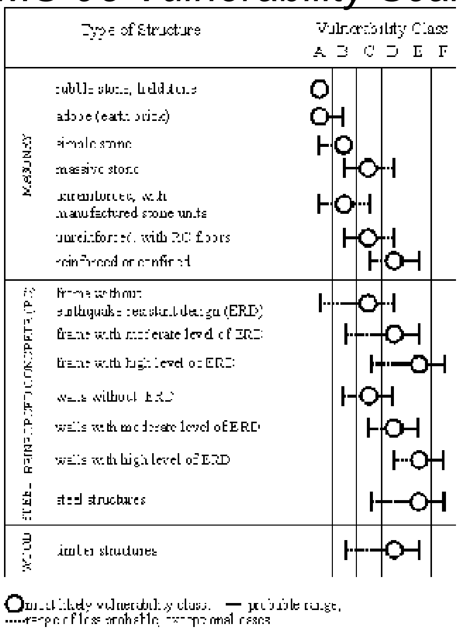
No. of storeys: 9
WHE Type: 6
Vulnerability (EMS-98): E



type	P(A)	P(B)	P(C)	P(D)	P(E)	P(F)
0	0.9334	0.04757	0.01903	0	0	0
1	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
2	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
3	0.175	0.56706	0.19842	0.01984	0.01984	0.01984
4	0.0181	0.215	0.427	0.2964	0.0435	0
5	0.0181	0.215	0.427	0.2964	0.0435	0
6	0	0.0303	0.06061	0.22	0.43911	0.24998
7	0	0.0303	0.06061	0.22	0.43911	0.24998

conditional probability table (V)

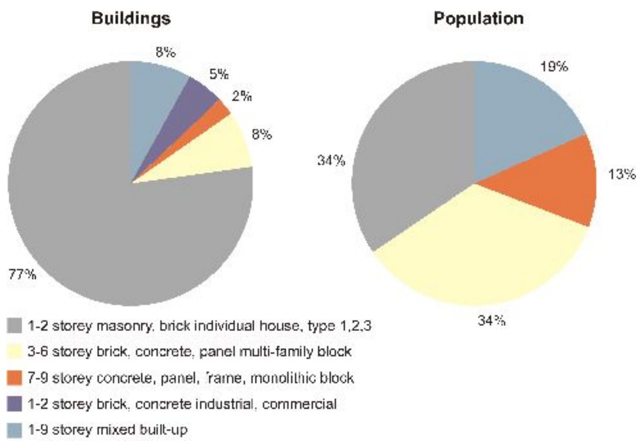
EMS-98 Vulnerability Scale

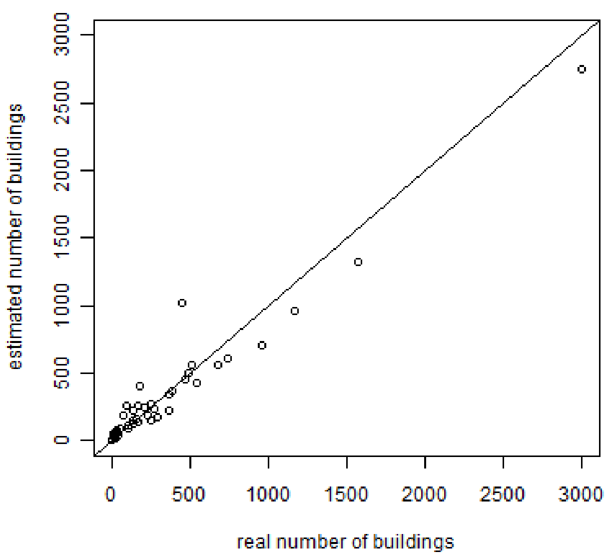


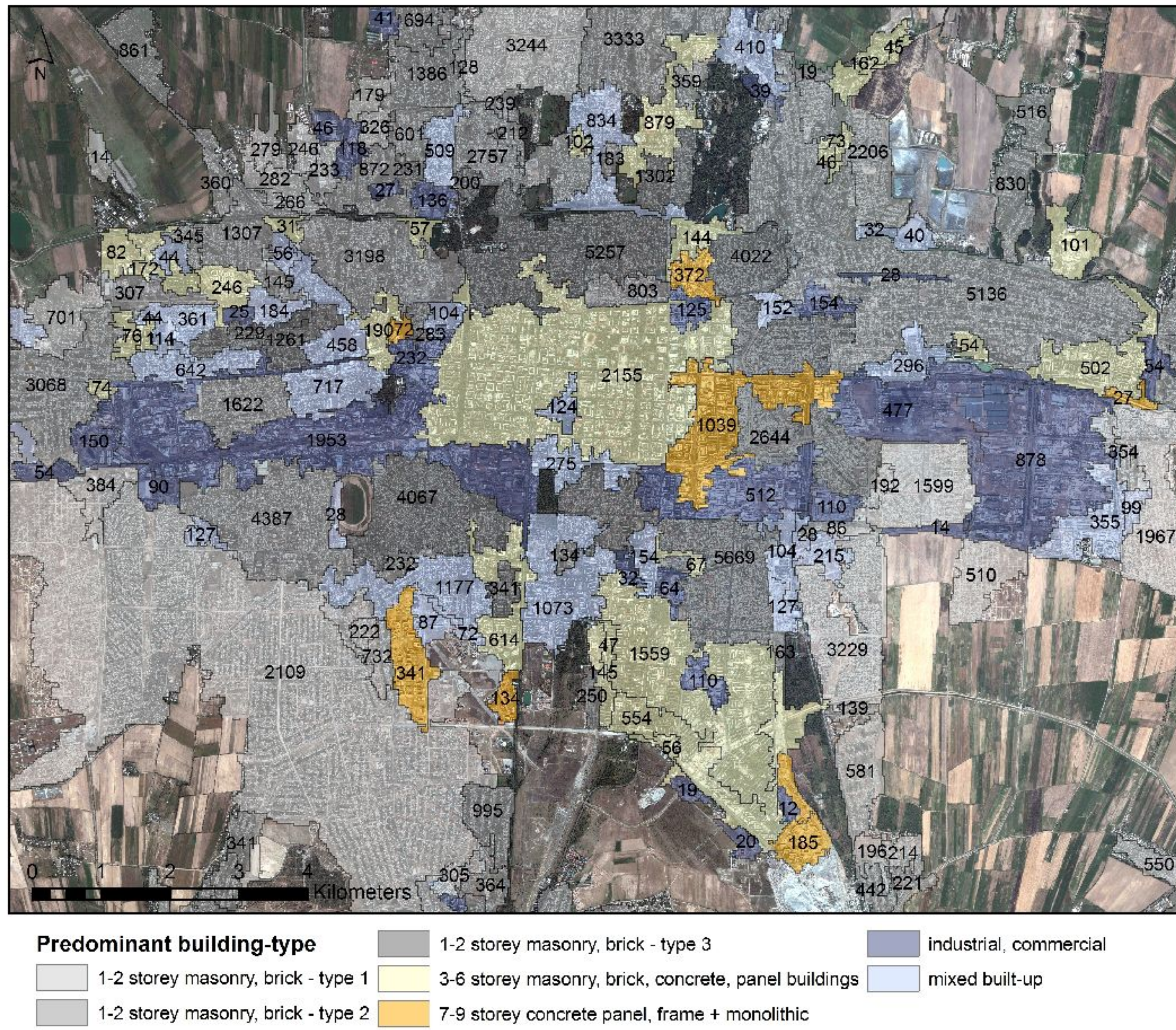
GFZ Helmholtz-Zentrum Potsdam

HELMHOLTZ ASSOCIATION

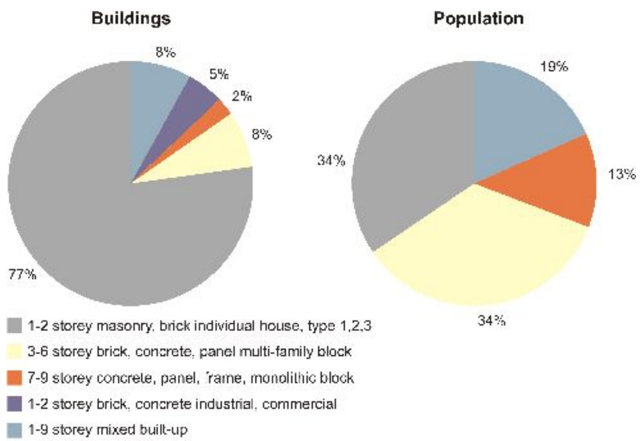
Preliminary results: inventory composition



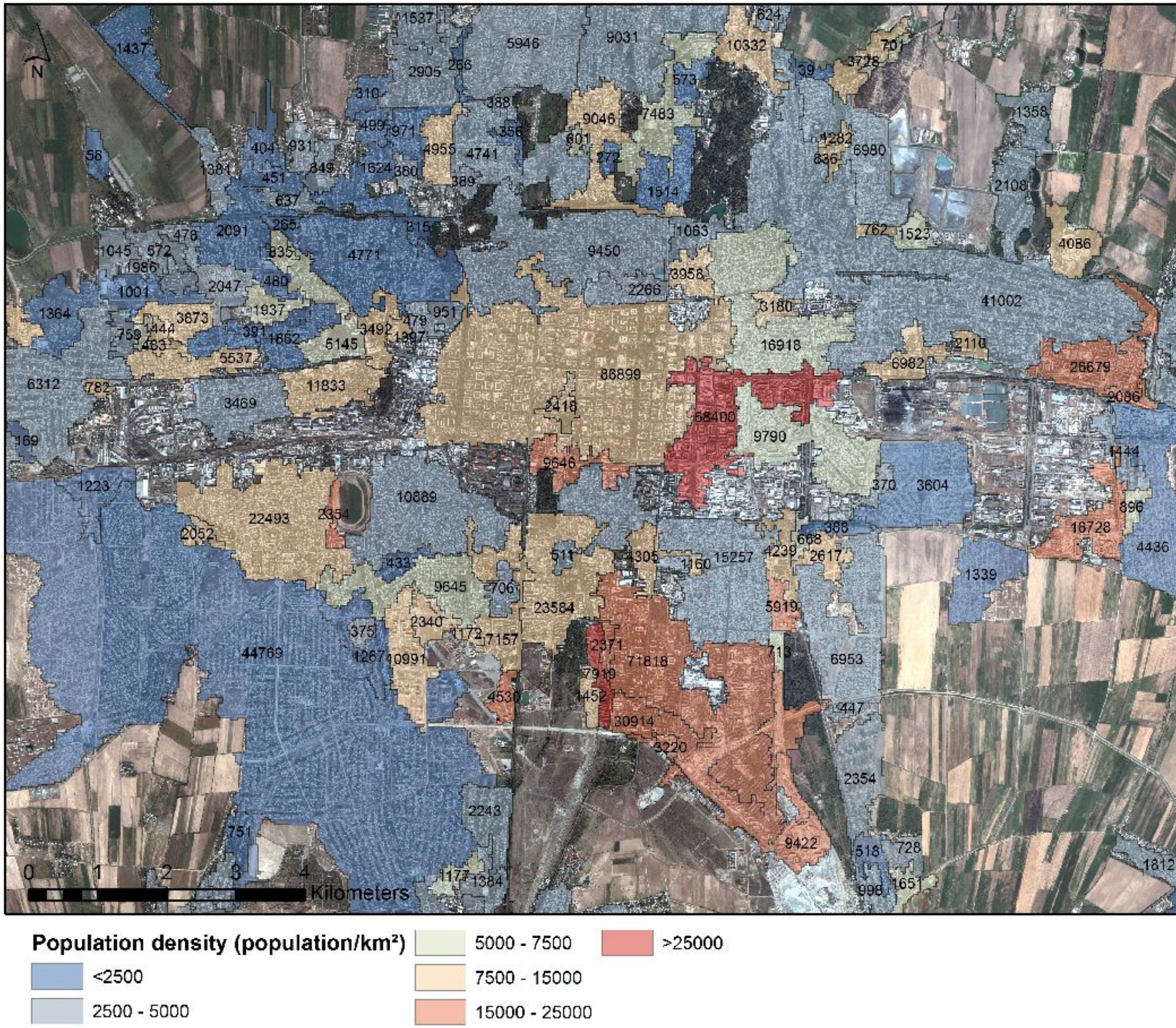




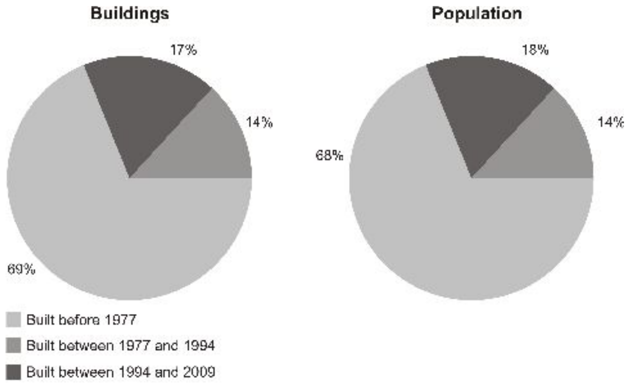
Preliminary results: spatial disaggregation of total population



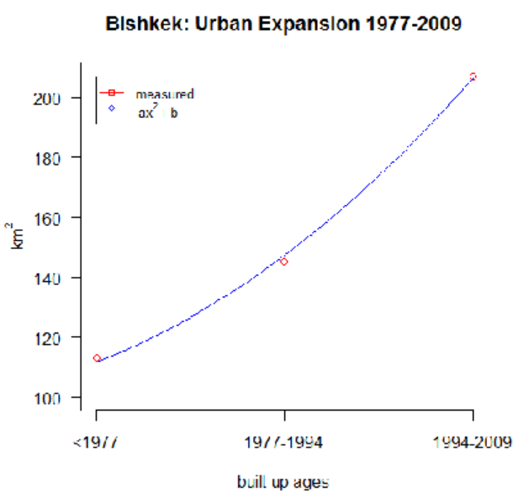
Building type	Est. nr. of buildings	Est. population
1-2 storey masonry, brick individual house, type 1,2,3	86842	292207
3-6 storey brick, concrete, panel multi-family block	8469	288030
7-9 storey concrete, panel, frame, monolithic block	2271	107936
1-2 storey brick, concrete industrial, commercial	5583	-
1-9 storey mixed built-up	9128	159466
TOTAL	**112293**	**847639**

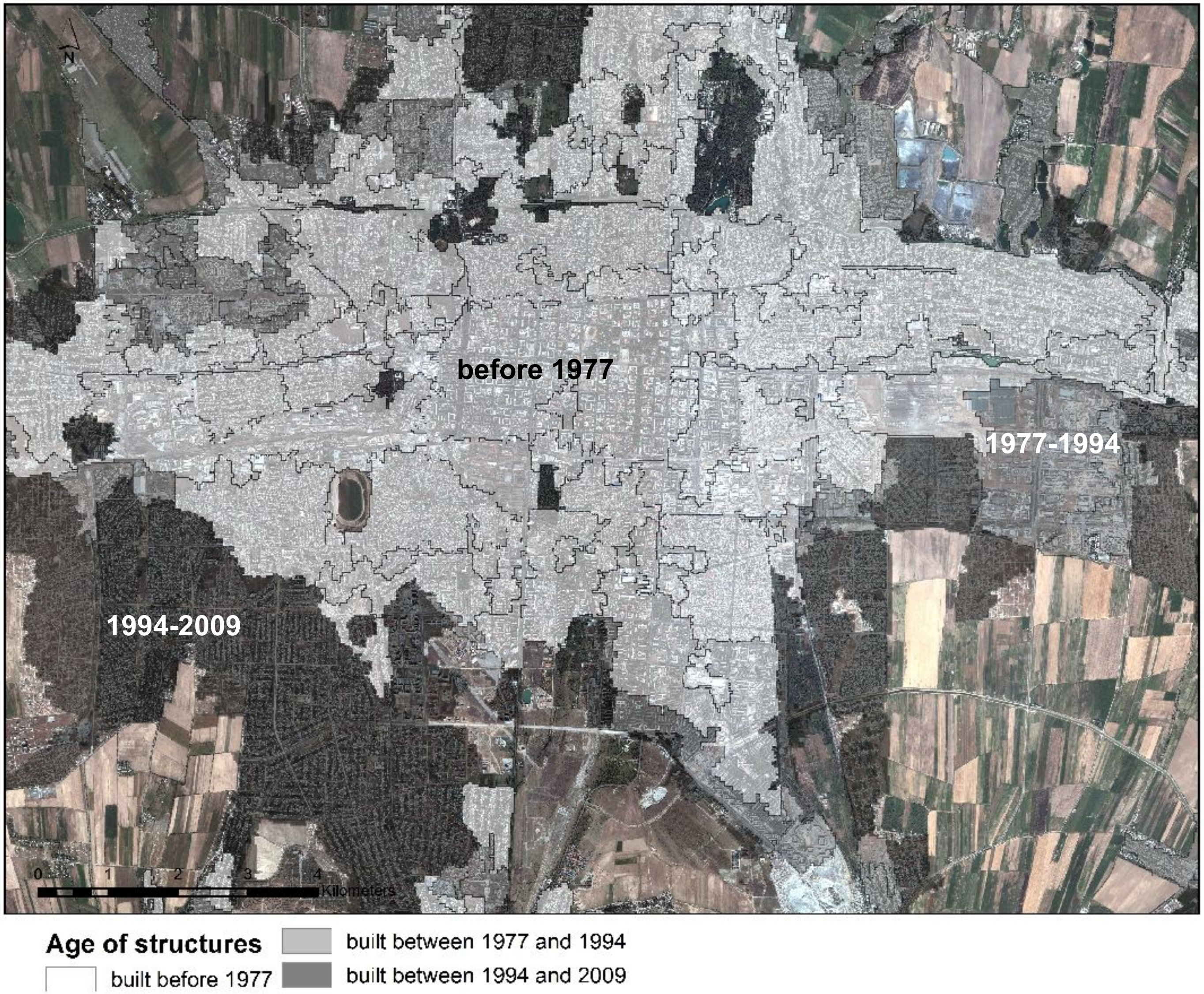


Preliminary results: multi-temporal change detection



Age of structure	Est. nr. of buildings	Est. population
Built before 1977	77292	579595
Built between 1977 and 1994	16205	115976
Built between 1991 and 2009	18796	152068
TOTAL	**112293**	**847639**

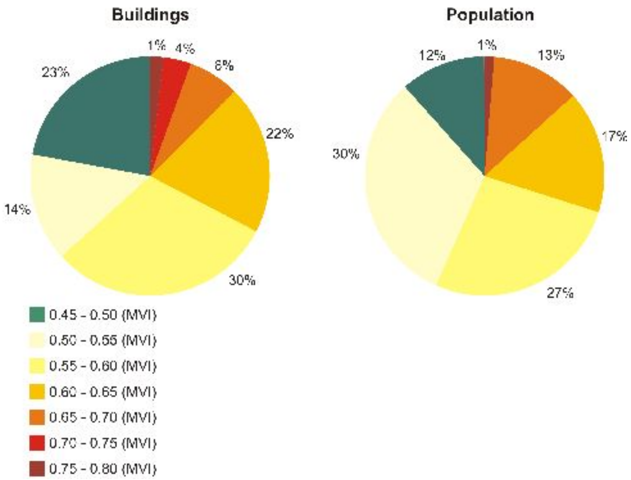




GFZ Helmholtz-Zentrum Potsdam

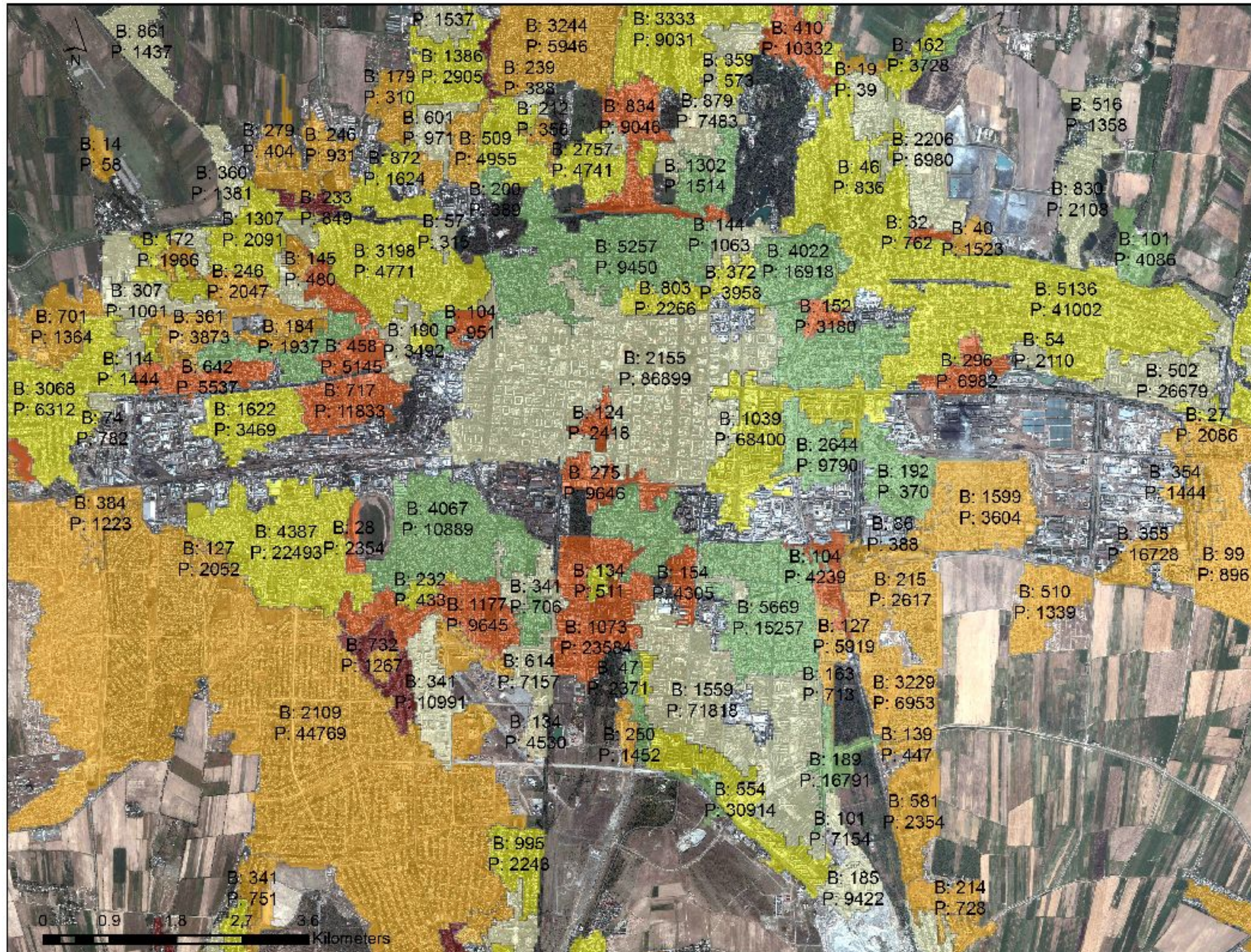
HELMHOLTZ ASSOCIATION

Preliminary results: spatial (probabilistic) distribution of vulnerability



Mean Vulnerability Index (MVI)	Est. nr. of buildings	Est. population
0.45-0.50	25582	99969
0.50-0.55	15722	266175
0.55-0.60	34377	227410
0.60-065	24322	140810
0.65-0.70	6606	110130
0.70-0.75	4177	0
0.75-0.80	1507	3145
TOTAL	**112293**	**847639**

$$MVI = \frac{1}{(n-1)}\left(\sum_{i=0\ldots n-1} p(V_i)(n-i) - 1\right)$$



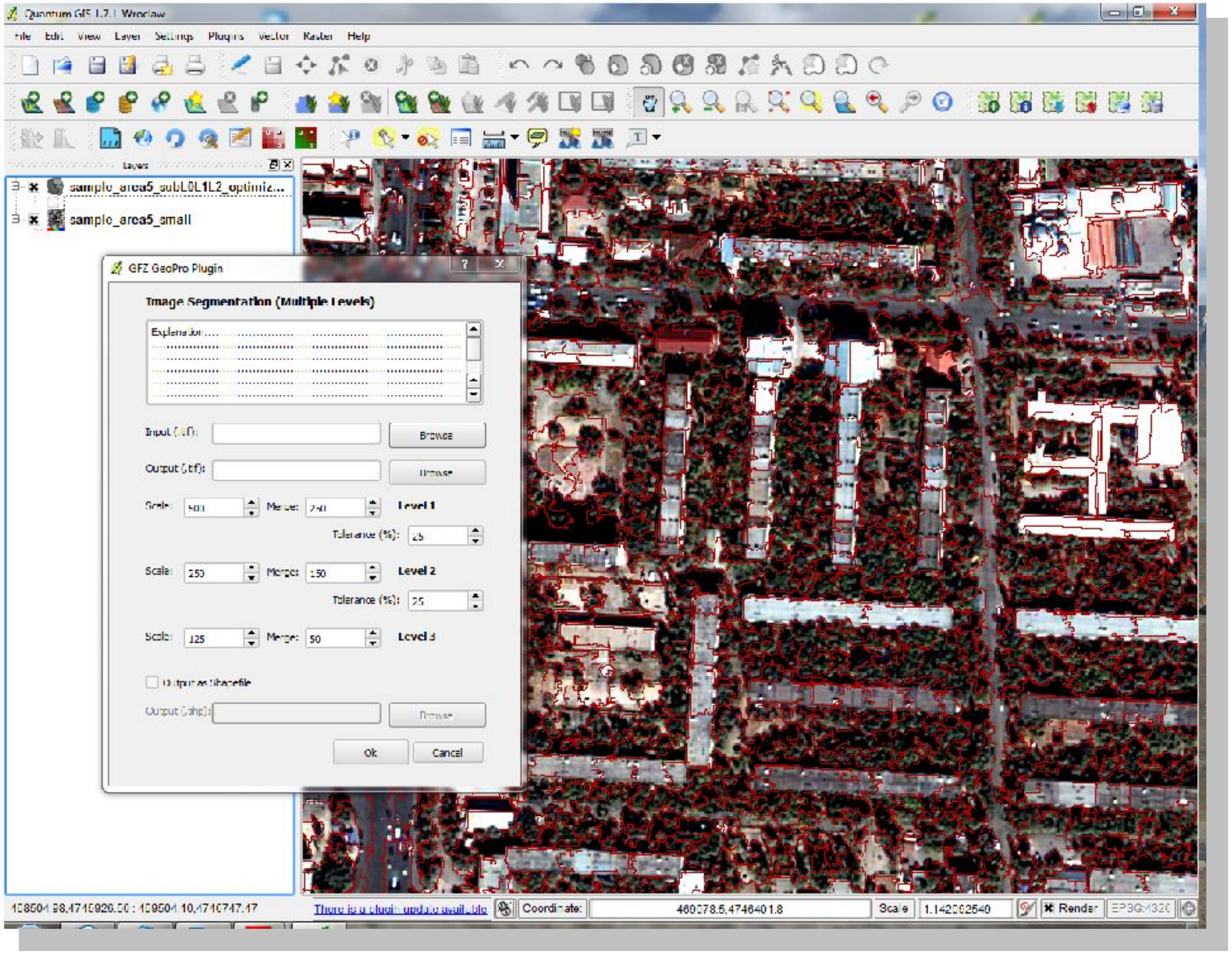
Mean Vulnerability Index (MVI)
0,45 - 0,50
0,50 - 0,55
0,55 - 0,60
0,60 - 0,65
0,65 - 0,70
0,70 - 0,75
0,75 - 0,80

B: Nr. of buildings
P: Population

Preliminary results: software implementation

Feature extraction **plugin for QGIS**

- Single segmentation
- Multi-scale segmentation
- Texture descriptors
- Shape descriptors
- ML classification
- …



Custom code

- **C++, Python**
- Libraries (**GDAL/OGR**)

PostGIS, QGIS, GRASS

- geo-data management
- adv. (vector-) analysis
- visualisation

Conclusions and Discussion

- Analysis of **medium-resolution satellite images** allows to:
  - Extract vulnerability relevant features on neighbourhood scale.
  - Focus the spatial extent for local analysis using stratified sampling.

- **Omnidirectional imaging**:
  - proved to be fast deployed, easily operated,
  - shows great potential for automated/manual inventory asssment.

- **Data integration** based on **Bayesian networks** allows to:
  - apply a fully probabilistic scheme in a simple, intuitive way,
  - merge heterogeneous sources of information,
  - include (local) knowledge accounting for uncertainties.

- **Future activities** include:
  - Comprehensive cross-validation of results with ground-truth data.
  - Extending and improving automated feature extraction.
  - Expert-system for remote rapid visual screening (RRVS).
  - Probabilistic Risk assessments for main urban areas in Central Asia.

http://www.emca-gem.org

Thank you for your attention!

Publications

M. Pittore, M. Wieland, “Towards a rapid probabilistic seismic vulnerability assessment using satellite and ground-based remote sensing”, *Natural Hazards*, accepted for publication.

M. Wieland, M. Pittore, S. Parolai, J. Zschau, “Exposure estimation from multi-resolution optical satellite imagery for seismic risk assessment”, *ISPRS International Journal of Geo-information*, 1 (2012) 69-88.

M. Wieland, M. Pittore, S. Parolai, J. Zschau, B. Moldobekov, U. Begaliev, “Estimating building inventory for rapid seismic vulnerability assessment: towards an integrated approach based on multi-source imaging”, *Soil Dynamics and Earthquake Engineering*, 36 (2012) 70-83.

M. Pittore, D. Bindi, S. Tyagunov, M. Wieland, M. Picozzi, M. Pilz, S. Ullah, K. Fleming, S. Parolai, J. Zschau, B. Moldobekov, K. Abdrakhmatov, U. Begaliev, P. Yasunov, A. Ishuk, N. Mikhailova, “Seismic hazard and risk in Central Asia”, *Scientific Technical Report,* STR 11/14 (2012), DOI: 10.2312/GFZ.b103-11149.

P. Felzenzwalb, D. Huttenlocher, “Efficient graph-based image segmentation”, *Int. J. Comput. Vis.,* 59 (2004), 67–81.