Prioritizing Heritage Sites Considering both Tangible and Intangible Factors from Seismic Perspective

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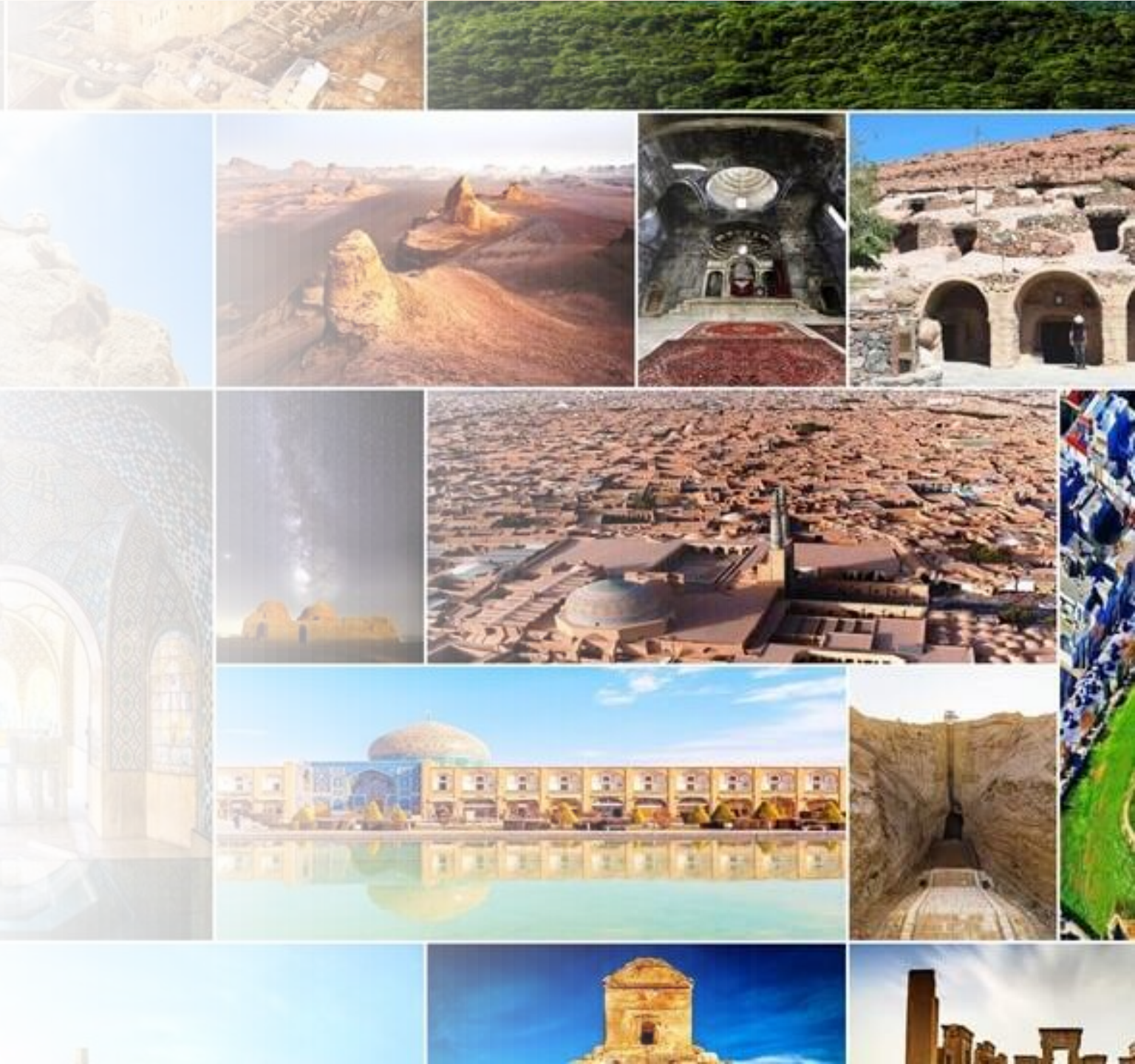
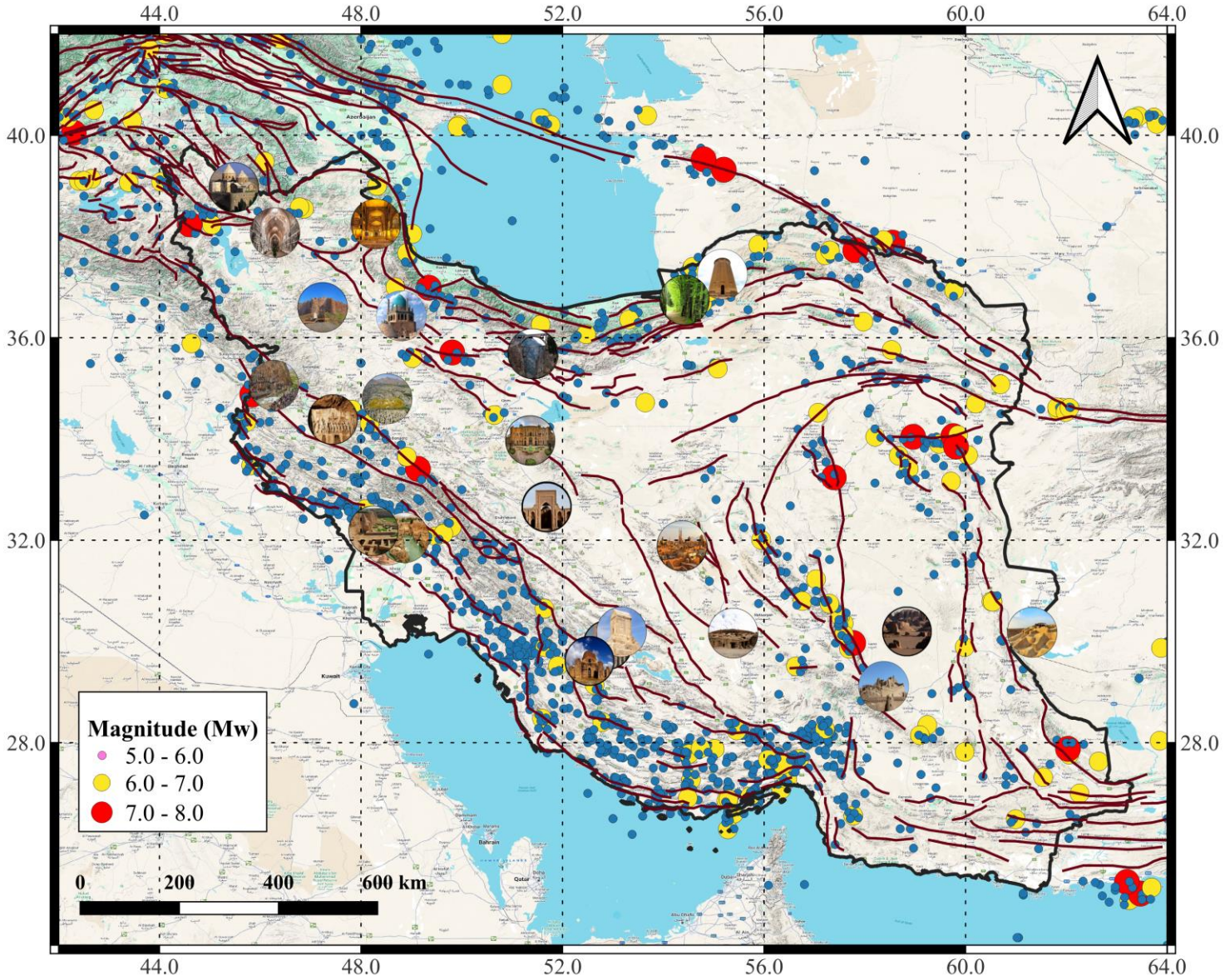


Why Protecting Heritage Sites is Important?

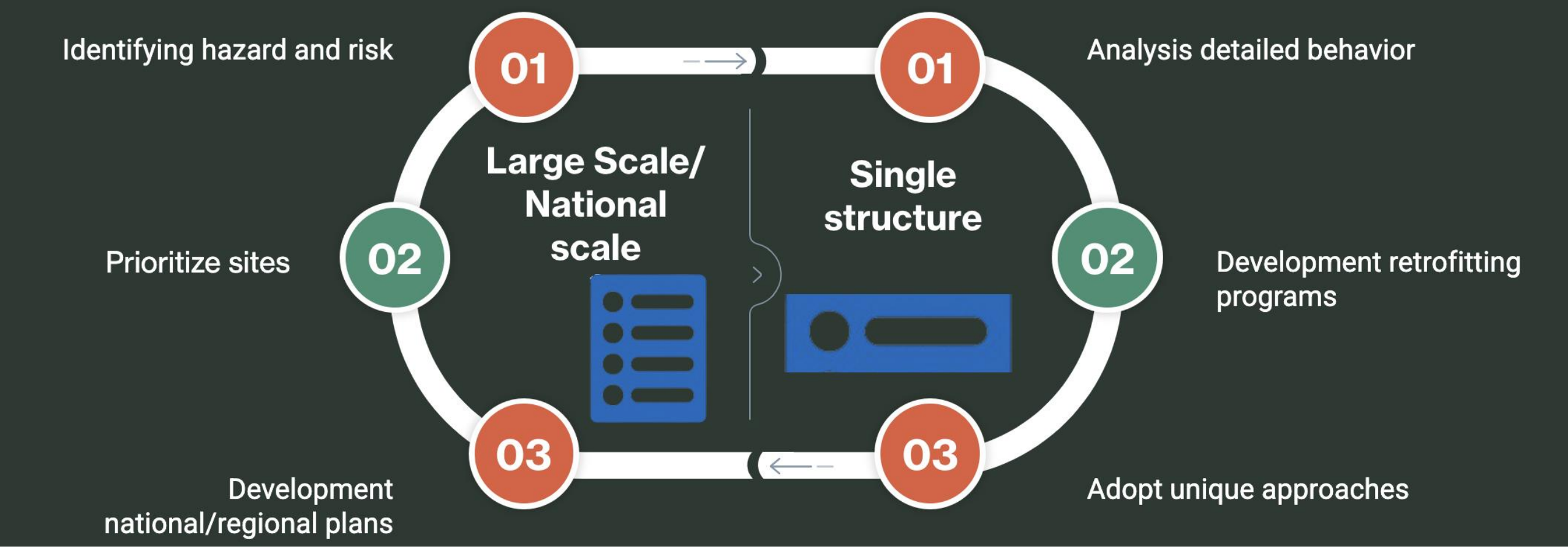
- CULTURAL SIGNIFICANT
- ECONOMIC/ TOURISM VALUE
- COMMUNITY ATTACHMENT
- ADDITIONAL FACTORS

28 UNESCO list; 48 Tentative list



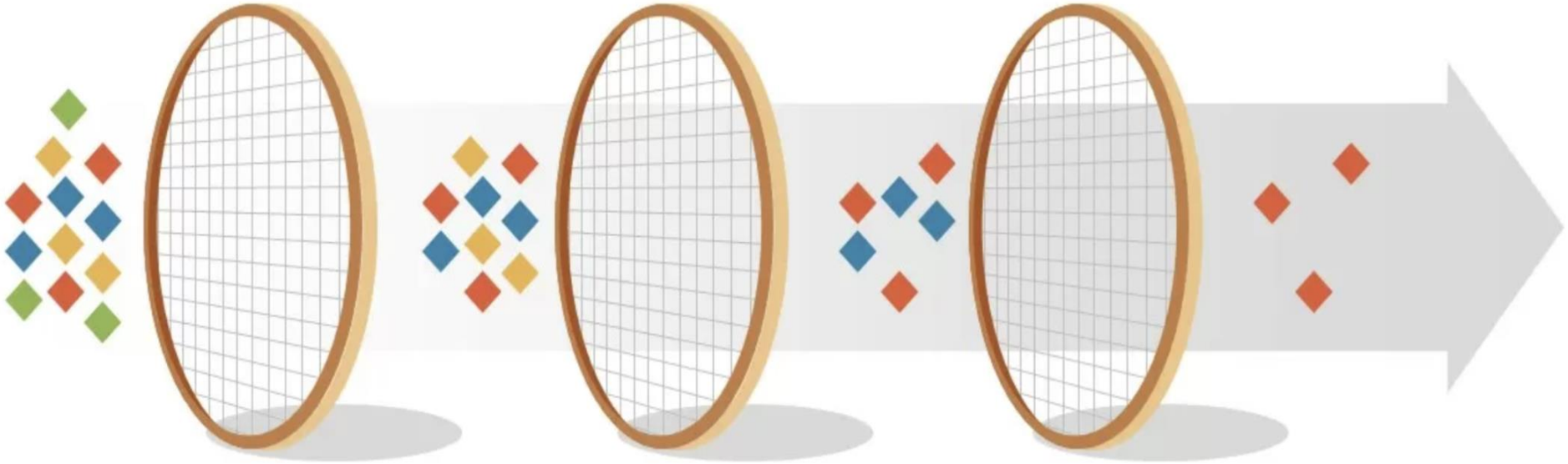
Past earthquake damages

Earthquake	Magnitude	Casualties	Heritage Impact
2003 Bam	6.6	~26,000	90% of city destroyed; Arg-e Bam citadel almost completely ruined
2006 Borujerd	6.1	~70	40+ monuments destroyed; 30% of historic center damaged; mosques severely impacted
1978 Tabas	7.4–7.8	~15,000	Entire town leveled; traditional adobe structures collapsed
1721 Tabriz	~7.7 (est.)	8,000–250,000	75% of city destroyed; mosques and schools lost



Analysis Level

Identifying the most vulnerable structures



Susceptibility Analysis

1) HAZARD ASSESSMENT

Recognizing site exposed hazard with PGA>0.2 g

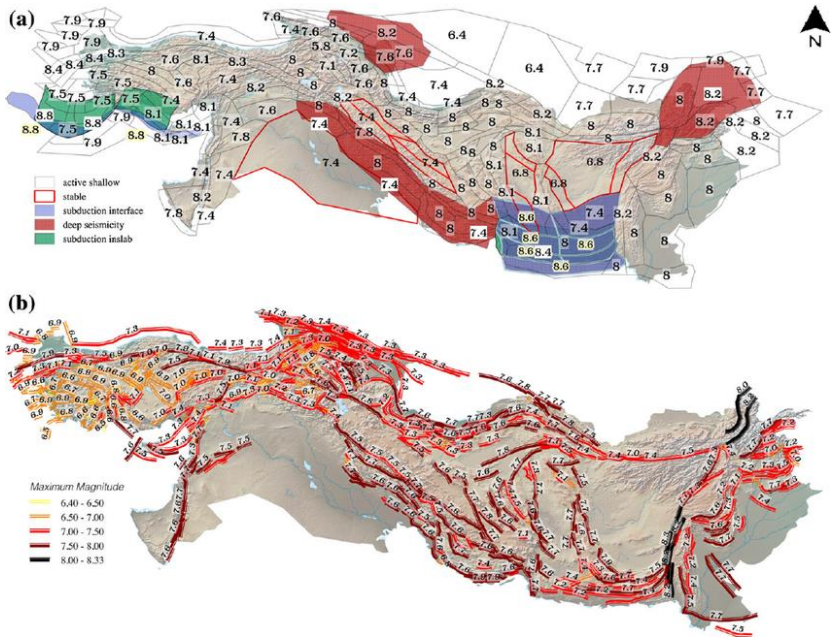
2) RISK ASSESSMENT

Vulnerability of sites:

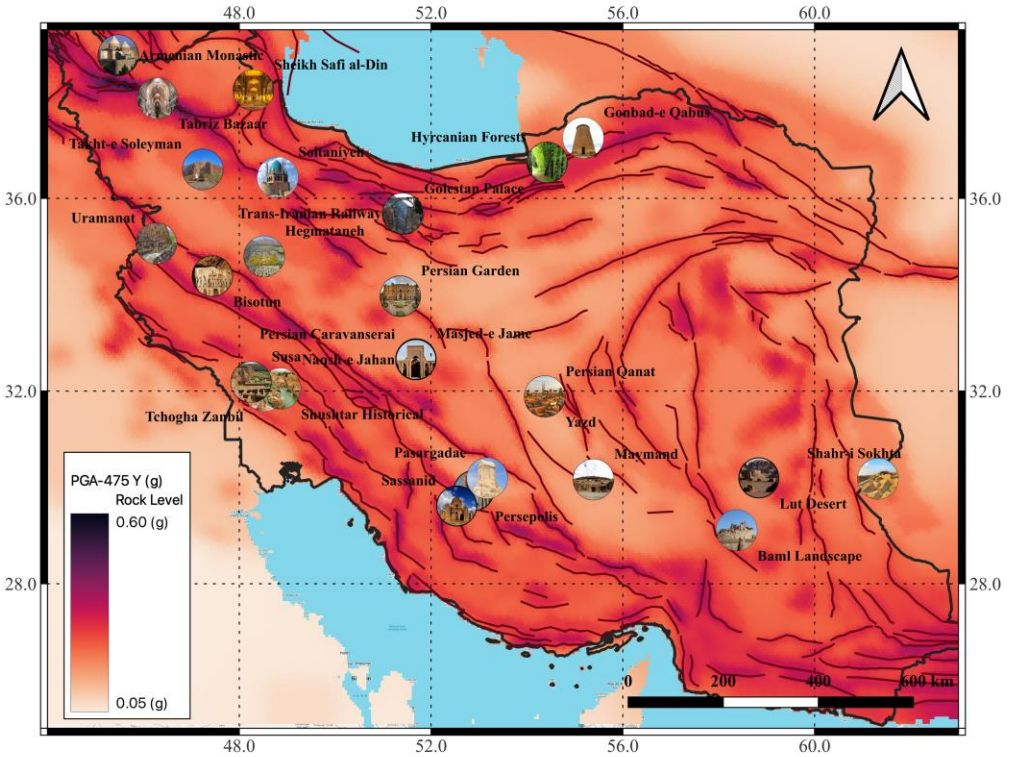
- Low vulnerable
- Moderate vulnerable
- High vulnerable

3) INTANGIBLE FACTORS

- Social value
- Economic value
- Institutional support
- Response capacity

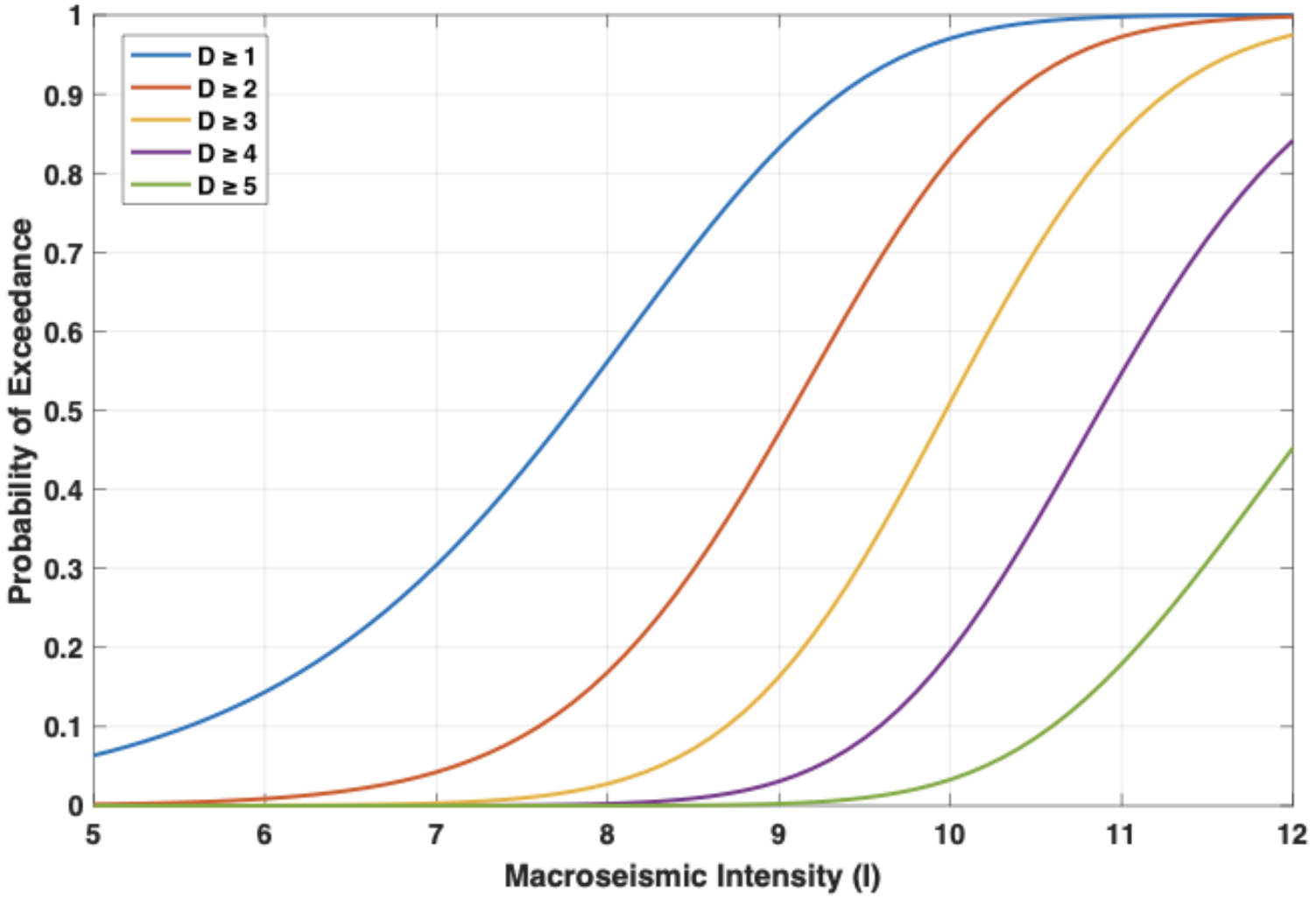


Seismic Scenario:
PGA 475Y



Hazard assessment

Vulnerability assessment



$$P\left[D_k|\mu_D\right] = \sum_{i=k}^{5} P_i$$

$$= \sum_{i=k}^{5} \frac{5!}{i!(5-i)!} \left(0.2\mu_D\right)^i \left(1-0.2\mu_D\right)^{5-i},$$

01

V: vulnerability index

vulnerability of heritage structures

02

Q: Ductility index

Rate at which damage increases

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 6.25V - 13.1}{Q}\right)\right],$$

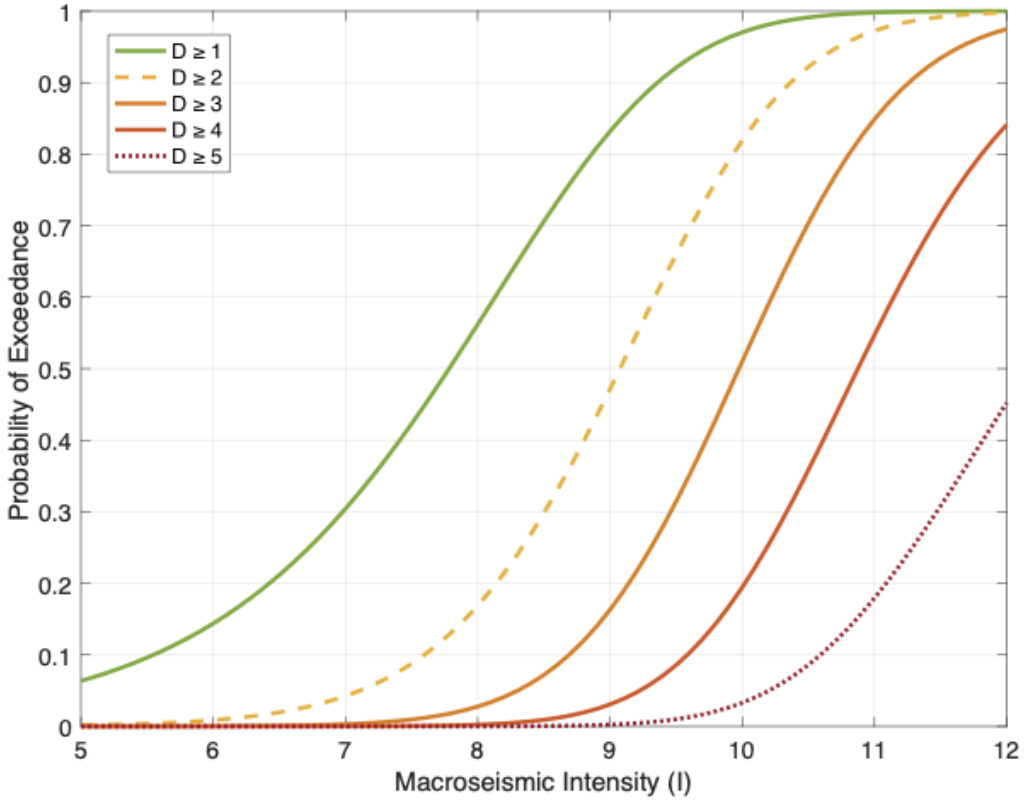
$$V = V_0 + \sum V_k.$$

Parameter	V_k
State of maintenance	very bad (0.08)—bad (0.04)—medium (0)—good (−0.04)
Quality of materials	bad (0.04)—medium (0)—good (−0.04)
Planimetric regularity	irregular (0.04)—regular (0)—symmetrical (−0.04)
Regularity in elevation	irregular (0.02)—regular (−0.02)
Interactions (aggregate)	corner position (0.04)—isolated (0)—included (−0.04)
Retrofitting interventions	effective interventions (−0.08)
Site morphology	ridge (0.08)—slope (0.04)—flat (0)

Parameter	Category	ΔV_k – Golestan Palace	ΔV_k – Naqsh-e Jahan Sq.
State of maintenance	Medium (0)	0.00	0.00
Quality of materials	Medium (0)	0.00	0.00
Planimetric regularity	Regular (0)	0.00	0.00
Reg. in elevation	Irregular (+0.02)	+0.02	+0.02
Aggregate interaction	Included (–0.04)	–0.04	–0.04
Retrofitting	Effective (–0.08)	–0.08	–0.08
Site morphology	Slope (+0.04) / Flat (0)	+0.04	0.00
🔷 **Total ΔV_k**		**–0.06**	**–0.10**
Base Index V0V_0	Typological baseline	**0.58**	**0.58**
📌 **Final V=V0+ΣΔVkV = V_0 + \sum ΔV_k**		**0.52**	**0.48**

Vulnerability index

Grade	Masonry buildings	
	Sketch	*Detailed description*
I		**Negligible to slight damage** **- negligible structural damage,** **- slight non-structural damage** Hair-line cracks in some walls. Detachment of small pieces of plaster. Very rare cases of detachment of individual loose parts of walls.
II		**Moderate damage** **- slight structural damage,** **- moderate non-structural damage.** Cracks in many walls. Detachment of larger pieces of plaster. Partial failure of chimneys.
III		**Substantial to heavy damage** **- moderate structural damage,** **- heavy non-structural damage.** Large and extensive cracks in most walls. Detachment of roof tiles. Failure of chimneys at roof level. Failure of individual non-structural elements (partition walls, gable walls).
IV		**Very heavy damage** **- heavy structural damage,** **- very heavy non-structural damage.** Extensive failure of walls. Partial failure of roof structures and floor structures.
V		**Collapse** **- very heavy structural damage.** Total or near total collapse.



Damage indicators

Damage: AAD

Collapse: AAC

Seismic Hazard Assessment

Classical Approach

Limitation: defining seismic sources, estimating seismicity parameters, GMPEs, recurrence models, modeling the aleatory uncertainty, capturing the spatial cross correlations, assessing the impact of different seismic scenario in risk

Monte Carlo Simulation

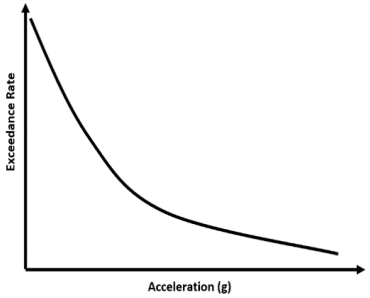
Limitation: high computation burden, Convergence issues, Dependency on the quality of input parameters

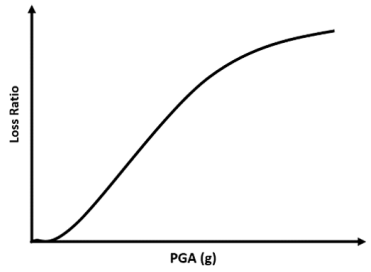
Compiling Exposure model

Challenges: Reliability of information, geographic resolution of data, classifying element at risk

Fragility/Vulnerability functions

Challenges: record to record, variability from building to building, and uncertainty in the damage criteria





Calculation engine

Convolution of hazard curve and vulnerability curve considering the characteristics of element at risk

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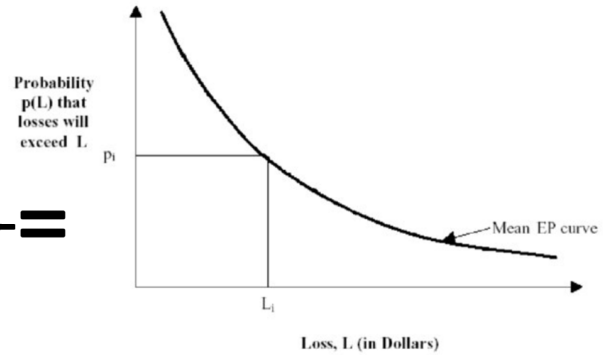
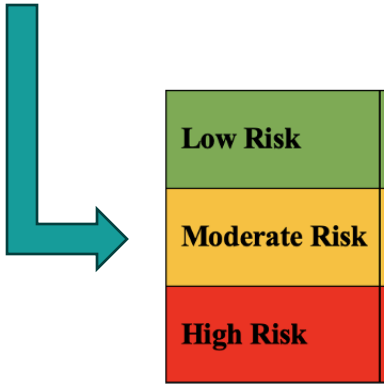


$$AAD_{modified} = AAD \times IRF$$



Intangible Factors

Social Value

Community attachment
Cultural continuity
Public awareness
Community participation
Local dependency

Institutional Support

Legal protection
Funding
Management instituitional strength

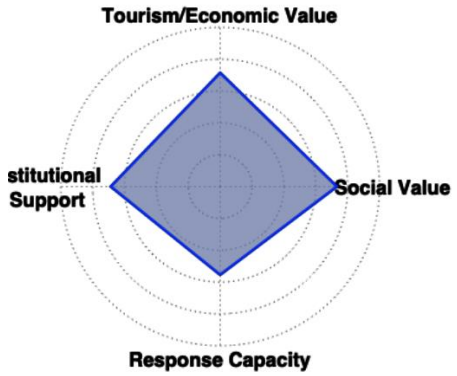
Economic/Tourism Value

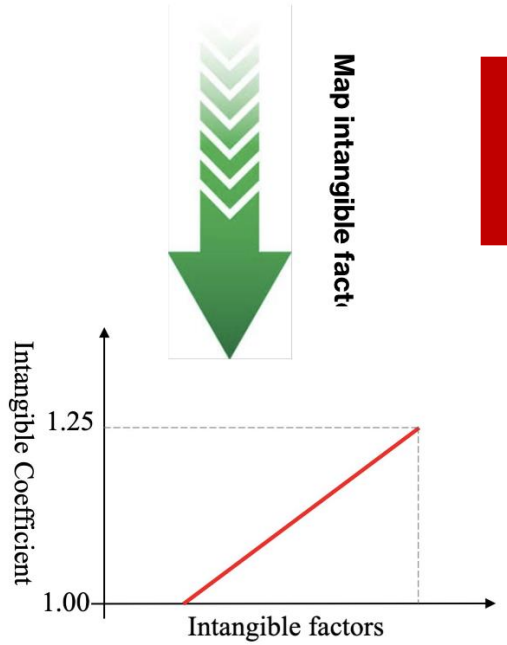
Visitor volume
Local economic
Cultural tourism Value

Response Capacity

Response planning
First-aid resources
Infrastructure resilience
Stakeholder condition

Intangible Risk Factor (IRF)





Heritage Site	IRF
Tabriz Bazaar	1.2500
Persepolis	1.2326
Naqsh-e Jahan	1.2252
Golestan Palace	1.2042
Yazd	1.1832
Masjed-e Jame	1.1618
Pasargadae	1.1253
Susa	1.1077
Soltaniyeh	1.1062
Sheikh Safi al-Din	1.1062
Trans-Iranian Railway	1.1062
Shushtar Historical	1.0988
Persian Garden	1.0952
Hegmataneh	1.0900
Sassanid	1.0834
Armenian Monastic	1.0772
Bisotun	1.0749
Gonbad-e Qabus	1.0664
Tchogha Zanbil	1.0607
Persian Caravanserai	1.0578
Persian Qanat	1.0524
Takht-e Soleyman	1.0393
Shahr-i Sokhta	1.0393
Uramanat	1.0393
Baml Landscape	1.0191
Maymand	1.0191
Hyrcanian Forests	1.0191
Lut Desert	1.0000

Prioritizing Heritage Sites

PGA<0.2 No Assessment

Low Risk	AAD<$5x10^{-4}$	AND	AAC<$5x10^{-5}$
Moderate Risk	$5x10^{-4}$<AAD<$5x10^{-3}$	AND	$5x10^{-5}$<AAC<$5x10^{-4}$
High Risk	AAD<$5x10^{-3}$	OR	AAD<$5x10^{-5}$

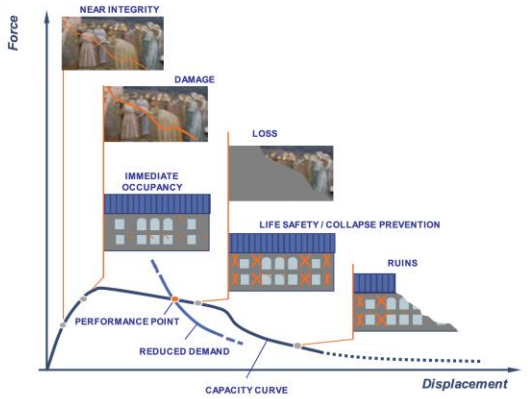
Initial Result

Rank	Name	Description	Risk Level
1	Tabriz Bazaar	One of the oldest and largest covered bazaars in the world	High-Risk
2	Golestan Palace	Historic Qajar-era palace in Tehran	High-Risk
3	Soltaniyeh	Mausoleum of Oljaytu, an Ilkhanid architectural masterpiece	High-Risk
4	Sassanid	Archaeological landscape of Sassanid-era cities and forts in Fars	High-Risk
5	Gonbad-e Qabus	Tallest pure-brick tower in the world, built in 1006 AD	High-Risk
6	Sheikh Safi al-Din	Mausoleum and religious complex in Ardabil	High-Risk
7	Baml Landscape	Cultural landscape with ancient structures near Bam	High-Risk
8	Armenian Monastic	Ensemble of medieval Armenian churches in northwest Iran	Moderate-Risk
9	Shushtar Historical	Ancient hydraulic system and watermills	Moderate-Risk
10	Uramanat	Rural stepped villages with intangible heritage	Moderate-Risk
11	Persian Garden	Network of nine gardens across Iran representing Persian design	Moderate-Risk
12	Bisotun	Ancient multilingual inscription site on a cliffside	Moderate-Risk
13	Takht-e Soleyman	Zoroastrian sanctuary and royal residence	Moderate-Risk
14	Susa	Ancient Elamite and Achaemenid capital	Moderate-Risk
15	Tchogha Zanbil	Elamite ziggurat and sacred complex	Moderate-Risk
16	Persepolis	Ceremonial capital of the Achaemenid Empire	Moderate-Risk
17	Naqsh-e Jahan	Historic square with Safavid-era architecture in Isfahan	Moderate-Risk
18	Masjed-e Jame	Congregational mosque in Isfahan with centuries of layered history	Moderate-Risk
19	Shahr-i Sokhta	Bronze Age city with well-preserved archaeological layers	Moderate-Risk
20	Persian Caravanserai	Chain of inns representing trade routes	Moderate-Risk
21	Hegmataneh	Ancient Median and Achaemenid capital	Moderate-Risk
22	Yazd	Historic desert city with adobe structures	Moderate-Risk
23	Persian Qanat	Traditional underground water channels	Low-Risk
24	Pasargadae	First capital of the Achaemenid Empire	Low-Risk
25	Maymand	Troglodyte village with rock-cut homes	Low-Risk
26	Trans-Iranian Railway	Historic rail system linking the north and south of Iran	Low-Risk
27	Hyrcanian Forests	Ancient temperate forest along the Caspian Sea	Low-Risk
28	Lut Desert	Salt desert with unique geological formations	Low-Risk

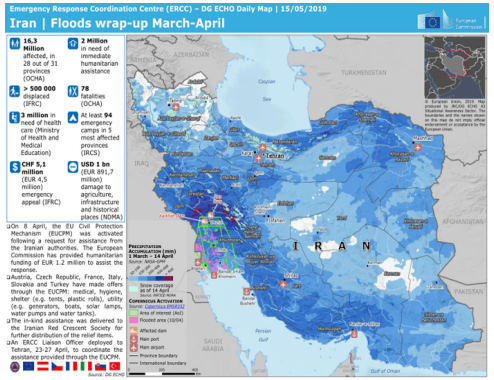
1) Budget allocation

2) Detail analysis

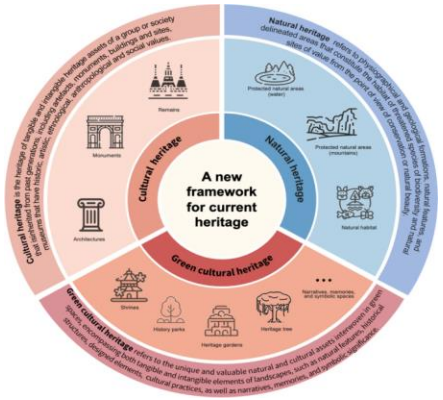
Moving Foward



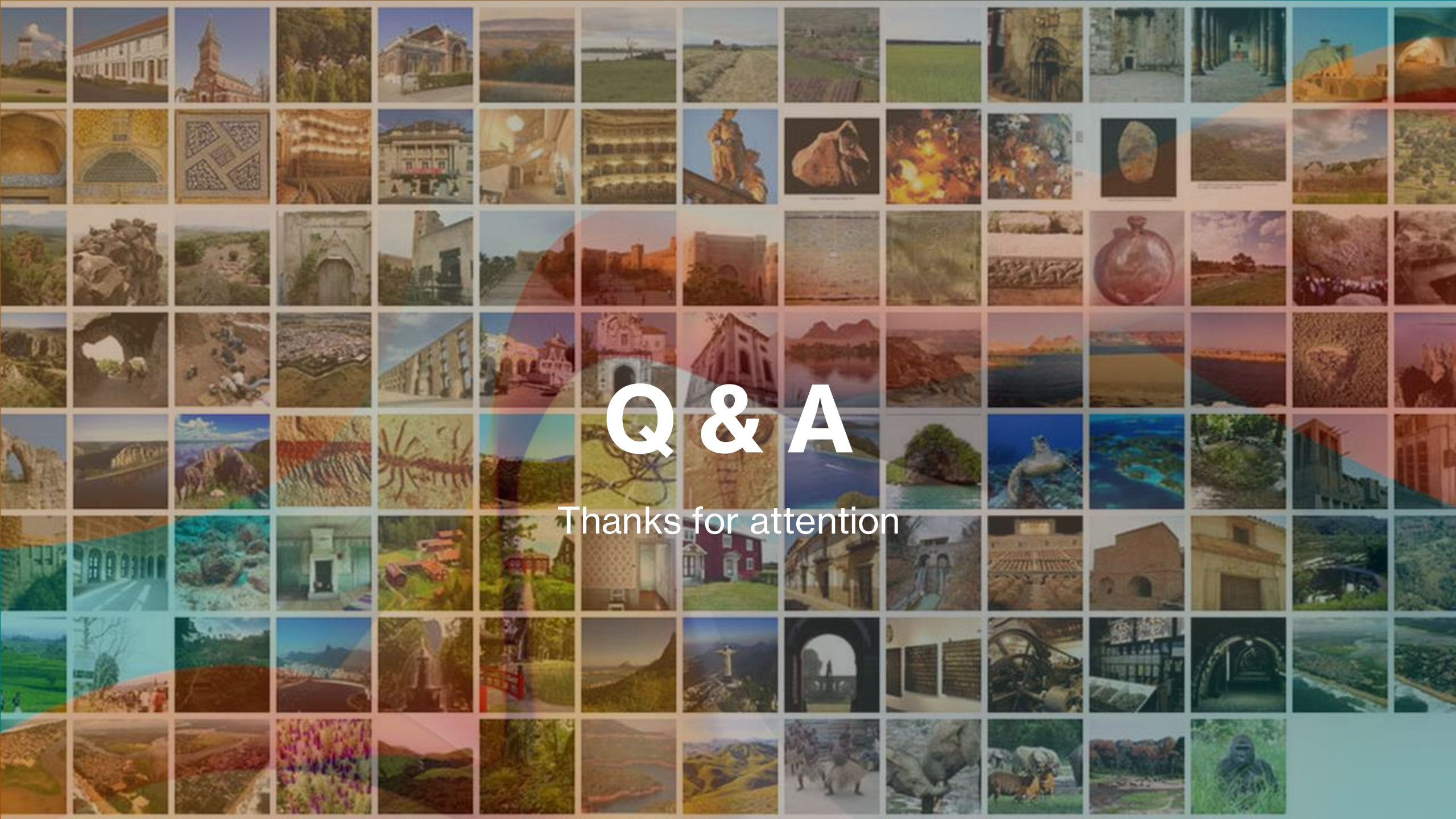
Refining vulnerability function



Expanding to multi-hazard framework



Considering more effective intangible factors


Q & A
Thanks for attention