TOWARDS AN INTEGRATED VULNERABILITY-BASED APPROACH FOR EVALUATING, MANAGING AND MITIGATING EARTHQUAKE RISK IN URBAN AREAS

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Summary

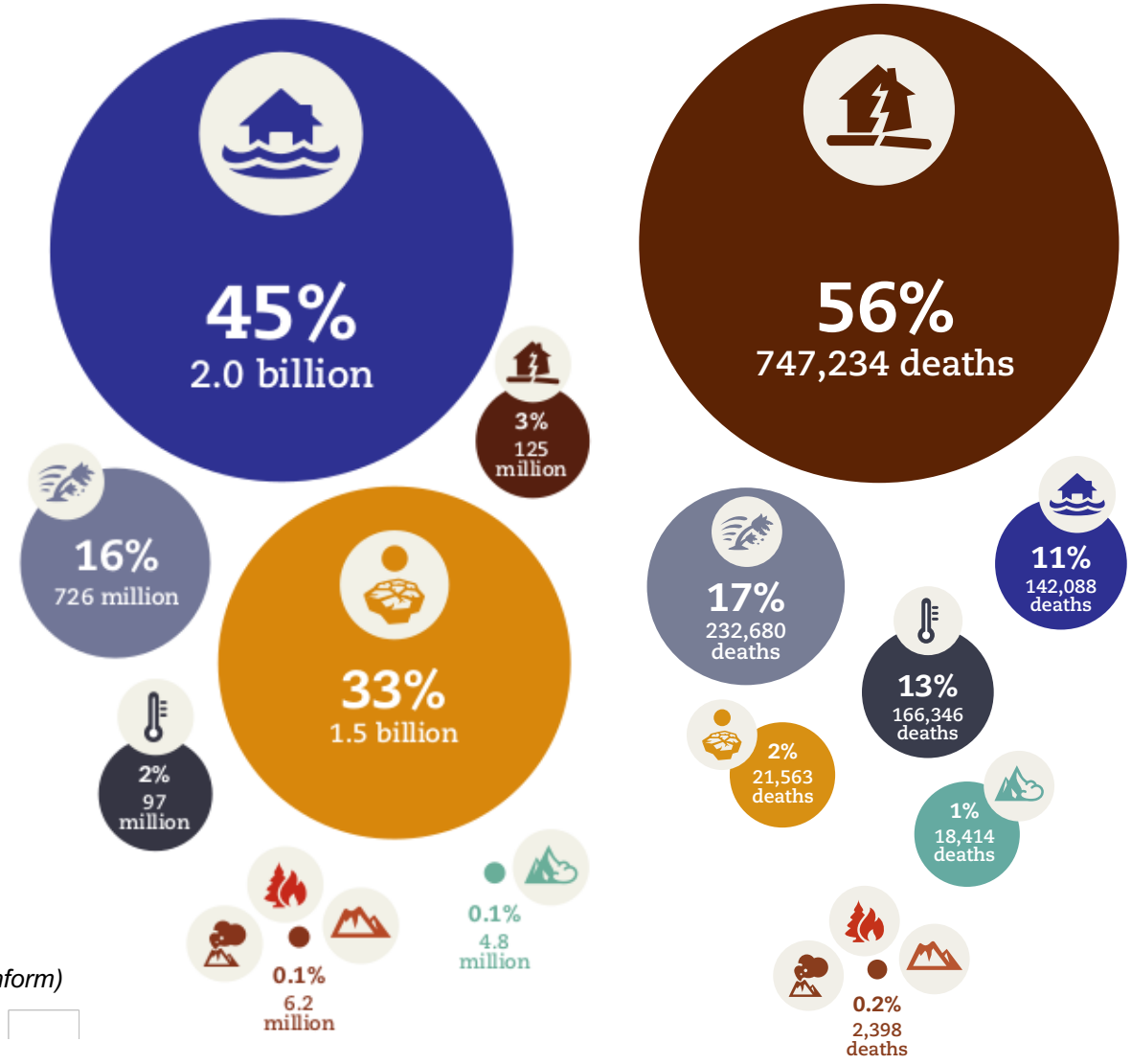
- Definition of the problem
- Objectives
- Literature review
  - 1. Selection of descriptors
  - 2. Data acquisition
  - 3. 3D urban models from point clouds
  - 4. Vulnerability assessment methodologies
  - 5. Urban FTA, ETA and FMEA analysis
- Project summary
- Schedule
- Conclusions

Definition of the problem

Earthquakes represent 7.8% of disastrous events from 1998 to 2017[1], affecting 125 million people. Despite this relatively low proportion, earthquakes also represent 56% of deaths associated to natural disasters.

Earthquakes also represent the 23% of economic losses related to natural disasters. The occurrence of seismic events in low-income countries is still an enormous challenge for the economic development.

- Earthquake
- Storm
- Extreme temperature
- Flood
- Drought
- Landslide
- Wildfire, Volcanic activity, Mass movement (dry)

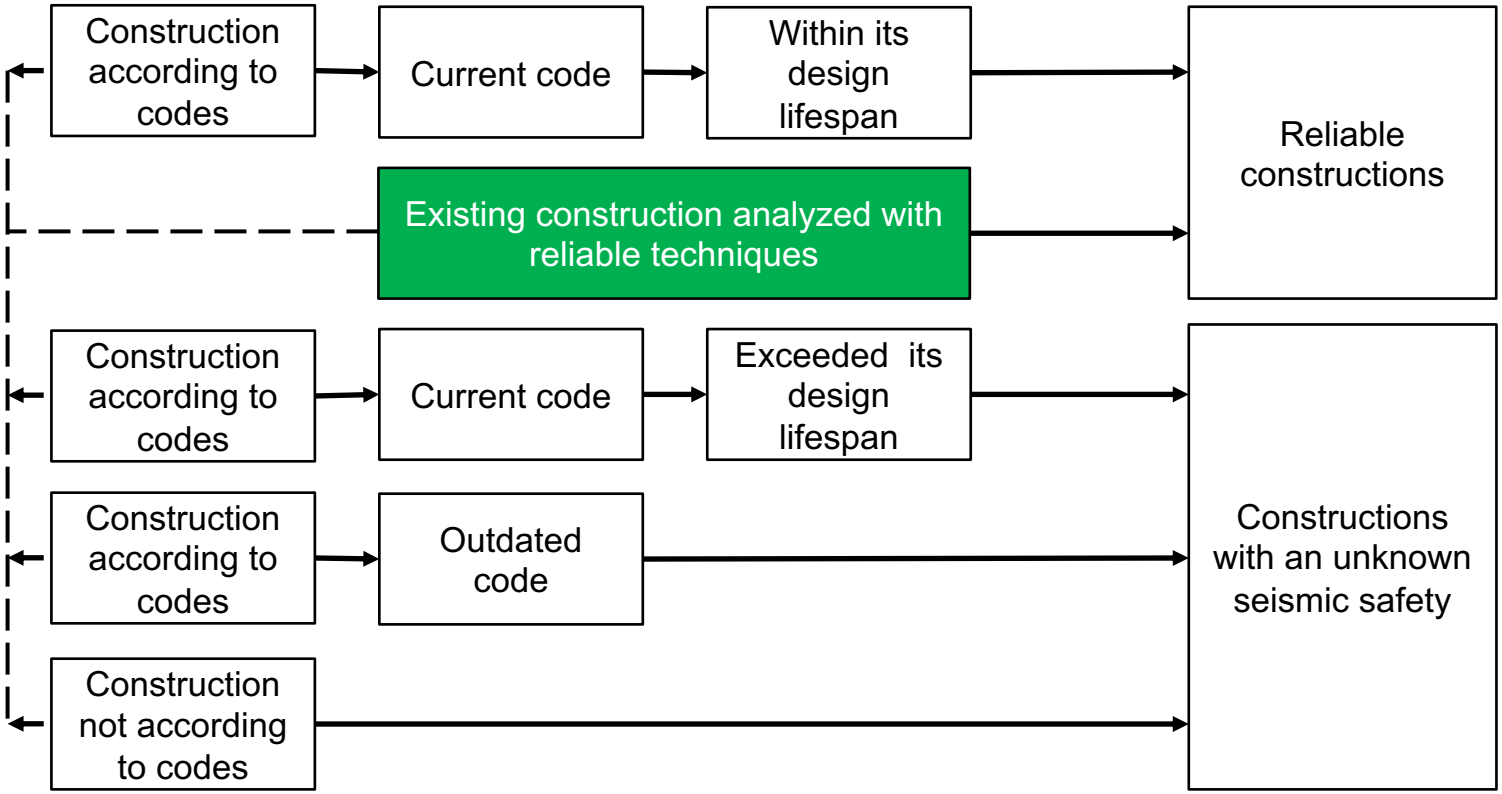


[1] *United Nations Office for Disaster Risk Reduction (Economic, Losses, Poverty & Disasters 1998-2017 inform)*

Definition of the problem

In order to prevent deaths and economic losses, it becomes necessary to assess the seismic safety of existing building stock with reliable techniques.

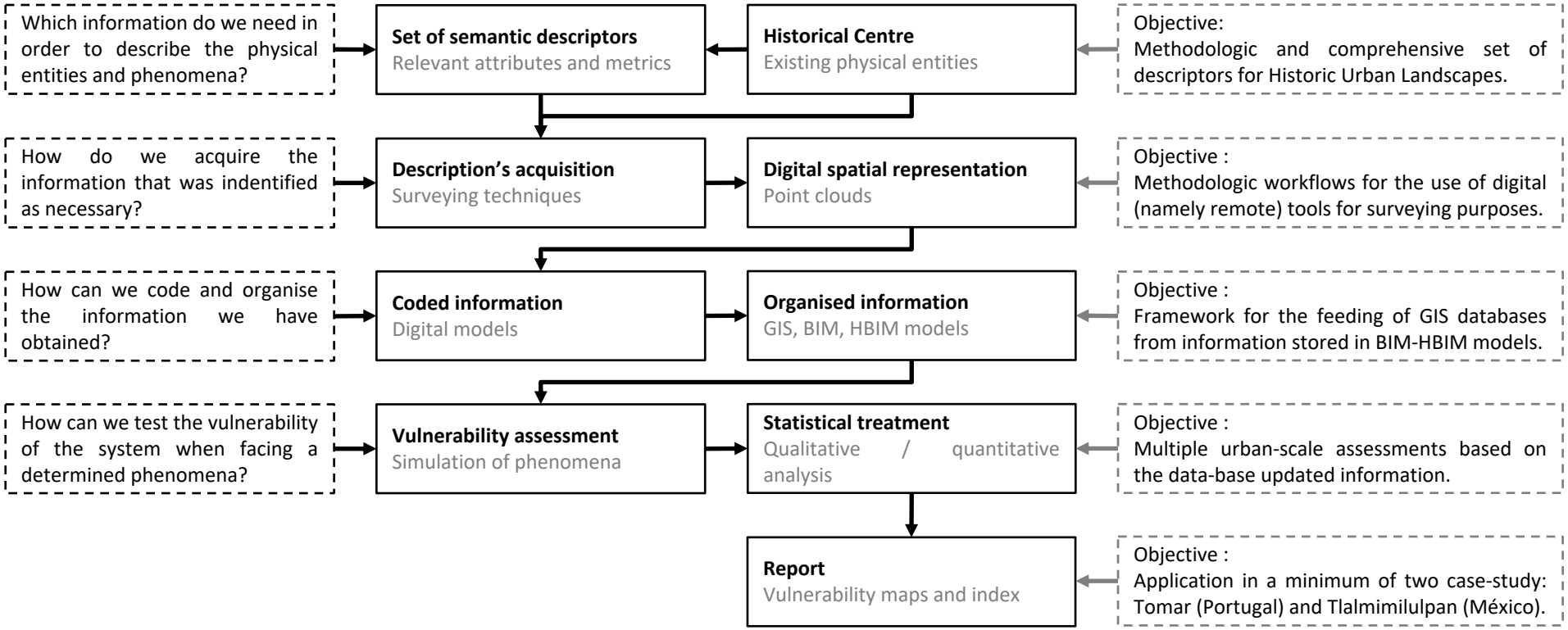
This strategy would allow to focus financial, material and human resources into the most vulnerable constructions, enhancing the urban resilience capacities.



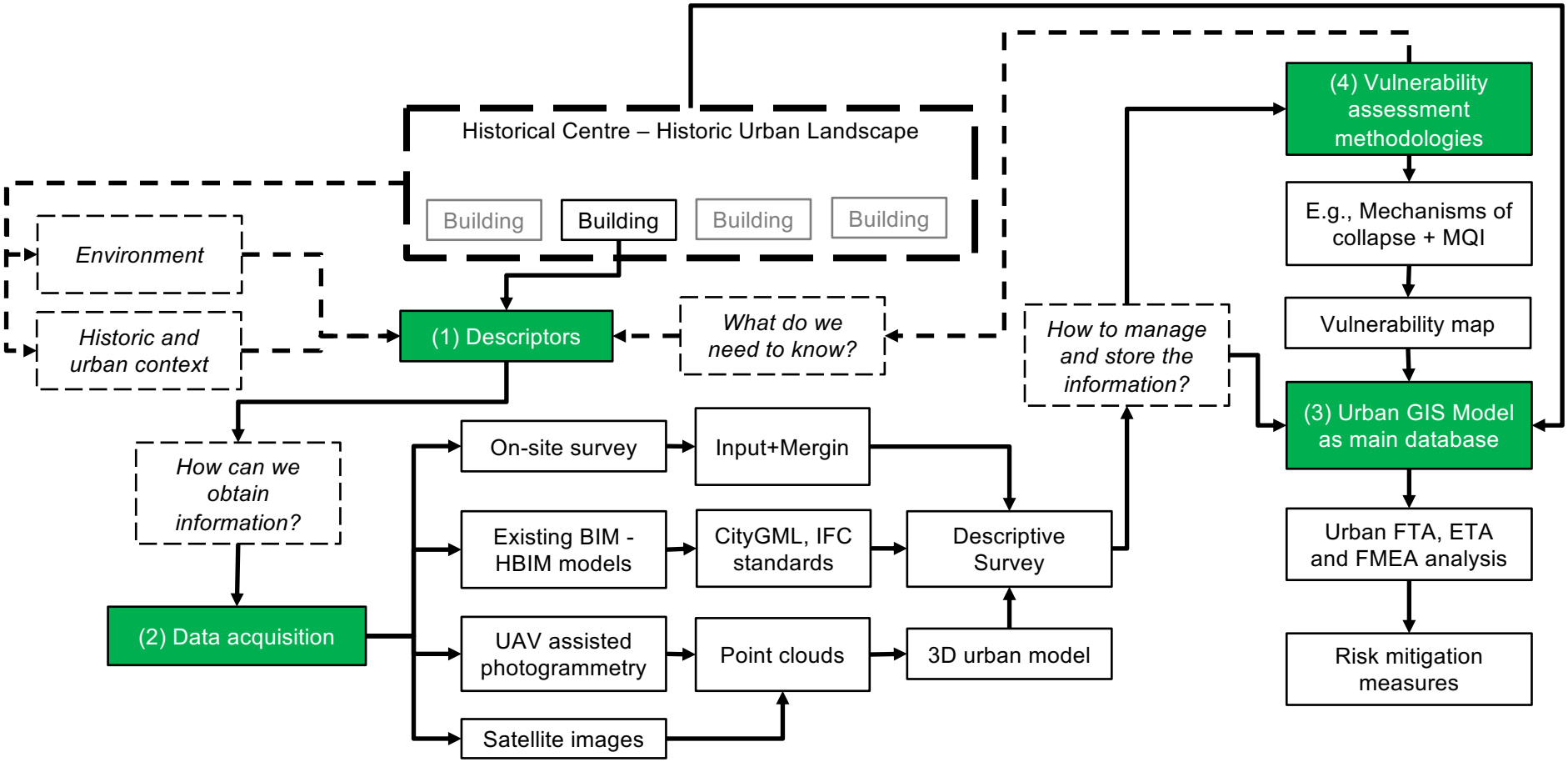
Objectives

As a departure point, we need to stablish which coded information is relevant and meaningful for approaching the constructions: the **descriptors**. The set of descriptors of a specific building constitutes its representative **description**.

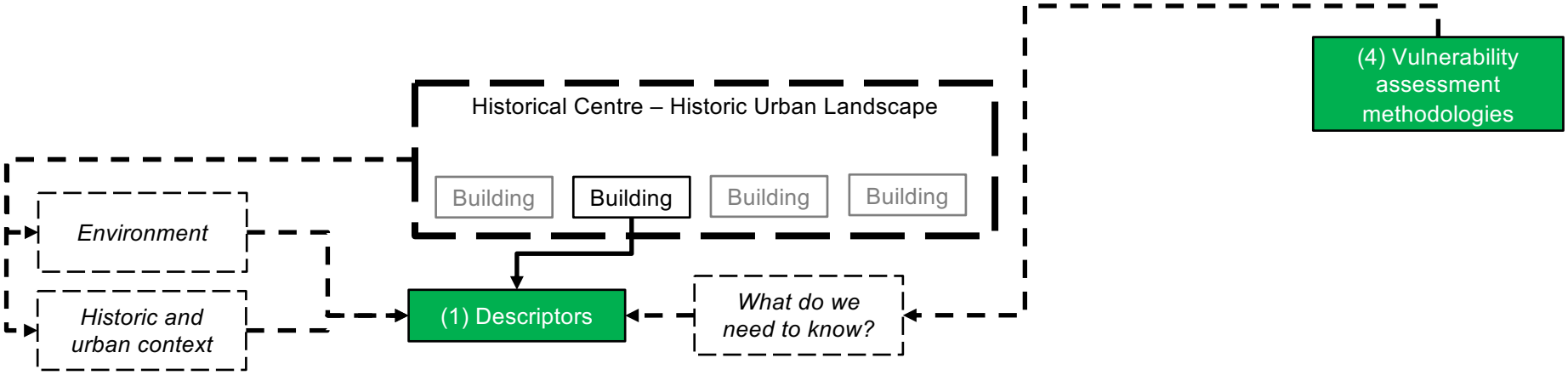
This description is the base for **models** that store the coded information and permit to test hypothesis, namely **vulnerability assessment** approaches.



Literature review



Selection of descriptors



Historic Urban Landscape.

Based on the definitions provided in the HUL Guidebook (2016), a practical guide to UNESCO's Recommendation on the Historic Urban Landscape.

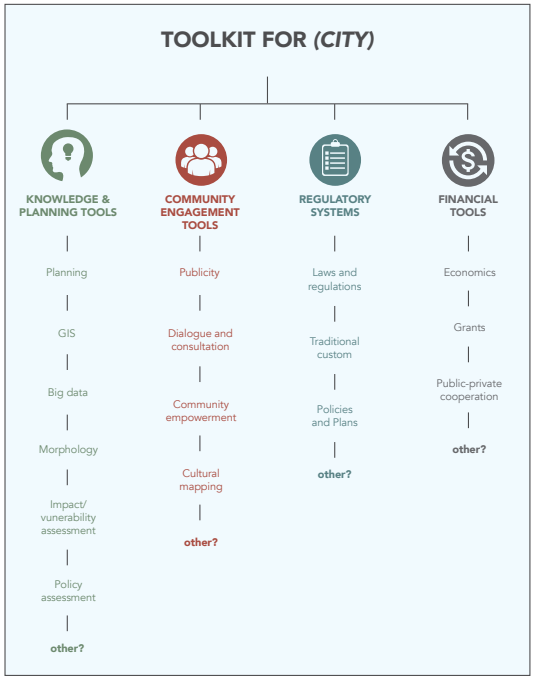
Structural assessment methodologies

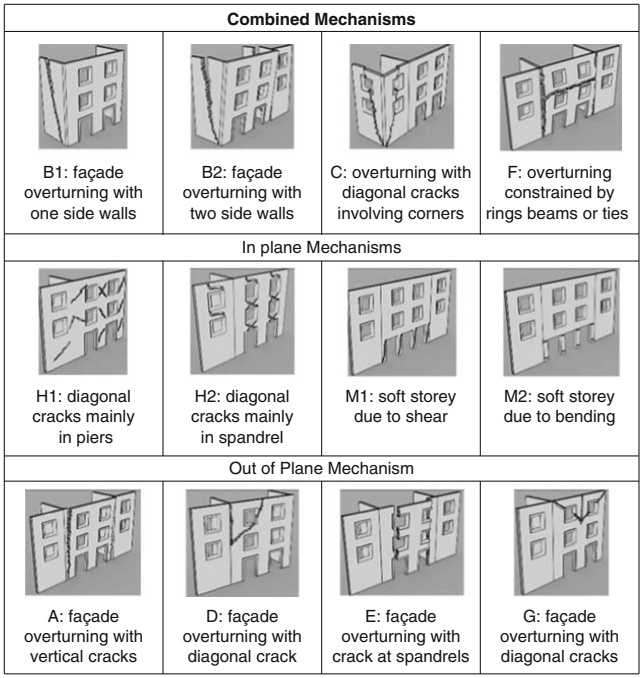
Based on the macro-elements approach, such as the ones developed by D'Ayala et al (1997, 2003) and the ones of Milano et al (2009). Also, the implementation of relevant semi-quantitative approaches such as the Masonry Quality Index is considered.

Building identification and historic data

Relevant information of the historical and cultural values of the asset, based on the existing Catalogue Sheet of the National Coordination for Historic Monuments of the National Institute for Anthropology and History, Mexico.

Selection of descriptors





Historic Urban Landscape.

Geomorphology, hydrology, infrastructures, open spaces and gardens, land use patterns, spatial organization, social and cultural practices and values, economic processes. **Territorial information**.

Structural assessment methodologies

General **geometry**, number or storeys, density of materials, flooring systems, slenderness of walls, presence of openings, etc…

Building identification and historic data

Year of construction, architectonic description, construction phases, photographic survey, summary of documental **historic sources**, etc. It can help to support further prognosis and/or intervention decisions.

Data acquisition

On-site surveys.

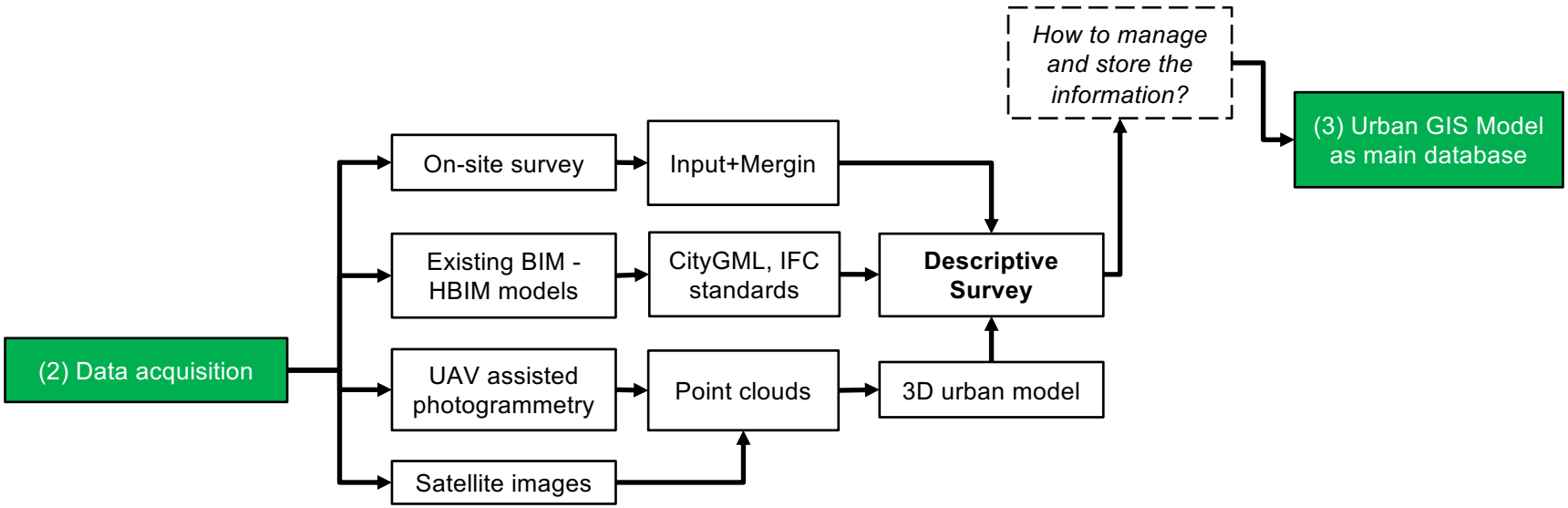
Based on the «Open Source Software for Preprocessing GIS Data for Hydrological Models» (Hans van der Kwast, IHE Delft), using Input and Mergin.

Existing BIM and HBIM models.

Thanks to the CityGML and IFC standards, it would be possible to fill most of the descriptive survey by taking information from existing BIM or HBIM models.

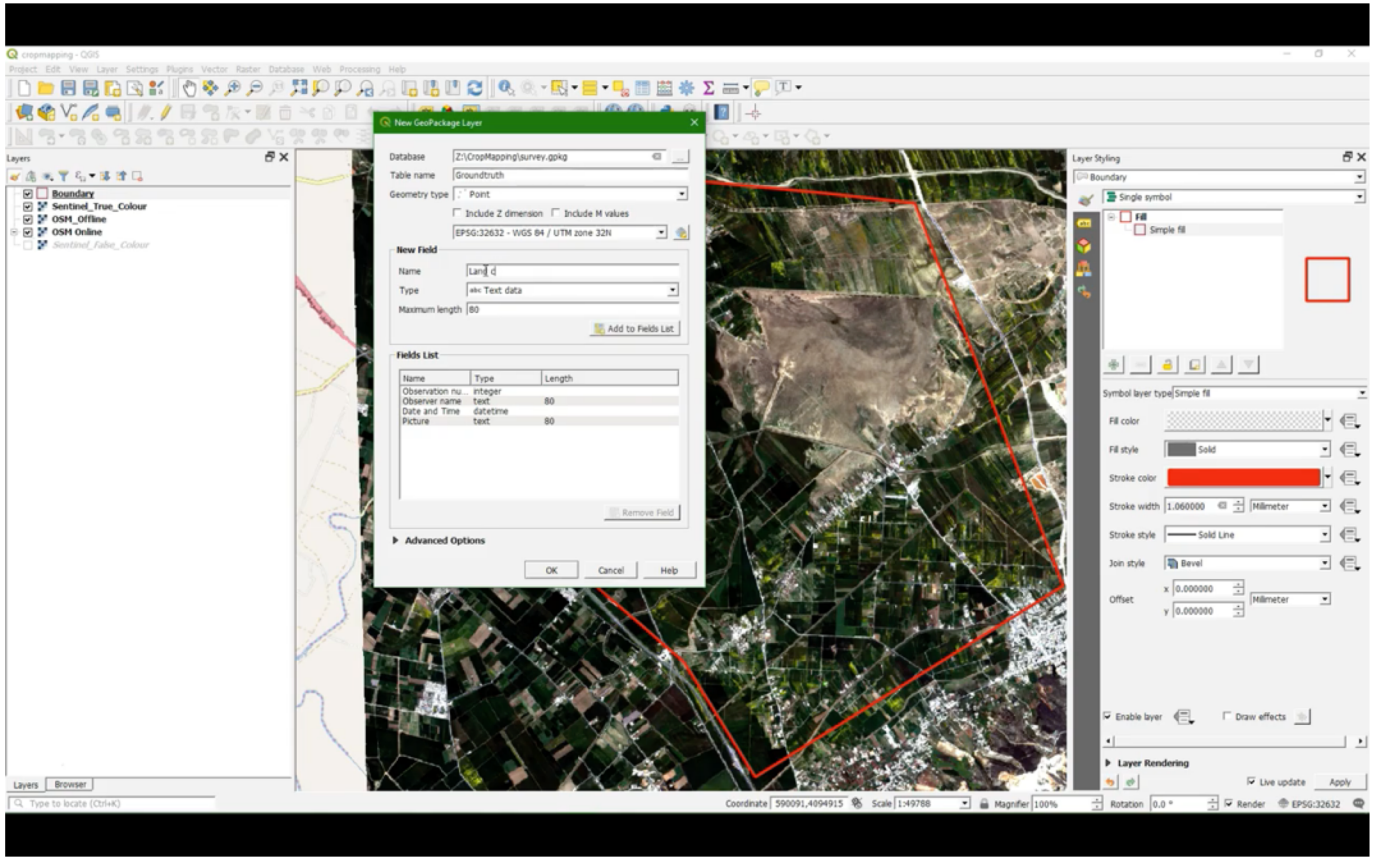
3D Point clouds.

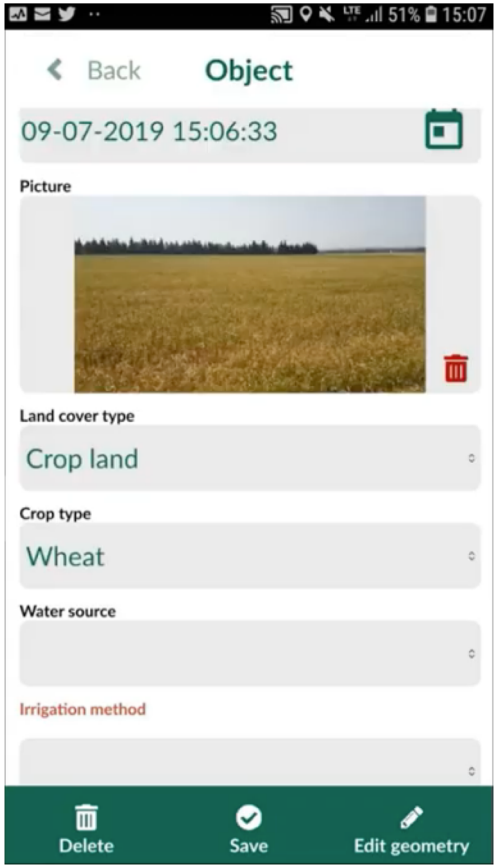
It is possible to carry urban-scale surveys with the assistance of satellite images and/or drones in order to have a documental basis for filling the descriptive survey.



Data acquisition: on-site survey

Information can be acquired through on-site surveys assisted by online GIS-databases, fed by using tools such as Input® and Mergin®.

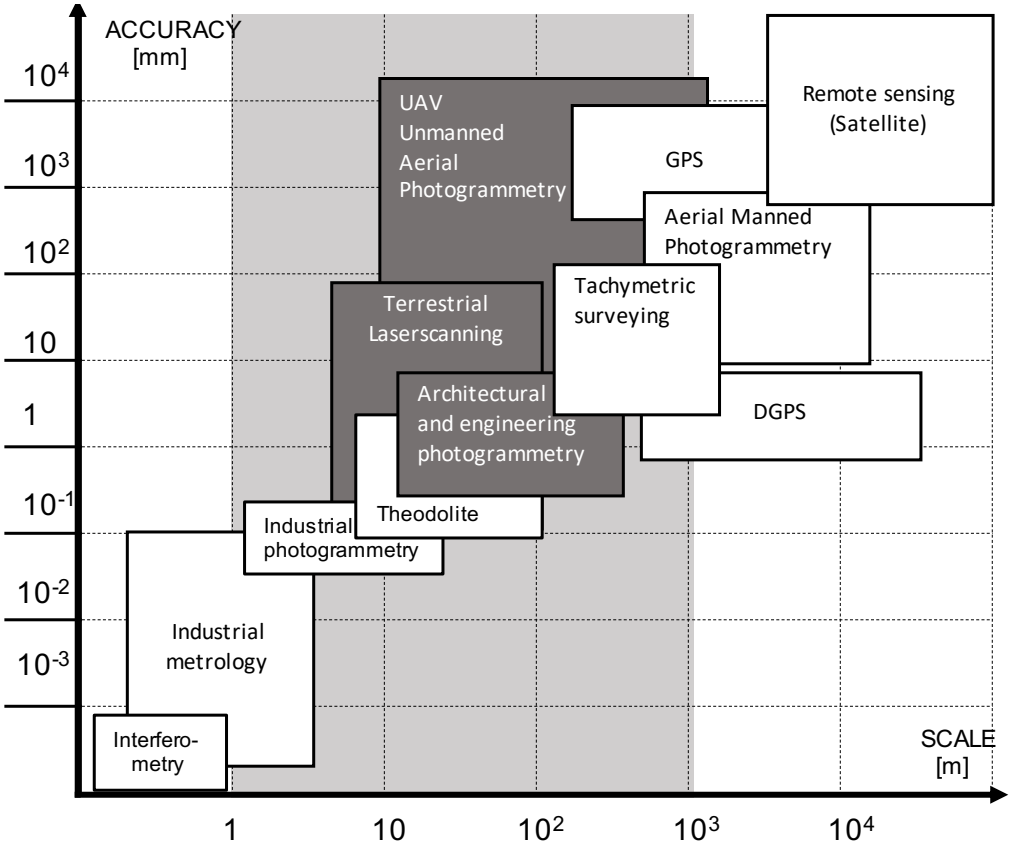




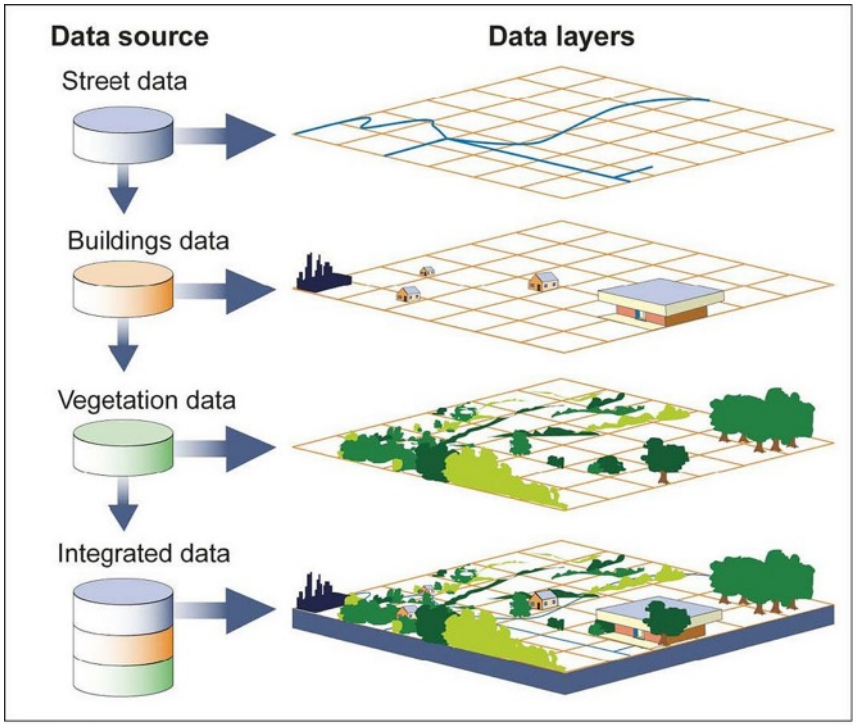
Screenshots of the «Open Source Software for Preprocessing GIS Data for Hydrological Models» tutorial. IHE Delft.

Data acquisition: 3D point clouds

Alternatively, a 3D point cloud can be generated from photogrammetric, lased scan or satellite surveys.



Based on Eisenbeiss et al. (Eisenbeiss, 2009)

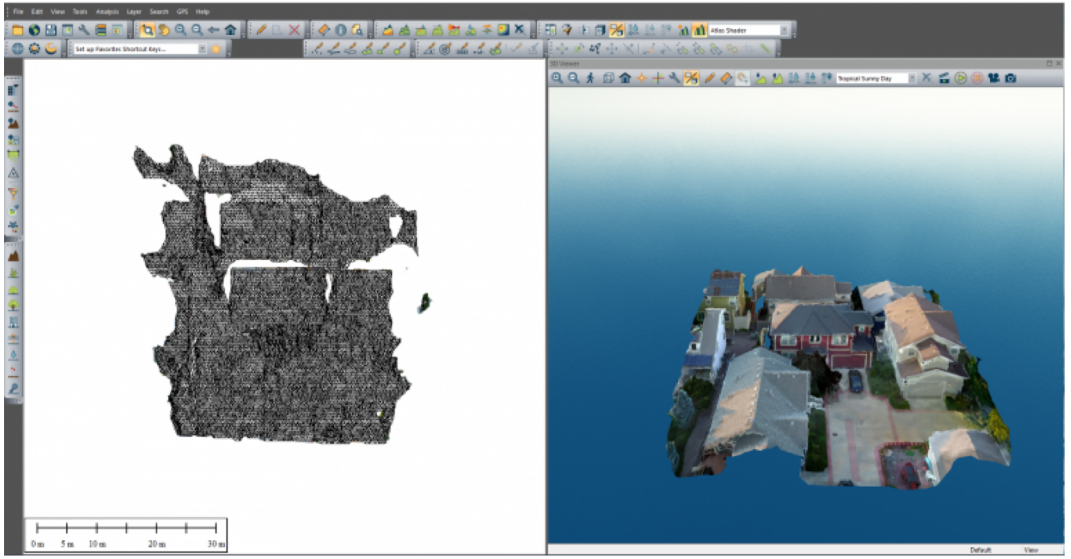


Layers of information in a GIS database. Source: https://www.nationalgeographic.org/encyclopedia/geographic-information-system-gis/

Data acquisition: 3D point clouds

Those point clouds may be the base for urban 3D model based on CityGML standard for GIS. The information documented in the model would permit to fill the descriptive survey. Information is able to be stored in a 2D or 3D GIS database.

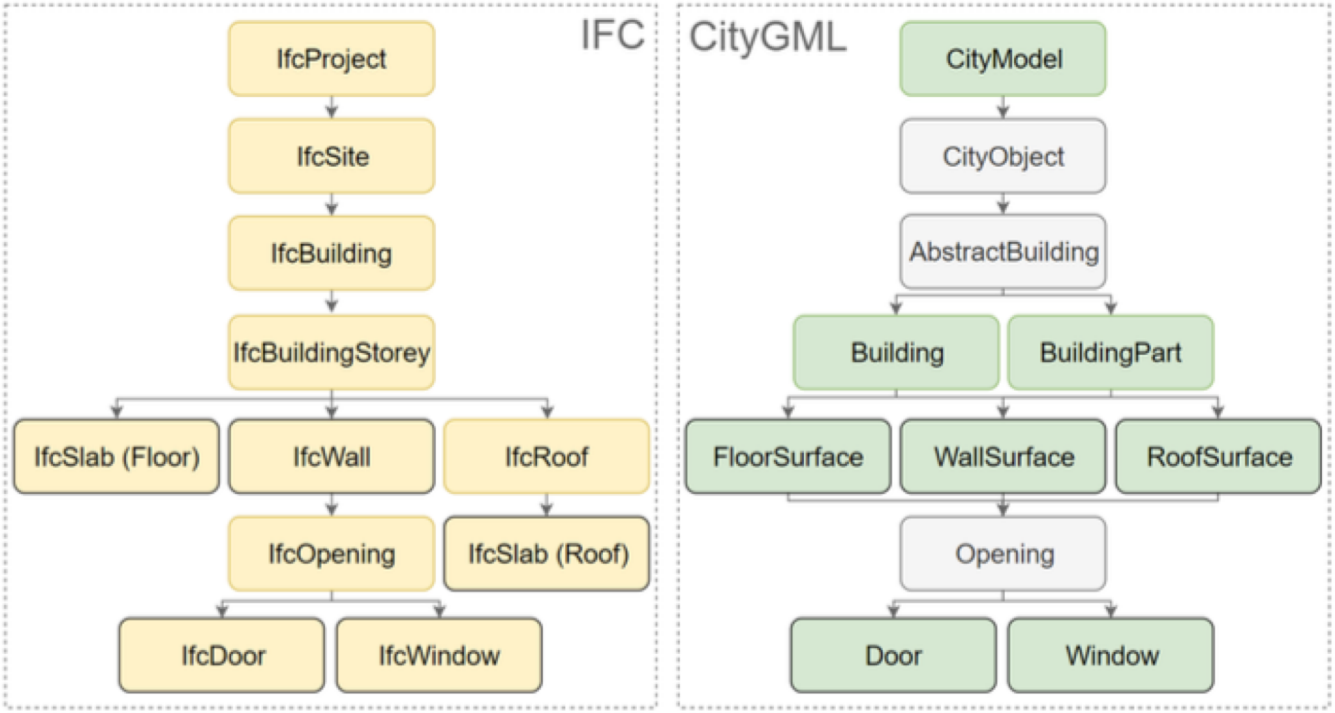
Schauer et al (2016). Würzburg Marketplace. Opensource file from http://kos.informatik.uni-osnabrueck.de/3Dscans/



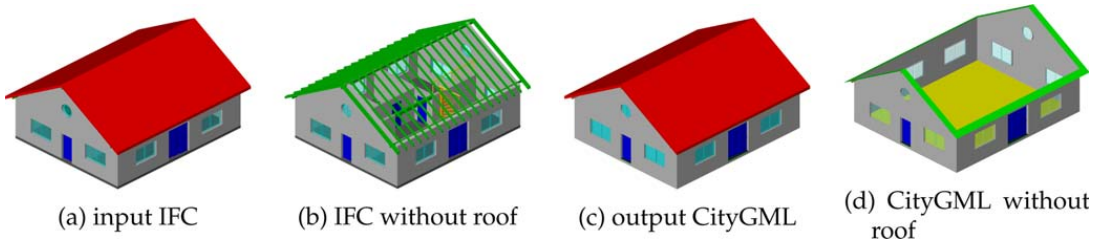
A 3D mesh created using Global Mapper's Pixels to Points tool displayed in the 2D and 3D views. https://blog.bluemarblegeo.com/2018/08/09/lidar-vs-photogrammetrically-generated-point-cloud-data/

Data acquisition: existing BIM and HBIM models

Some recent experiences have successfully integrated a full conversion between BIM and GIS models by the means of algorithms for translating BIM IFC standards into GIS CityGML standard objects.



Cecchini (2019) From Data to 3D digital archive: a GIS-BIM spatial database for the historical centre of Pavia (Italy)



Donkers et al (2009) Automatic conversion of IFC datasets to geometrically and semantically correct CityGML LOD3 buildings

Vulnerability assessment methodologies

Some simplified approaches are based on the assumption of rigid macro-blocks that permit specific failure modes with mathematic expressions for their energy of activation. Hence, it is possible to test several failure modes of a building in order to assess which are the more likely to occur and which buildings on a set are more likely to present failure when facing a seismic event. It is possible to include local/national code's approaches as well as «blocks» in the workflow.

Equazione dei lavori virtuali:

$$\alpha\left[W_1\cdot\delta_{1x}+W_2\cdot\delta_{2x}+F_V\cdot\delta_{Vx}\right]+F_H\cdot\delta_{Vx}+$$
$$-W_1\cdot\delta_{1y}-W_2\cdot\delta_{2y}-N\cdot\delta_{Ny}-P_S\cdot\delta_{Py}-F_V\cdot\delta_{Vy}=0$$

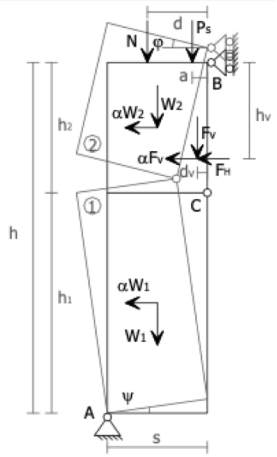
Moltiplicatore di collasso:

$$\alpha=2\frac{(\mu-1)\left(N\,d+P_S\,a+F_V\,d_V-F_H\,h_V\right)+s\left(W+N+P_S+F_V\right)}{(\mu-1)\left(W\,h/\mu+2\,F_V\,h_V\right)}$$

Il valore di α è valutato al variare di μ, termine che consente di individuare la posizione della cerniera cilindrica lungo l'altezza della parete:

$$h_1=\frac{\mu-1}{\mu}h;\ h_2=\frac{h}{\mu};\ W_2=\frac{W}{\mu};\ W_1=\frac{\mu-1}{\mu}W$$

Foto: Arch. Fot. Vice Comm. Del. Beni Culturali - Sisma Abruzzo 2009



Momento stabilizzante:

$$M_{S(A)}=W\cdot\frac{s}{2}+F_V\cdot d_V+P_S\cdot d+T\cdot h$$

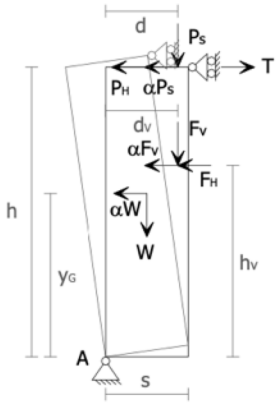
Momento ribaltante:

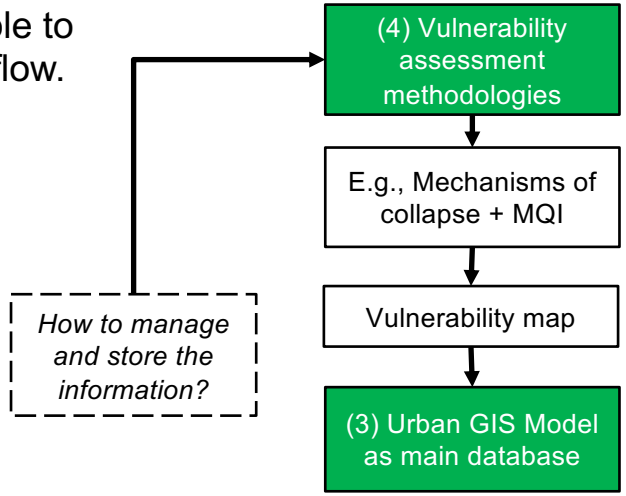
$$M_{R(A)}=\alpha\cdot\left[W\cdot y_G+F_V\cdot h_V+P_S\cdot h\right]+F_H\cdot h_V+P_H\cdot h$$

Moltiplicatore di collasso:

$$\alpha=\frac{W\cdot\frac{s}{2}+F_V\cdot d_V+P_S\cdot d+T\cdot h-F_H\cdot h_V-P_H\cdot h}{W\cdot y_G+F_V\cdot h_V+P_S\cdot h}$$

Foto: Arch. Fot. Vice Comm. Del. Beni Culturali - Sisma Abruzzo 2009

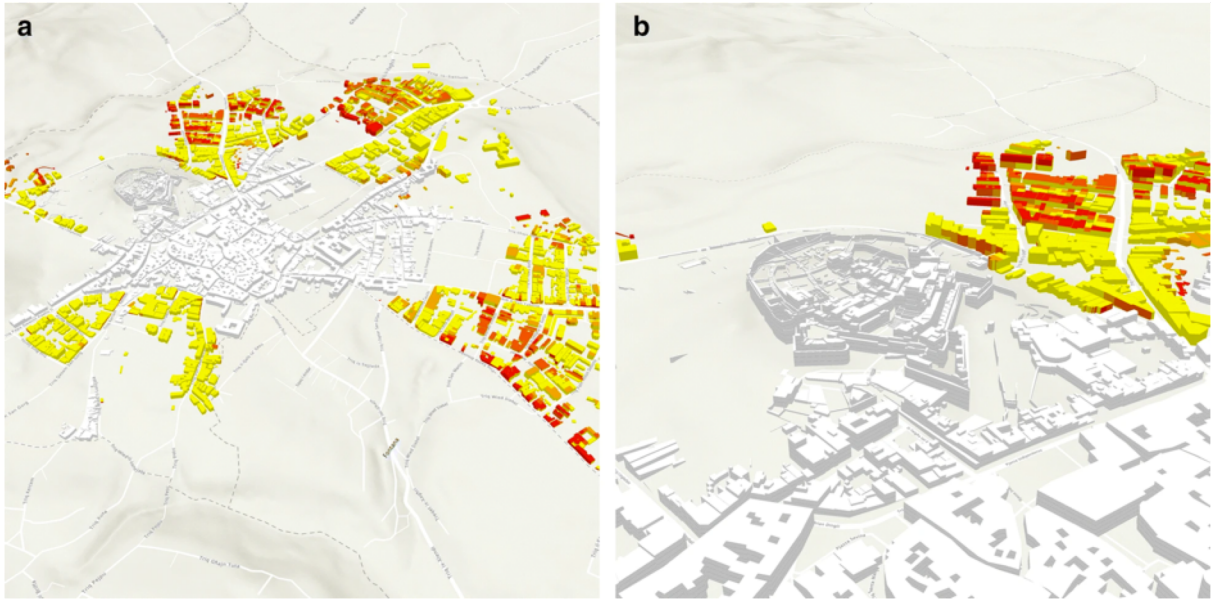




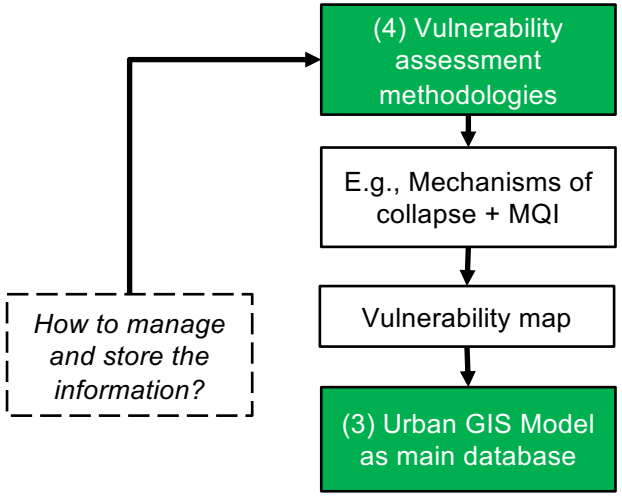
Examples extracted from Milano et al (2009) Schede illustrative dei principali meccanismi di collasso locali negli edifici esistenti in muratura e dei relativi modelli cinematici di analisi

Vulnerability assessment methodologies

The assessment of a set of buildings would permit to have a qualitative index for labelling the relative vulnerability of each construction. This would permit to suggest post-event scenarios and prioritise urgent action on the most vulnerable constructions.

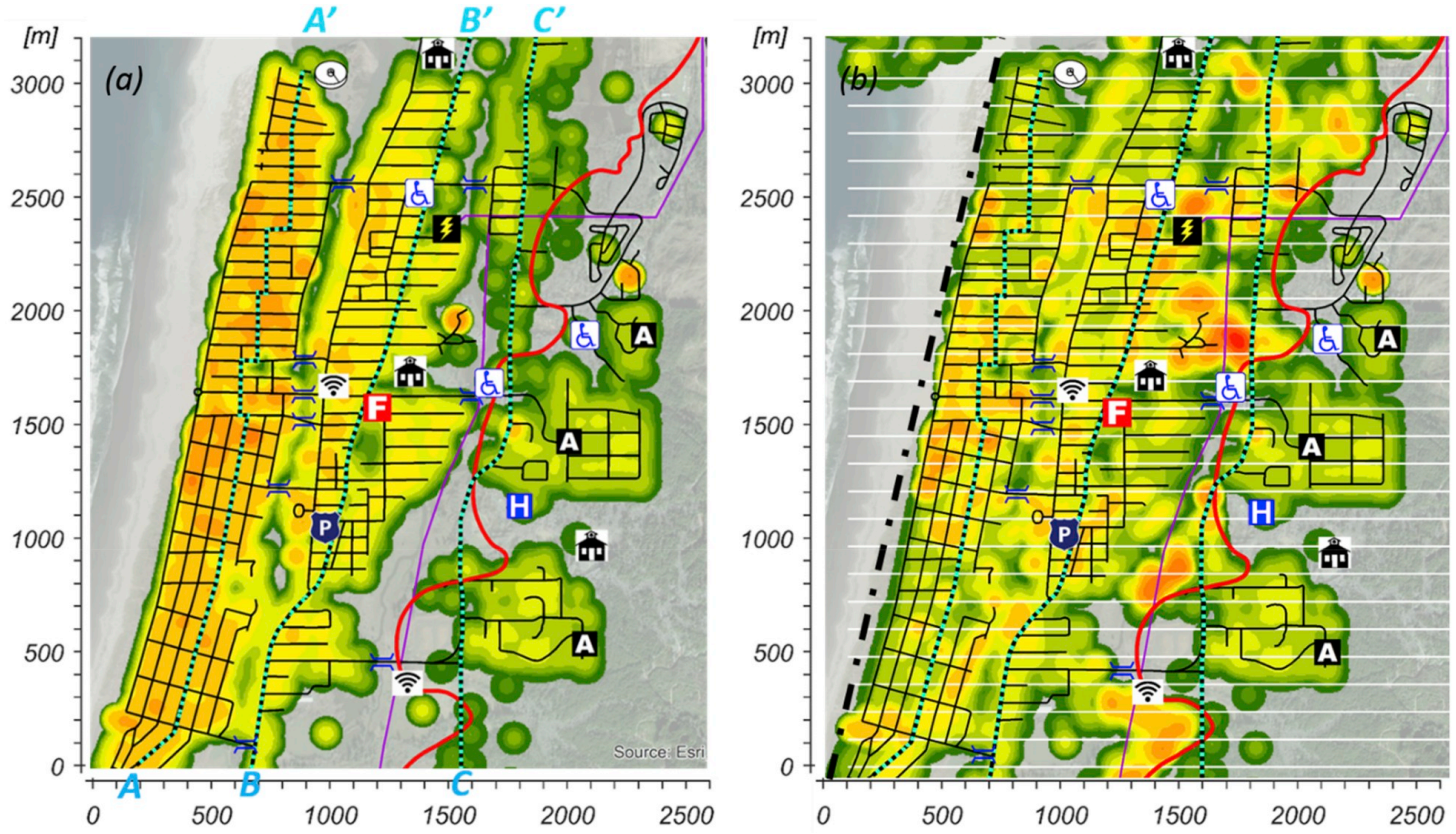


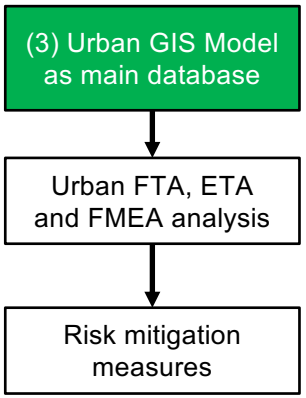
Target image for a potential vulnerability cartography. Based on Morosini et al (2019) Land use and urban sustainability assessment: a 3D-GIS application to a case study in Gozo



Urban FTA, ETA and FMEA analysis

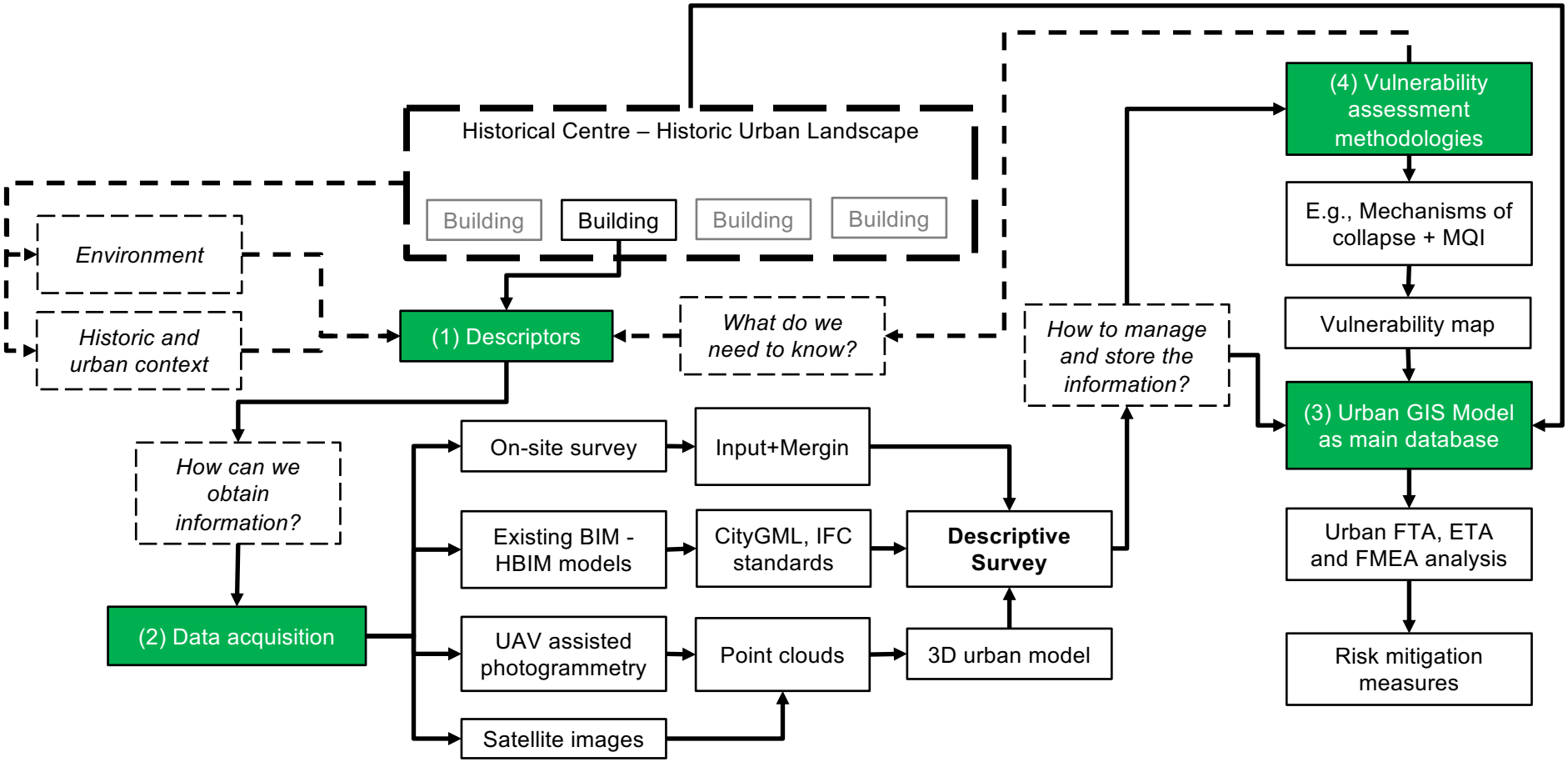
These approaches would also permit to analyse the components of the city in order to prevent potential urban failures due to the presence of debris, failure of basic services and critical infrastructures.





Detailed contour map of total debris volume including both buoyant debris and non-buoyant debris with critical structure and transportation network at Seaside, Oregon, for 1000 year-event: (a) before the advection, (b) after advection. Park et al (2019).

Project summary



Schedule

		1st Year Trimester				2st Year Trimester				3st Year Trimester			
Task	**Task description**	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**
T0	State-of-the-art and literature review												
Paper	State-of-the-art.												
T1	Design of semantic characterisation models												
Paper	HUL entities semantic characterisation oriented to vulnerability assessment.												
T2	Design of survey methods												
Paper	HUL Vulnerability-oriented HUL surveying tools.												
T3	Design of vulnerability assessment frameworks												
Paper	HUL Multi-level seismic vulnerability assessment for HUL entities.												
T4	Design of an unified data management framework												
Paper	Unified framework for HUL seismic vulnerability assessment.												
T5	Integration and application												
Paper	Seismic vulnerability assessment for the Historic Urban Centre of Tomar: a methodological approach.												

Conclusions

- A feasible approach for estimating the seismic vulnerability of existing masonry constructions is the macroelement analysis.
- This analysis is able to be done with information from proper data models, stored and managed in a GIS database.
- Models can be built from information obtained by multiple and complementary means, such as on-site surveys, point cloud-based 3D models and existing BIM and HBIM models, based on standards such as CityGML and IFC.
- Urban surveys are able to be carried-out with a high grade of quality, and with a relatively low investment of time and resources thanks to tools such as the UAV-assisted photogrammetry or satellite images.
- The representativeness of models depends on the correct selection of the attributes that accurately represent the information required on the selected vulnerability assessment methodology as well as complementary approaches such as the UNESCO's HUL approach, socioeconomic and historic data.
- The analysis of vulnerability for single buildings in a historic centre would provide a basis for FTA, ETA and FMEA analysis for the identification of potential post-disaster scenarios and proper mitigation interventions at an urban level.

Thank you