Building Information Extraction from Satellite Imagery for Regional Risk Assessment

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Outline

- **Background and Motivations**
- **Objective of the Research**
- **Loss Estimation Tools, Loss Estimation Methodology and its Shortcomings (example: HAZUS®)**
- **Building Inventory Updates and Loss Estimation**
- **MIHEA: Building Inventory Extraction Tool**
- **Examples of 3D Models Created by MIHEA**
- **Loss Estimation Using Updated Inventory Data**
- **Conclusions**
- **Future Plans**

Background

- **Pre-disaster vulnerability assessment and post-disaster response have become essential components in disaster management.**

- **Loss estimation has became a useful tool for decision-making agencies to measure and localize high priority locations for post-disaster response.**

- **Existing loss estimation tools most often lack accurate building inventory.**

Motivations

- **Demand for more accurate risk estimates at an intra-regional scale (emergency response, planning, insurance and etc.)**
- **Advancements in Remote Sensing technology.**
- **Availability of High Resolution Imagery.**
- **RS data are becoming more affordable compared to land surveys.**
- **Frequent building inventory updates are not available.**
- **Electronic building inventory information is not available at many locations in the world.**

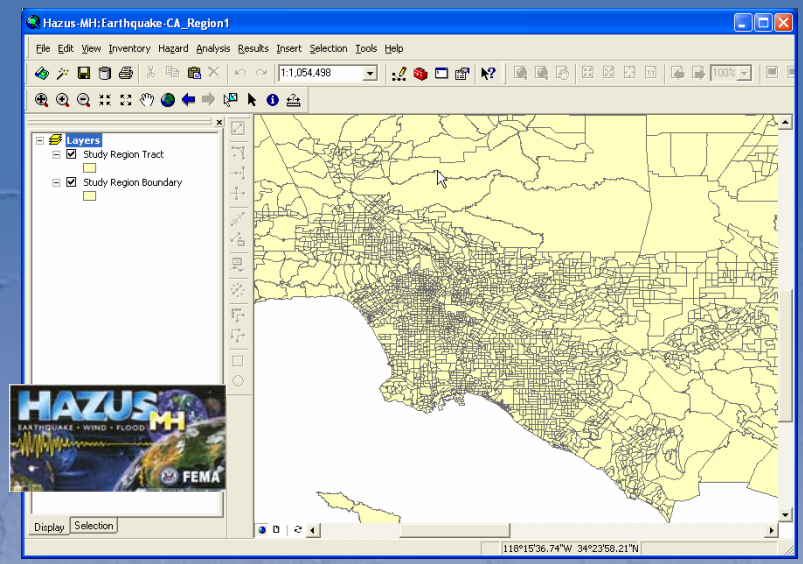
Objective

- **This study presents a methodology for extracting critical structural attributes (such as height and footprint area) -used in earthquake loss models- from remotely sensed data.**
- **This study also presents a 3D urban modeling tool called MIHEA which is developed for the purpose of updating current building inventories.**

Current Loss Estimation Tools

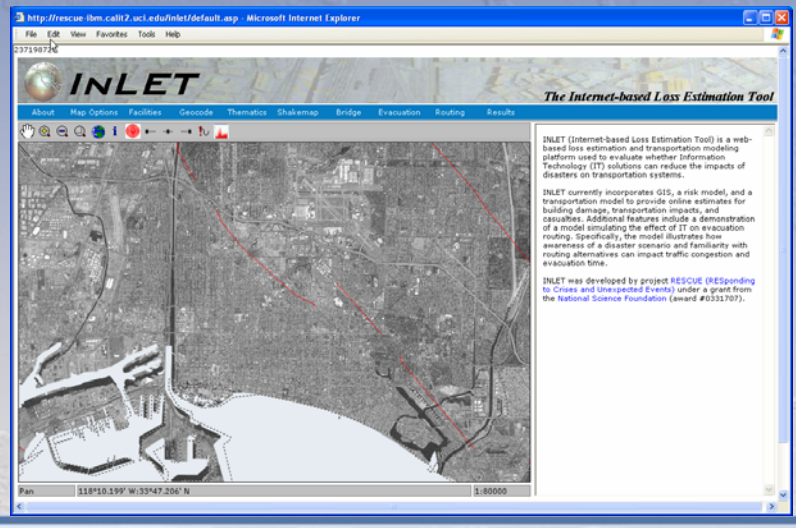
- **HAZUS®**

  HAZard-US by FEMA

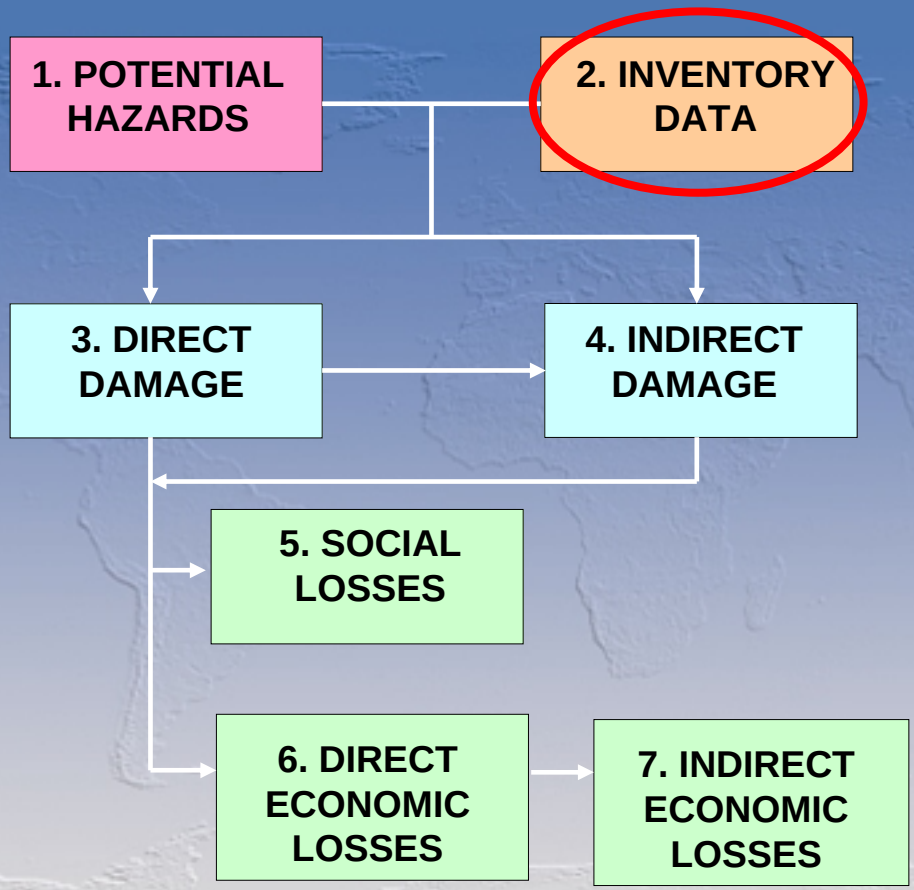


- **INLET**

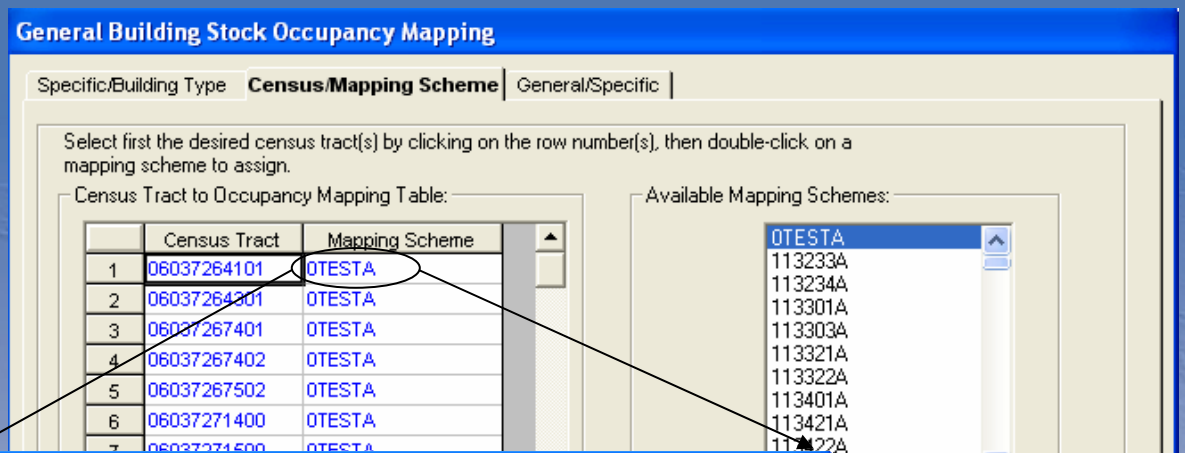
  INternet-based Loss Estimation Tool

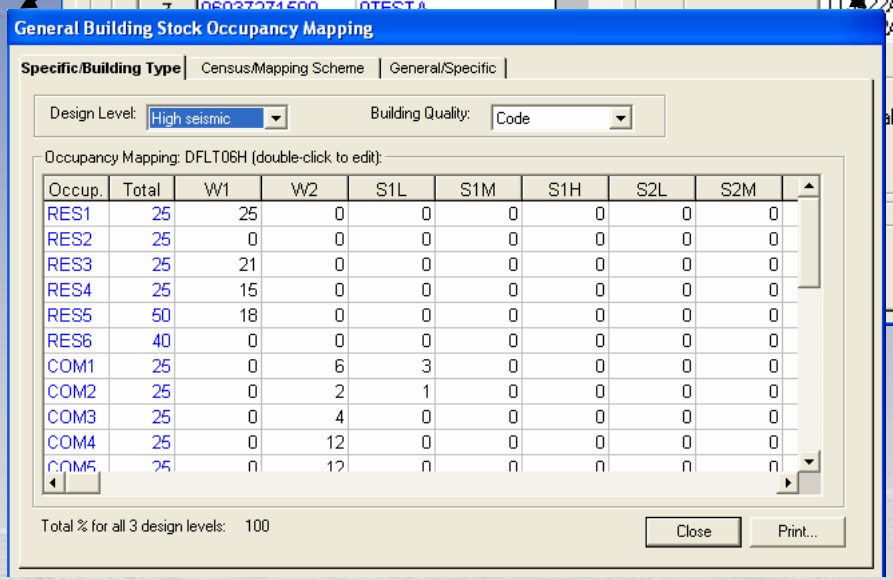


Loss Estimation Methodology (Example: HAZUS)



Loss Estimation Methodology - cont'd (example: HAZUS)

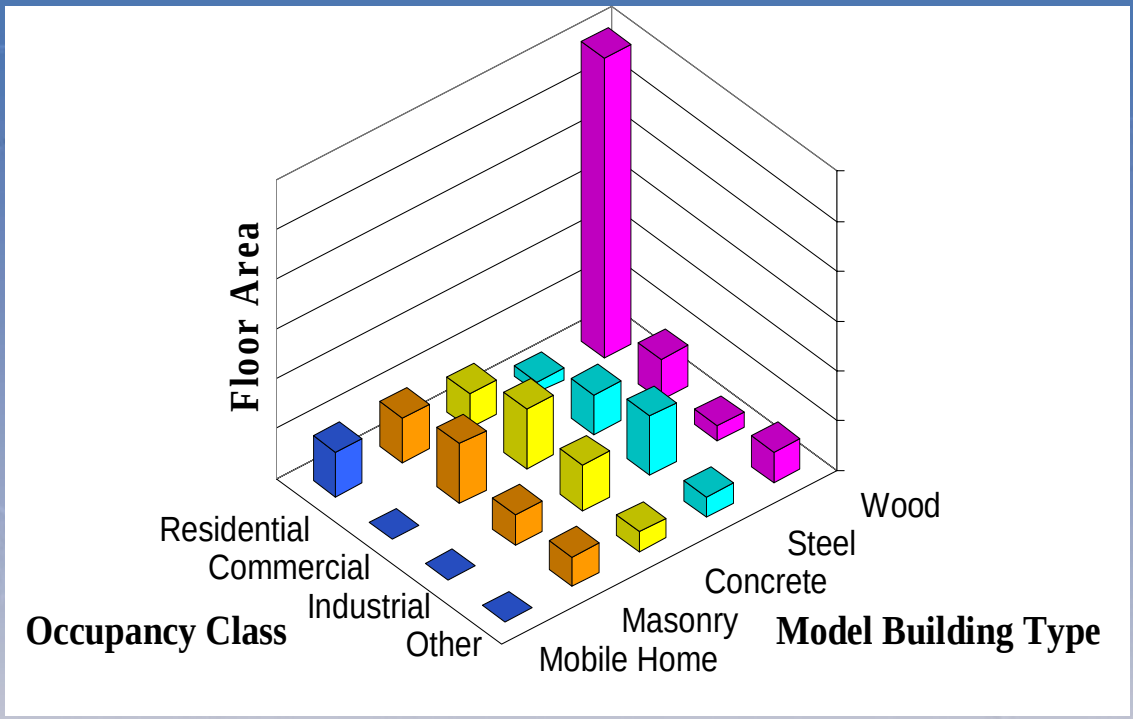




		Model Building (Structure) Types (W1, W2, S1L, S1M, S1H, S2L, S2M, S2H…and Quality			
OCCUPANCY	RES1~6	Code (C %)	Inferior (I %)	Superior (S %)	Total (100%)
	COM1~10				
	IND1~6				
	AGR1				
	REL1				
	GOV1~2				
	EDU1~2				

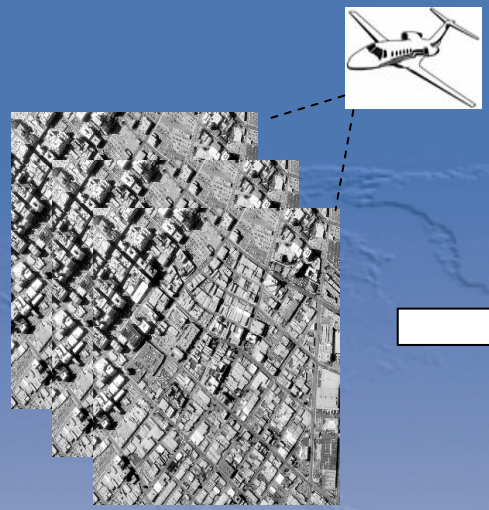
Loss Estimation Methodology and Its Shortcomings (example: HAZUS) – cont'd

- Mapping schemes only for few countries besides the US.
- Highly generalized regional statistical profile of inventory characteristics.
- Limited representation of building characteristics.
- Attributes for high-rise buildings rarely captured by regional statistics used in inventories.

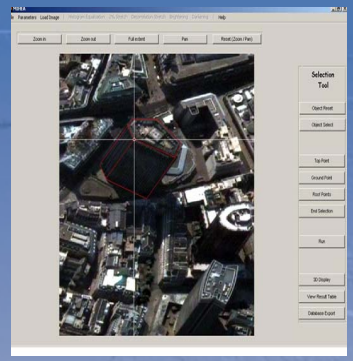


HAZUS®99 AEBM Tech. & User Manual

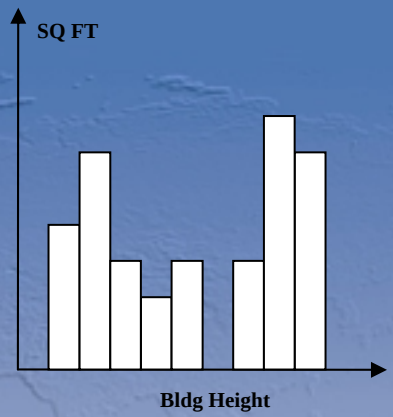
Building Inventory Updates and Loss Estimation



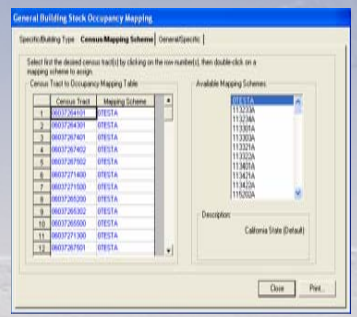
Remote Sensing Data



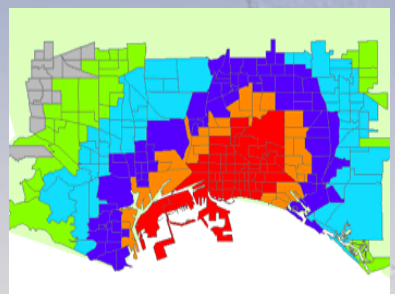
3D city modeling tools: MIHEA Process



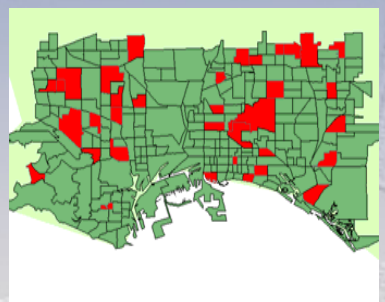
Building Inventory Algorithm



Occupancy/Mapping Scheme

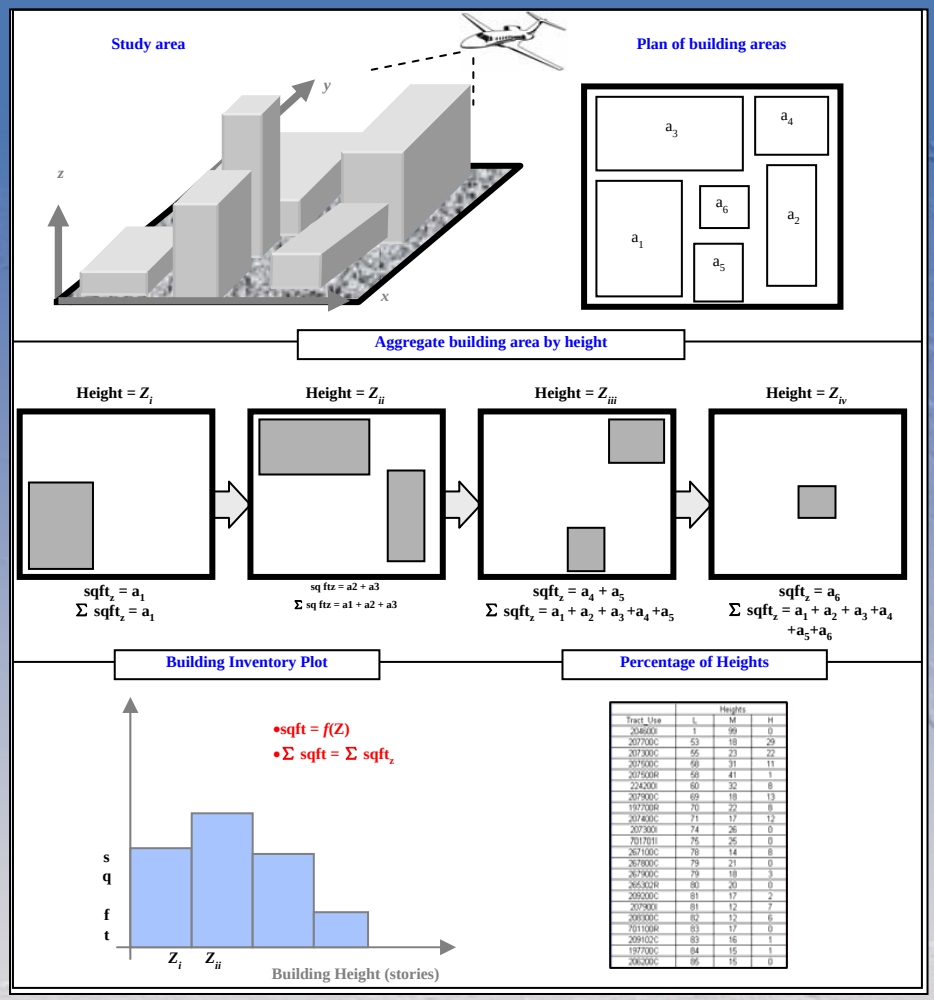


Natural Hazards

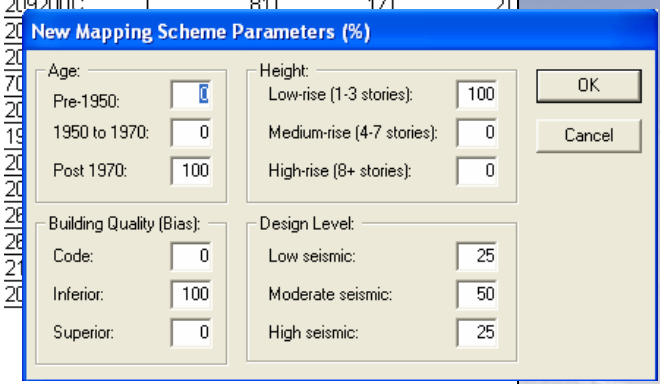


Loss Estimation Report

Building Inventory Updates and Loss Estimation



Tract_Use	Story Heights (%) Low 1-3 Stories 1-11 m	Moderate 4-7 Stories 12-23 m	High >8 Stories >23m
204600I	1	99	0
207700C	53	18	29
207300C	55	23	22
207500C	58	31	11
207500R	58	41	1
224200I	60	32	8
207900C	69	18	13
197700R	70	22	8
207400C	71	17	12
207300I	74	26	0
701701I	75	25	0
267100C	78	14	8
267800C	79	21	0
267900C	79	18	3
265302R	80	20	0
209200C	81	17	2



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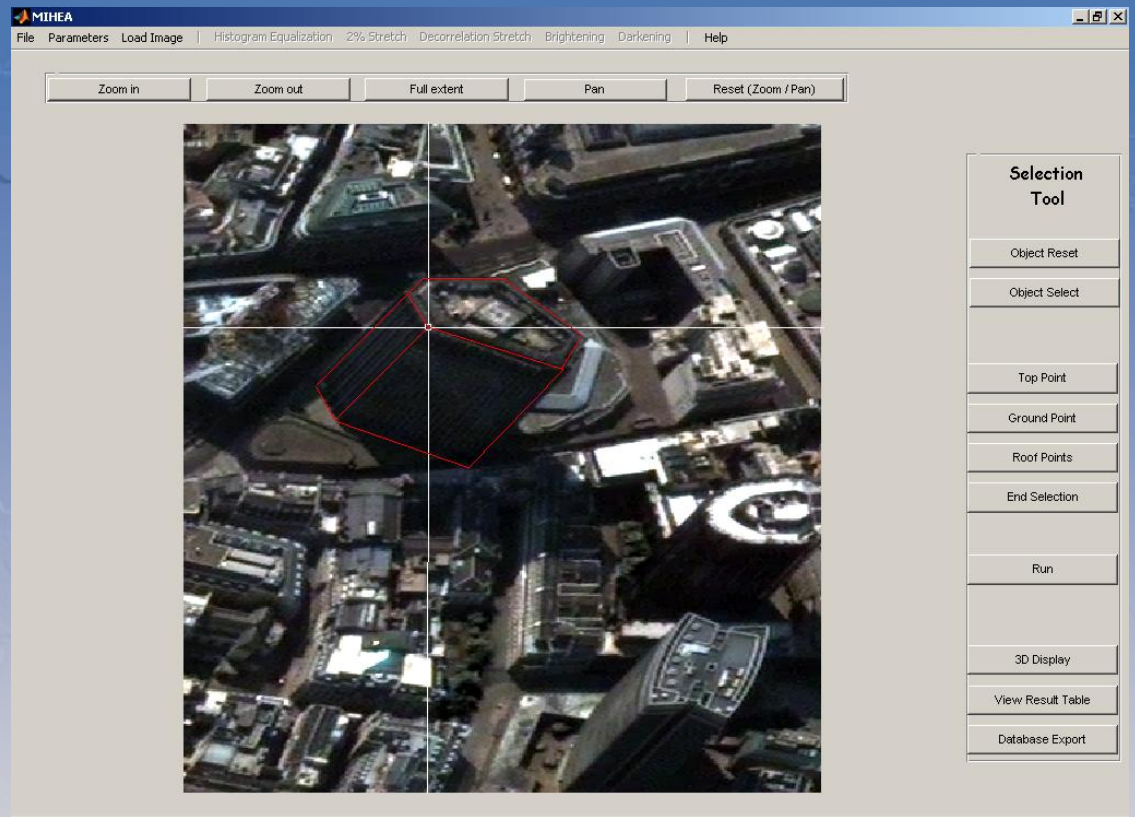
- Examples of 3D Models Created by MIHEA
- Loss Estimation Using Updated Inventory Data
- Conclusions
- Future Plans

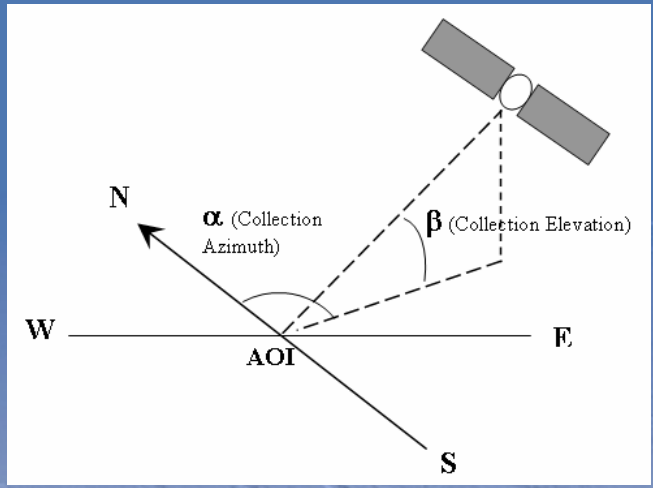
MIHEA:
Building Inventory Extraction Tool

- Mono Image Height Extraction Algorithm
- Software package designed for extracting spatial and structural information
- Single high-resolution satellite images
- Developed at Stanford University in collaboration with ImageCat, Inc.



MIHEA:
Building Inventory Extraction Tool – cont'd

- Satellite orientation (azimuth and elevation)
- Rational Function representation of camera model.
- Solve a system of homogeneous, non-linear and over-determined equations



$$r_{roof} = \frac{f_1(\phi,\lambda,h_2)}{f_2(\phi,\lambda,h_2)}$$

$$c_{roof} = \frac{f_3(\phi,\lambda,h_2)}{f_4(\phi,\lambda,h_2)}$$

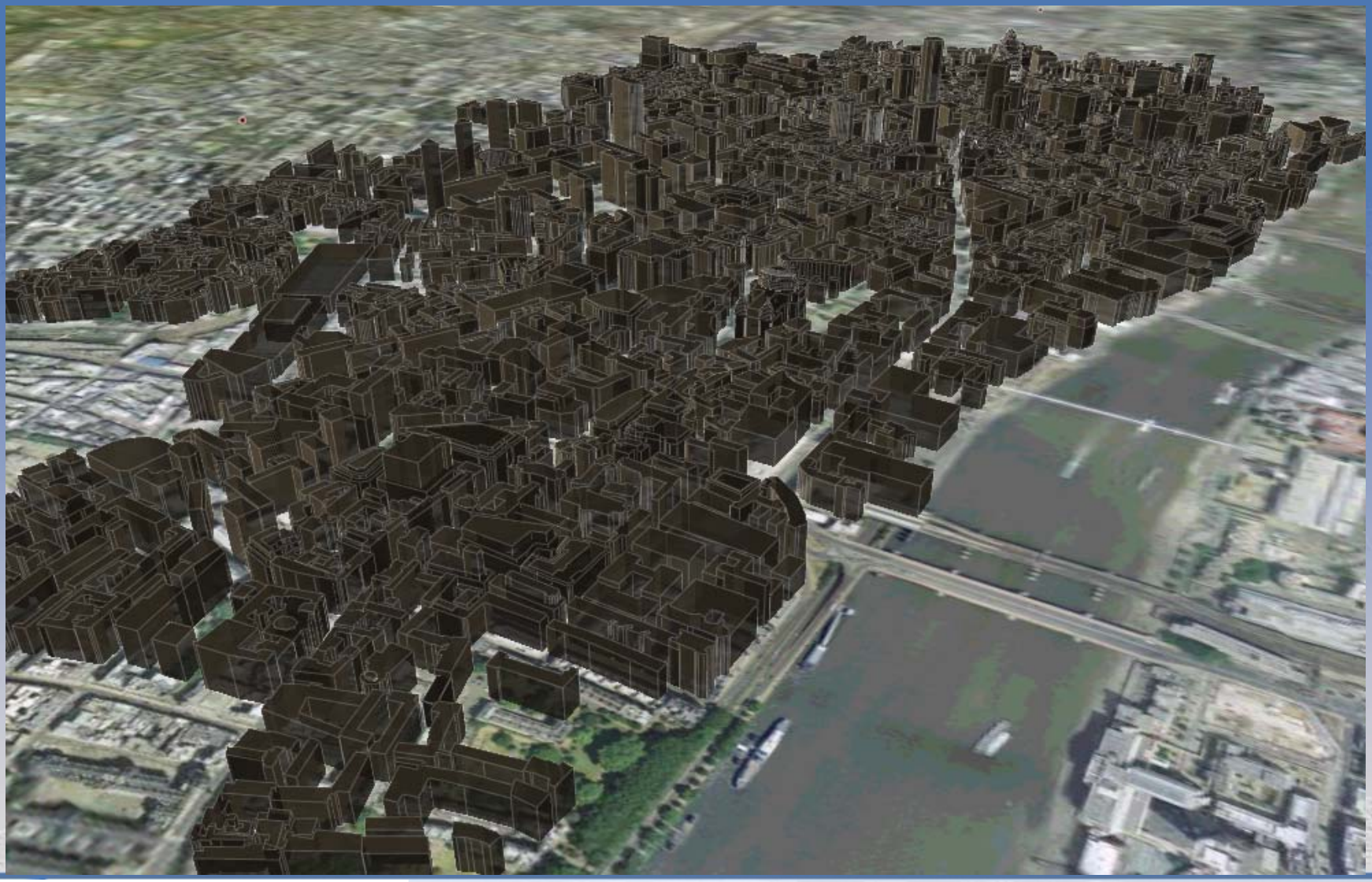
$$r_{ground} = \frac{f_1(\phi,\lambda,h_1)}{f_2(\phi,\lambda,h_1)}$$

$$c_{ground} = \frac{f_3(\phi,\lambda,h_1)}{f_4(\phi,\lambda,h_1)}$$

H

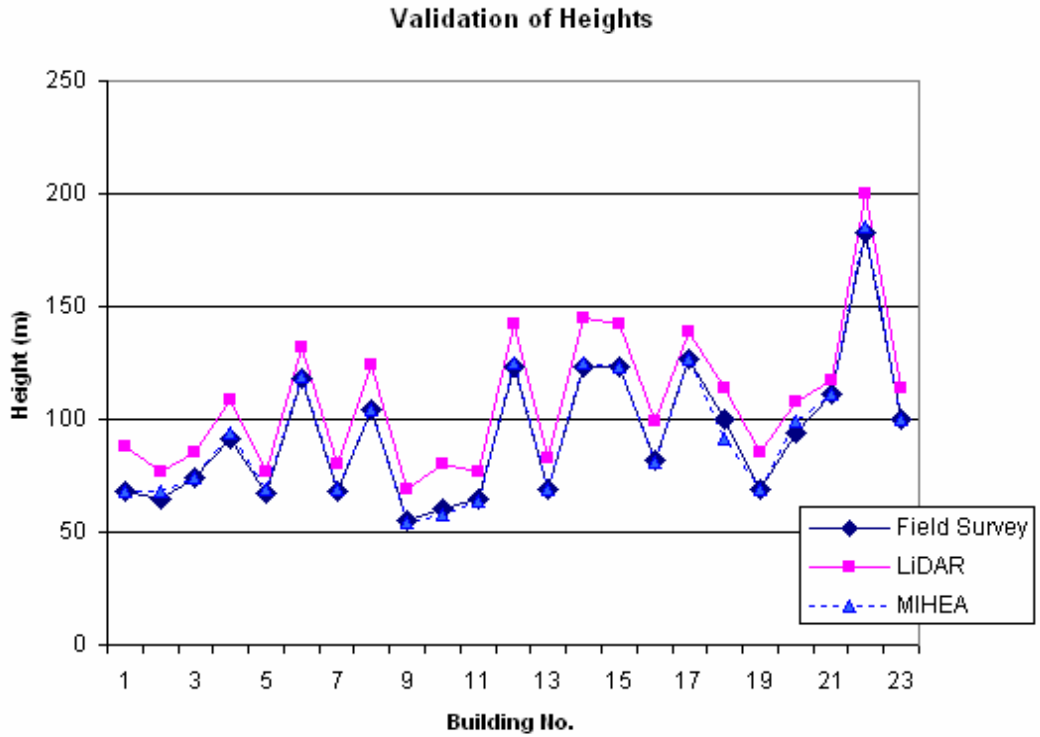
$$\begin{cases} \frac{f_1(\phi,\lambda,h_1)}{f_2(\phi,\lambda,h_1)} - r_g = 0 \\ \frac{f_3(\phi,\lambda,h_1)}{f_4(\phi,\lambda,h_1)} - c_g = 0 \\ \frac{f_1(\phi,\lambda,h_2)}{f_2(\phi,\lambda,h_2)} - r_r = 0 \\ \frac{f_3(\phi,\lambda,h_2)}{f_4(\phi,\lambda,h_2)} - c_r = 0 \\ (h_2 - h_1) - H = 0 \end{cases}$$

Examples of 3D models created by MIHEA : London, U.K

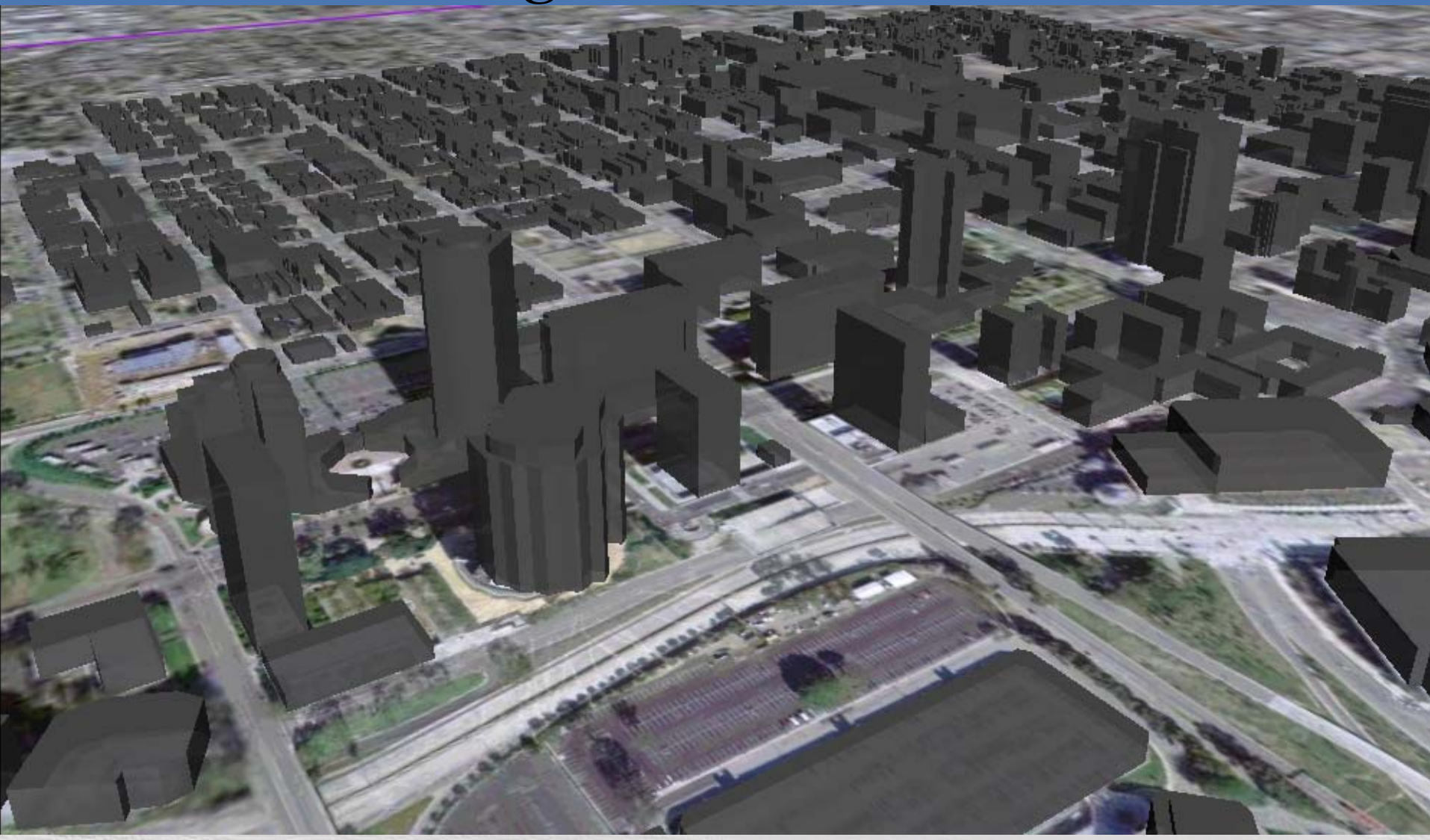


Examples of 3D models created by MIHEA : London, U.K – cont'd

No	Building Name
1	Plantation Place
2	2 Minster Court
3	1 Minster Court
4	20 Fenchurch St
5	1 America Sq, Cross Wall
6	Aviva Tower, Undershaft
7	Petticoat Tower
8	99 Bishopsgate
9	10 Exchange sq
10	Bishops gate exchange 135, 155 & 175
11	Exchange House, Exchange Sq
12	Cromwell tower (Barbican)
13	St. Alphage House, Fore st
14	Shakespere tower (Barbican)
15	Lauderdale Tower (Barbican)
16	125 London Wall
17	Citypoint
18	Drapers Gardens
19	City Tower Basinghall St.
20	1 Angel Court
21	St. Pauls Cathedral
22	Tower 42
23	Stock Exchange



Examples of 3D models created by MIHEA : Long Beach, CA, USA



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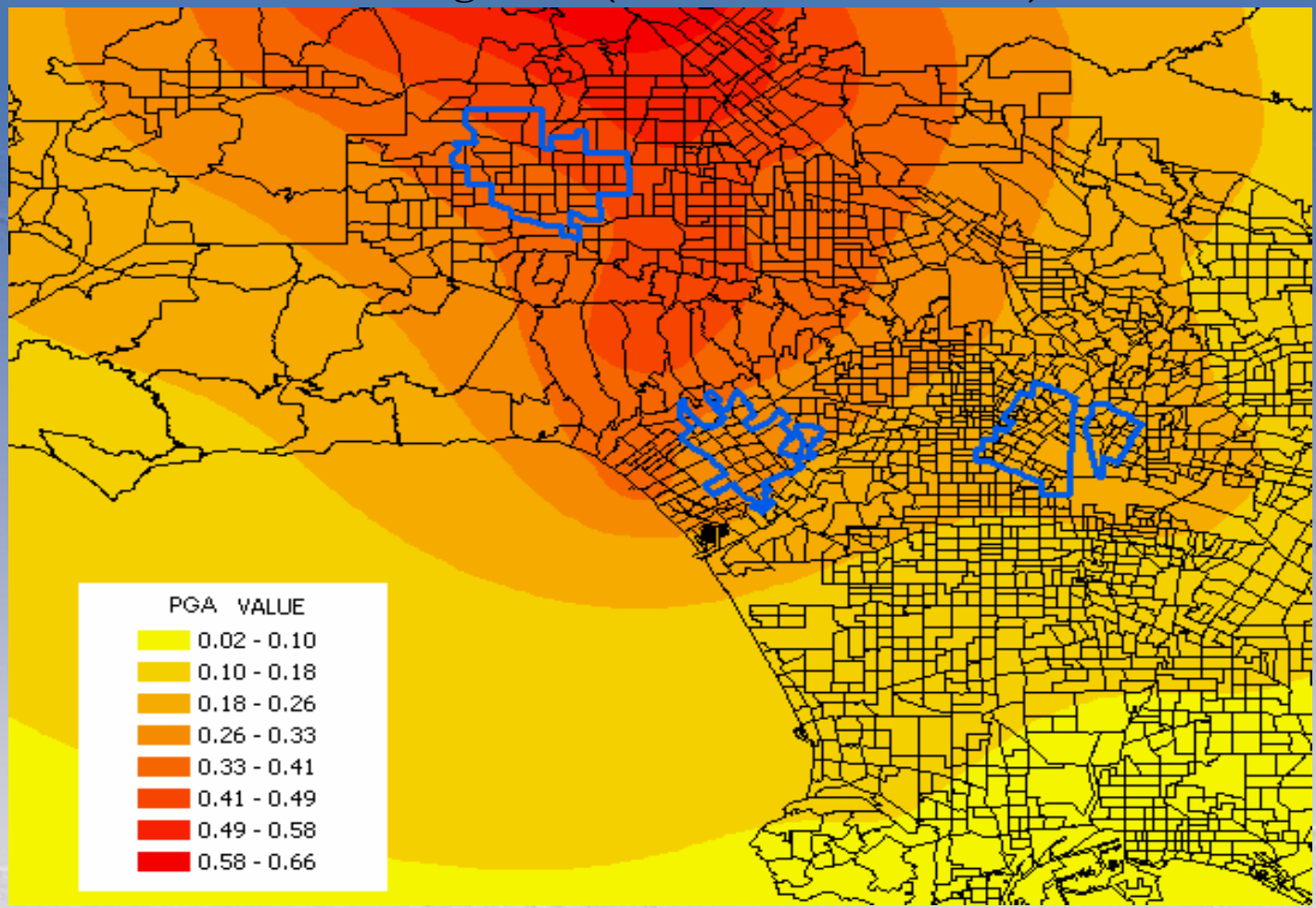
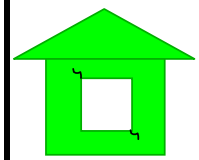
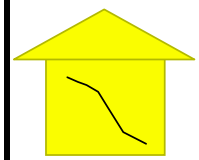
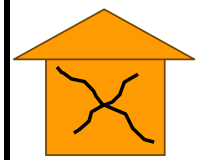
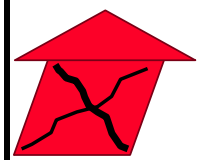
Loss estimation using updated inventory data : Ground Motion Input

1994 Northridge EQ. (Somerville, et al., 1995)



Selected areas: Valley, Wilshire, Downtown

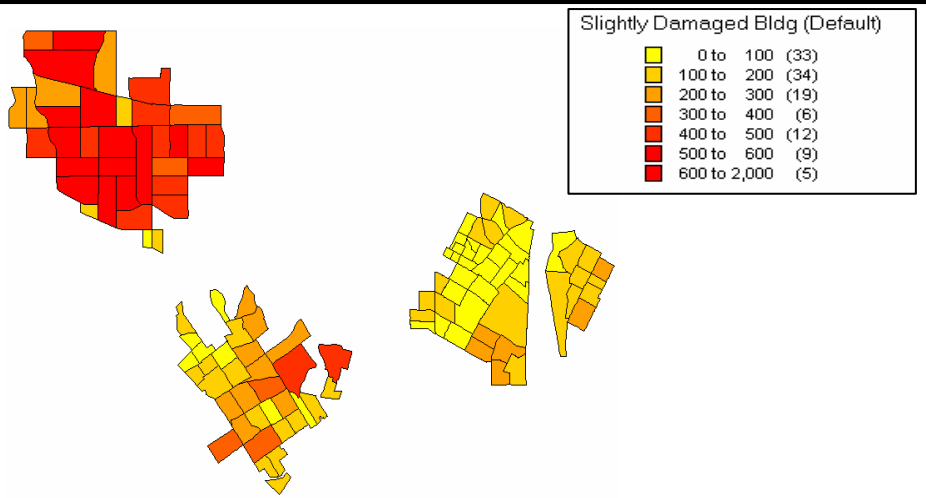
Loss estimation using updated inventory data : Building Damage States in HAZUS®99

Damage State		Description
	**Slight**	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	**Moderate**	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	**Extensive**	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	**Complete**	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

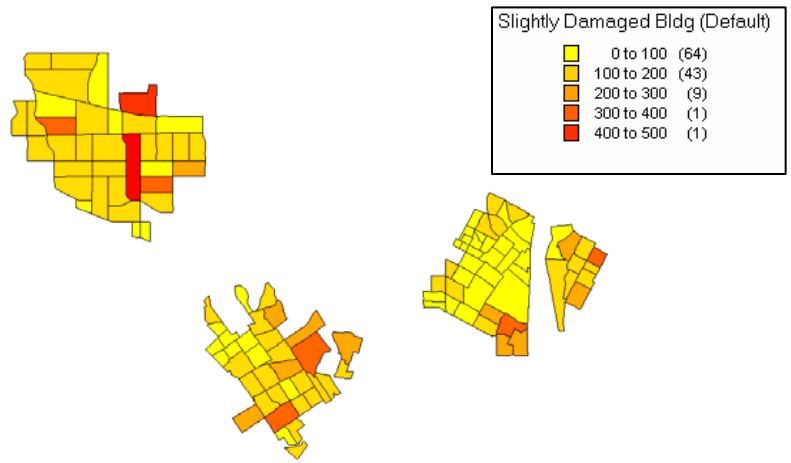
HAZUS®99 AEBM Tech. & User Manual (pp. 2-7)

Loss estimation using updated inventory data : Study Results (1)

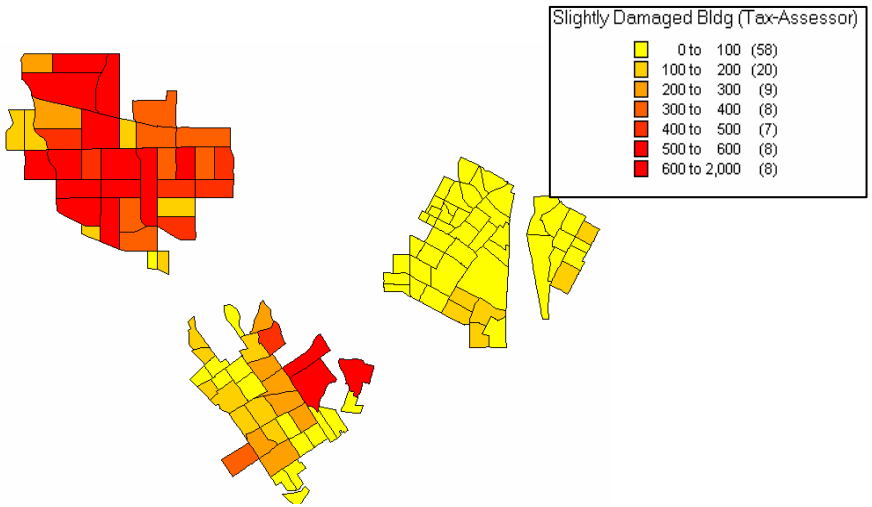
Slight Damage



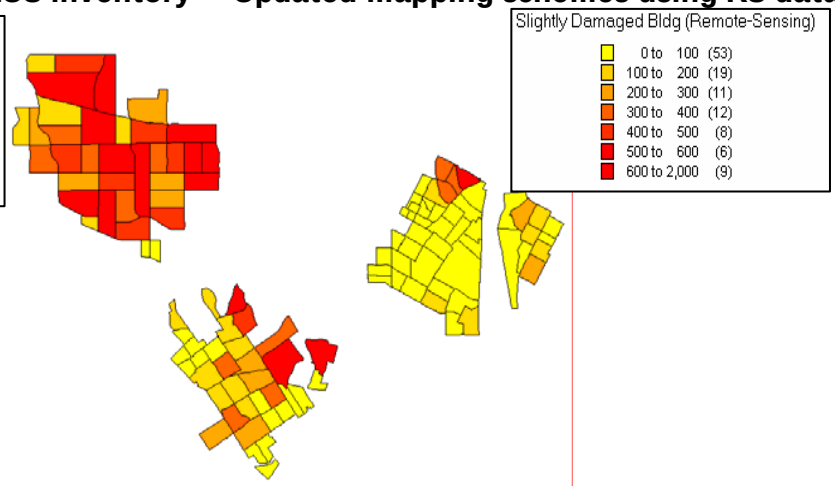
HAZUS default (inventory and mapping schemes)



HAZUS inventory + Updated mapping schemes using RS data



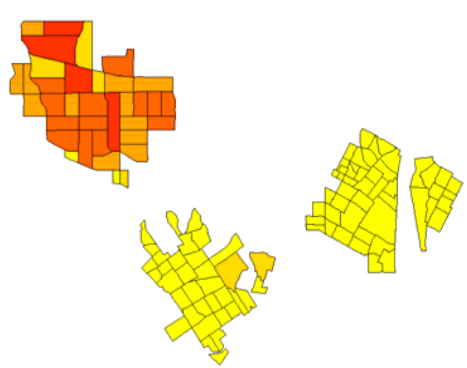
Updated inventory using tax assessor data + HAZUS mapping

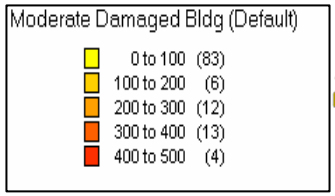


Updated inventory using remote sensing data

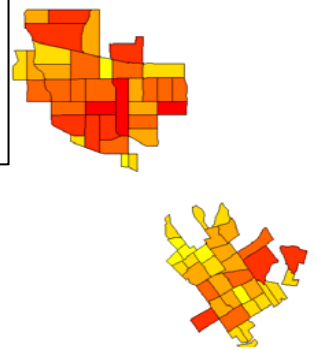
Loss estimation using updated inventory data : Study Results (2)

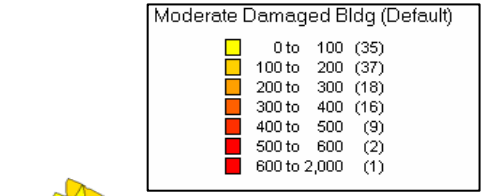
Moderate Damage



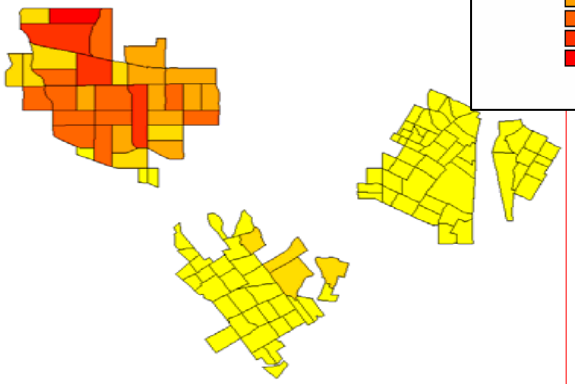


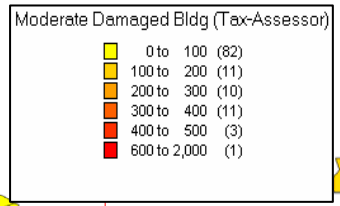
HAZUS default (inventory and mapping schemes)



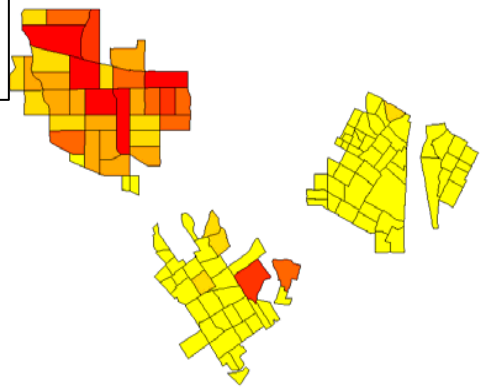


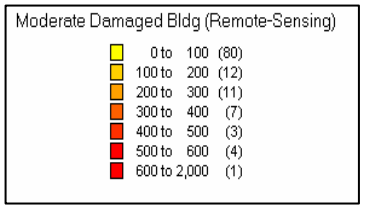
HAZUS inventory + Updated mapping schemes using RS data





Updated inventory using tax assessor data + HAZUS mapping

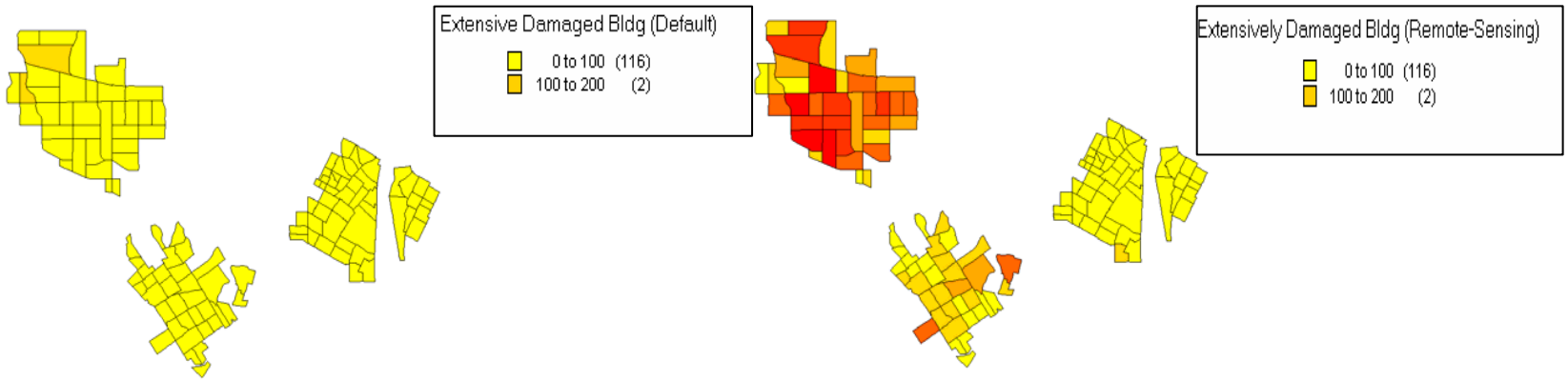




Updated inventory using remote sensing data

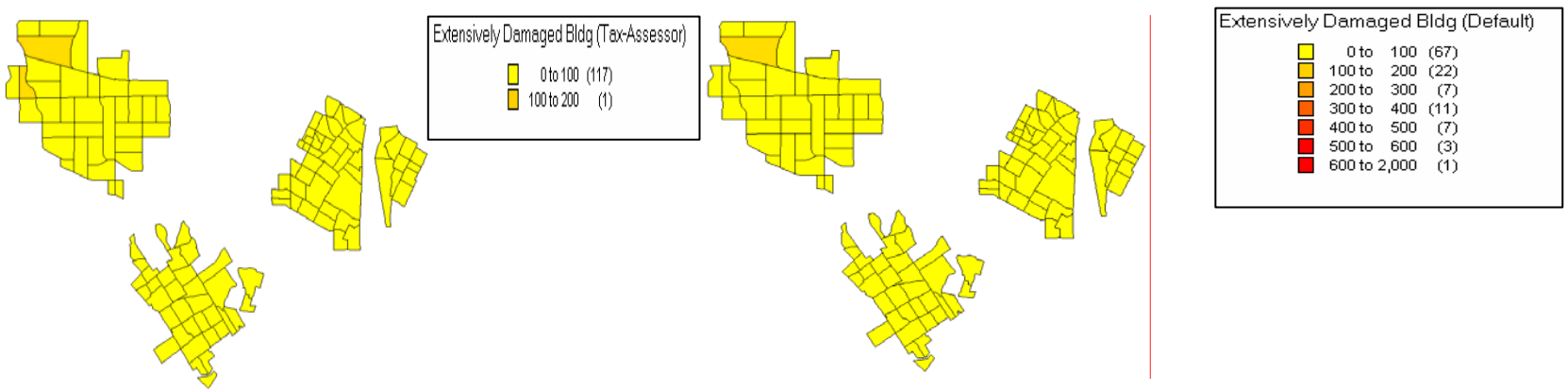
Loss estimation using updated inventory data : Study Results (3)

Extensive Damage



HAZUS default (inventory and mapping schemes)

HAZUS inventory + Updated mapping schemes using RS data

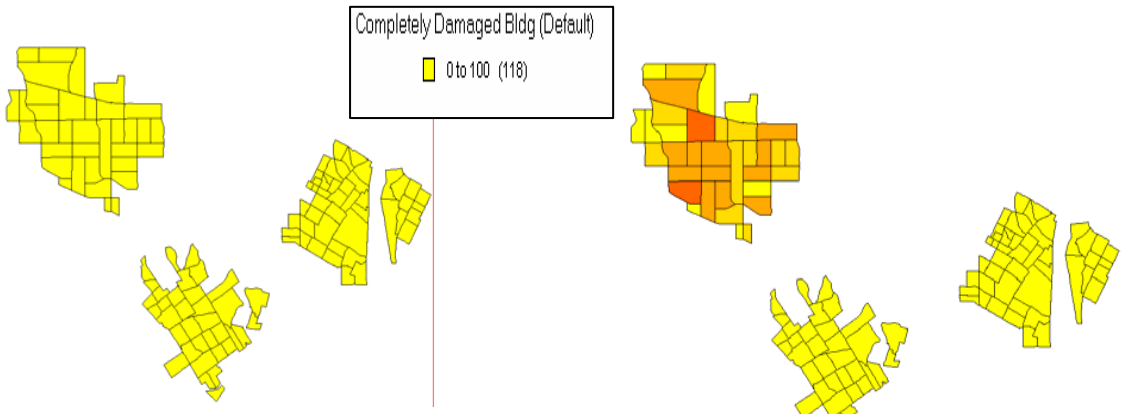


Updated inventory using tax assessor data + HAZUS mapping

Updated inventory using remote sensing data

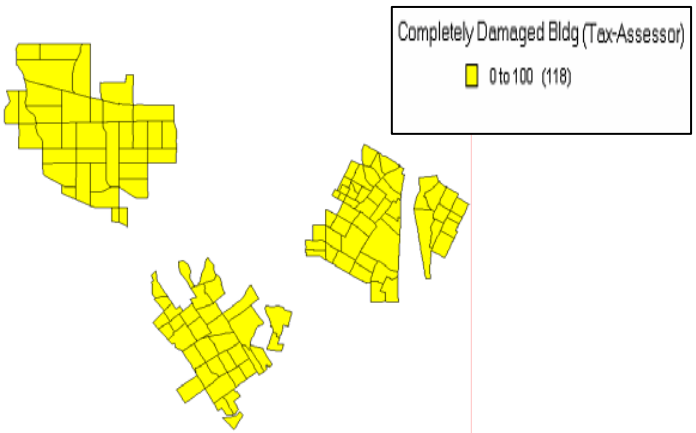
Loss estimation using updated inventory data : Study Results (4)

Complete Damage

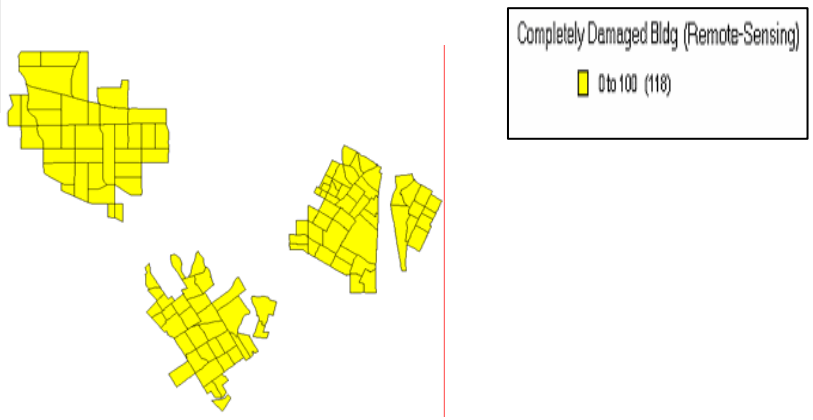


HAZUS default (inventory and mapping schemes)

HAZUS inventory + Updated mapping schemes using RS data

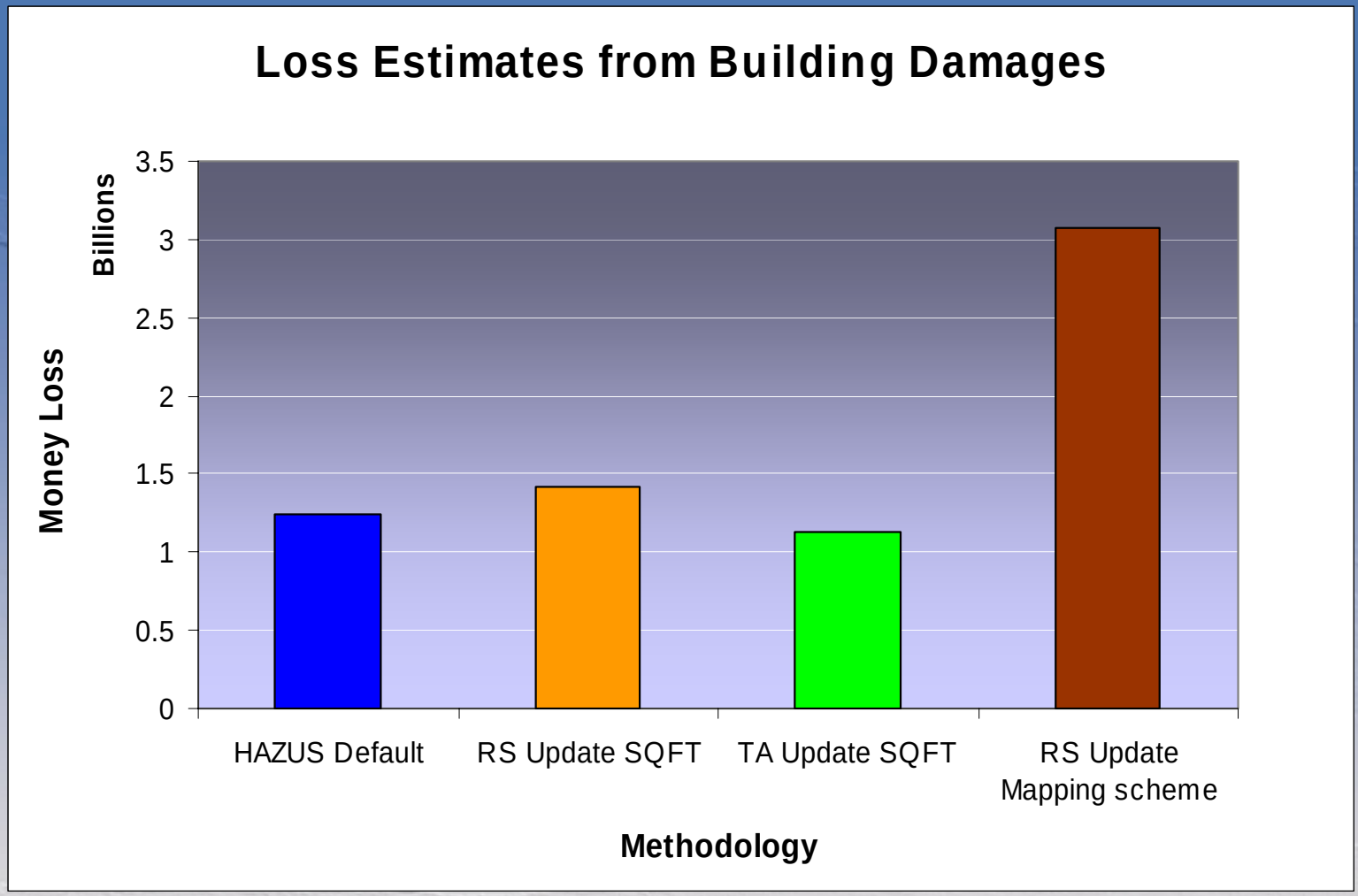


Updated inventory using tax assessor data + HAZUS mapping



Updated inventory using remote sensing data

Loss estimation using updated inventory data



Conclusions

- Developed a semi-automated tool to create 3D city models from *single or stereo* RS imagery
- More detailed information on height and footprint area extracted from RS imagery
- Increased the accuracy of building inventory information through
  - *Modification of regional inventory statistics*
  - *Building specific information*
- Additional inventory information is shown to result in change of loss estimates.
- As Remote Sensing data become increasingly more available, inventory information can be obtained in an efficient and cost effective manner.

Future Plan

- Currently, a visual inspection method is used to identify structural and occupancy categories. A statistical model to correlate geometric attributes of structures (i.e. height, footprint, proximity and etc.) to structural and occupancy type is being developed.
- Building inventory updates will be validated within the regional loss estimation software.
- Develop a building inventory from RS for a region without existing building information.
- Develop additional tools for near-real time multi-level damage identification using 3D inventory information.

Acknowledgment

- Stanford University-UPS Grants
- National Science Foundation (NSF)
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- ImageCat, Inc., Long Beach, CA

Thank You