Seismic and solar performance of historical city

Urban form-based multicriteria analysis

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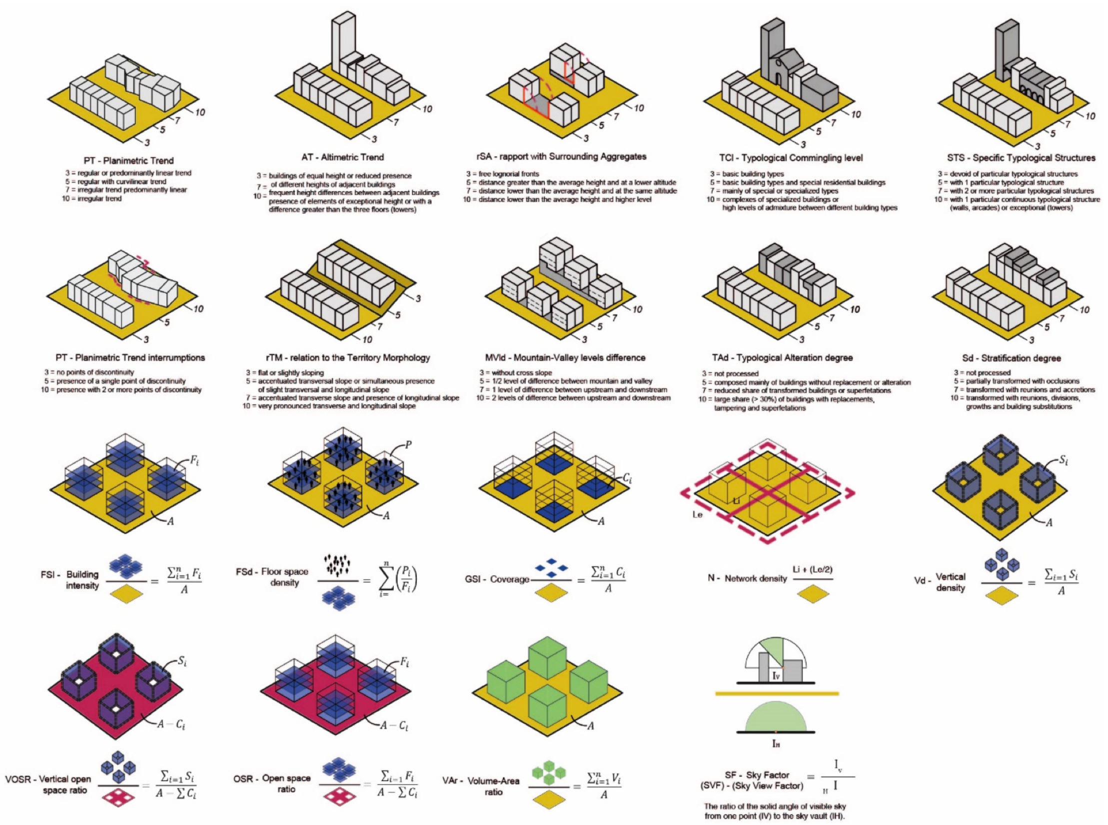


INTRODUCTION

This paper focuses on the potential of urban metrics and morpho-typological indicators for exploring the causal relation urban form/seismic vulnerability/solar energy in the historical city through an integrated approach.

The paper describes the results of the first step of an ongoing study: evaluation of the proposed method on case studies.

The method is conceived for two purposes:

- to support policy maker decisions according to the performances of urban aggregates, in order to differentiate public investments and incentives;
- to be integrated in the early stage of design process in order to guide urban renovation strategies.

BACKGROUND

- **The historical city is a complex system**, and the understanding of its evolution requires specific attention to face urban actual phenomena and **challenges**: such as **natural disasters and climate change.**

- **Seismic risk and energy efficiency** are two of the most important challenges, as demonstrated by actual policies, e.g. EU incentives.

- **Urban scale approaches,** rather than the building scale, help understanding all the elements that affect the functioning of a city: different urban forms correspond to different performances among which the seismic and the solar performances must resort to the analysis of the physical features of basic components of the built environment.

- The historical city of **the Mediterranean** represents a significant example of urban system characterized by a typological processes of growth that is closely related to climate conditions and seismic events over time.

BACKGROUND

SEISMIC PERFORMANCE

The **shift of attention** from the scale of the building to the urban fabric relies on the morpho-typological parameters, which together with the constructive ones, are crucial for appropriate assessments of vulnerability on the urban context.

SOLAR PERFORMANCE

Solar energy availability is a key variable to assess buildings energy performance in the **urban environment.** On one hand, building's solar gains account for a significant part of the energy balance during both winter and summer; on the other hand, the potential for harvest solar energy in the urban context is directly connected to the potential for renewable energy systems to enhance energy efficiency at urban scale.

ACTUAL LIMITATION AND KNOWLEDGE GAP

- The **importance of the urban scale is nowadays recognized** and investigated in several types of research for both the **energy** and the **seismic performance**, focusing the **influence of urban morphology** on these features.
- The **integration of the approaches is still focused on the building scale.**

The aim of this research is to overcome this compartmentation of knowledge, proposing a preliminary approach on integrated multicriteria analysis for the historical city, based on morpho-typological indicators in order to describe the seismic vulnerability and the solar radiation availability.

METHOD: The city of Rieti

The city of Rieti, located in Central Italy, is the ideal urban environment to test seismic and
solar performance of historical urban form. It is a significant example in terms of:

- Dimension
- Urban form and structure
- Seismic event and location

Rieti concerned with the category of medium sized (between 5,000 and 60,000 inhabitants) local council areas, which make up about 30% of the total of Italian local government bodies and concern over 50% of the population.

The municipality of Rieti is characterized by well-conserved historic centre covering an area in proportion to its population and which falls in an area of medium-high seismic risk (zone 2), the area recently stroke by the 2016 Central Italy Earthquake.

METHOD: The city of Rieti

Case studies are three representative aggregates of typical urban texture of Rieti: case I is located in the core of the roman town, following the ancient settlement, along the decumanus; the aggregate, as a portion of an urban texture characterized by a clear hierarchy of streets and public space, is the result of stratification and alteration of the original seventieth century buildings; case II, close to the medieval walls, is part of a more articulated urban fabric with narrow streets; case III is located in the first medieval expansion, with a regular street pattern and mainly based on row houses, partially modified or replaced in recent times.

METHOD: Metrics

The range of variation of several Urban Metrics (UM) and Morpho-Typological Indicators (MTI) have been calculated.

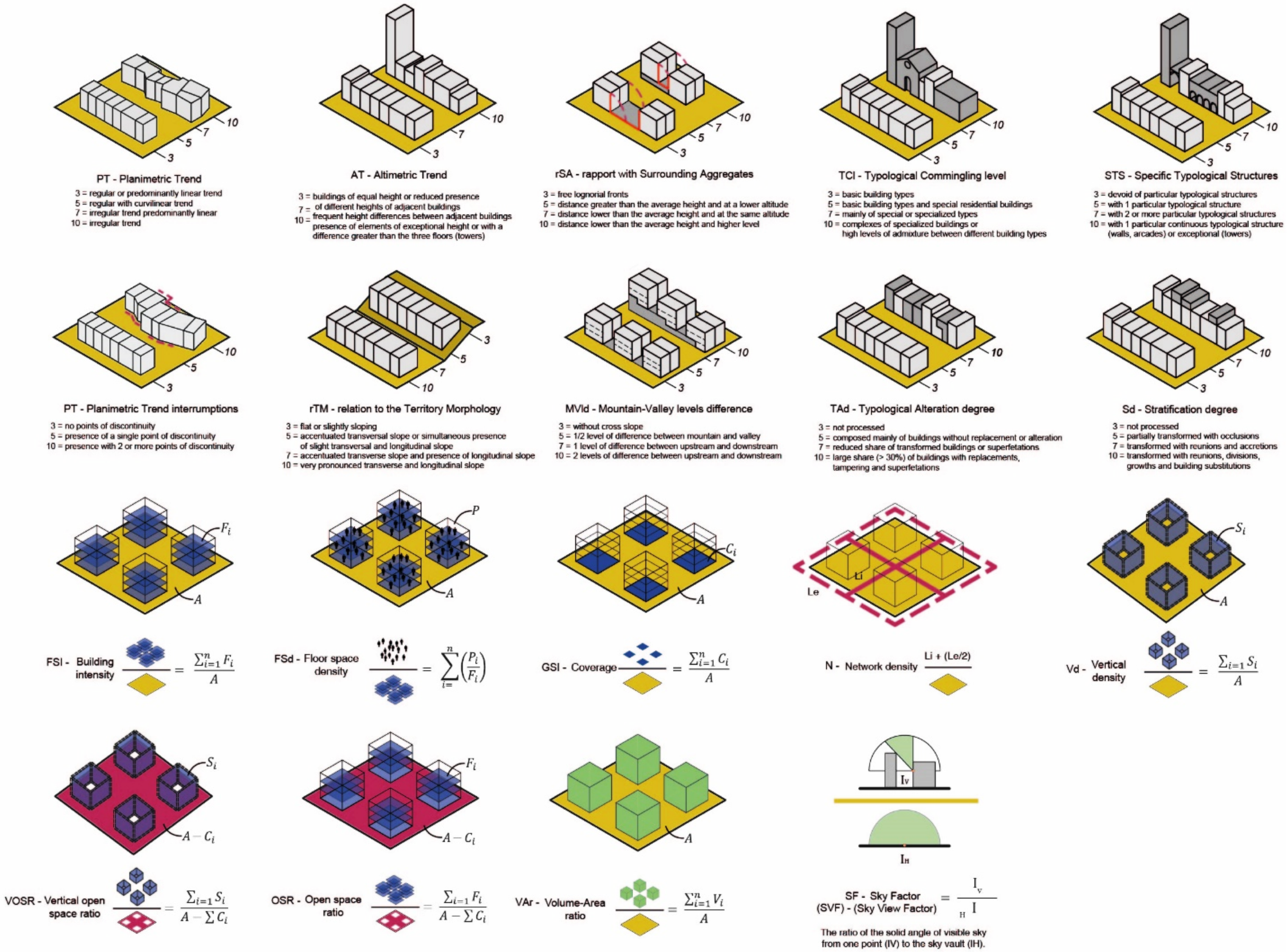
- UM have been derived from 3D models of the urban textures LoD1: derived from 8 basic variables common and easily accessible.

Table 1 Urban metrics basic variables.

Symb.	Unit		I	II	III
P	[inhab.]	Population	646	382	374
A	[m^2]	Base land area	5362	3482	4396
C	[m^2]	Footprint	3693	2288	3117
F	[m^2]	Gross floor area	15095,4	9222,64	9817,41
S	[m^2]	Façade surface	10216,5	7131,4	5711,2
V	[m^3]	Built-up volume	64571	38236	37403
L_i	[m]	Interior network	0	0	0
L_e	[m]	Edge network	325	266	377

- MTI have been derived from typological-observational methods, based on data of damage and vulnerability observed on previous earthquakes and normally calibrated on the use of existing databases with a level of accuracy 1. The MTI analyzed are derived from the studies conducted on the case study of Nocera Umbra and from the studies of Borri and Avorio, Fazzio. Qualitative indicators have a variable weight ranging from 3 to 10.

METHOD: Metrics



METHOD: Metrics

- UM and MTI have been divided into three groups: Plan, Space and Analysis-oriented.
- a comparison between cases has been conducted by means of normalization.

Plan indicators are able to represent the main features on the horizontal **plan**;

Space indicators describe the **three-dimensional complexity**;

Analysis-oriented indicators are useful to **predict solar and seismic performance** at early stage of analysis.

Table 1 Values of morpho-typological indicators and urban metrics regarded to case studies.

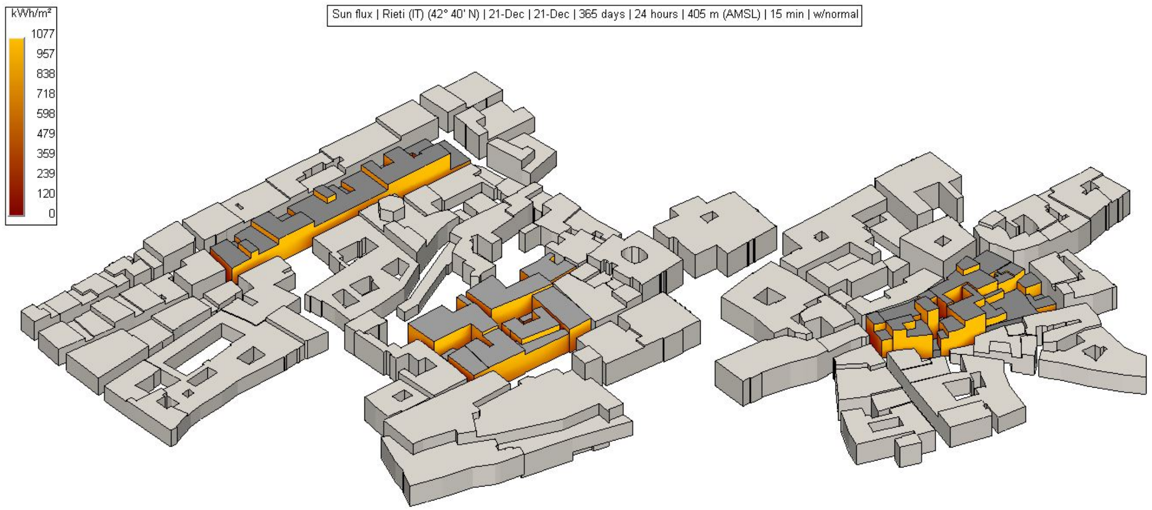
		Plan	**I**	**II**	**III**
FSI	[m^2/m^2]	Building intensity	2,82	2,65	2,23
FSd	[inhab./m^2]	Floor space density	0,04	0,04	0,04
GSI	[m^2/m^2]	Coverage	0,69	0,66	0,71
N	[m/m]	Network density	0,030	0,038	0,043
OSR	[m^2/m^2]	Open space ratio	0,111	0,129	0,130
PT	adim.	Planimetric Trend	7	10	3
PTis	adim.	Planimetric Trend Interruptions	7	10	7
		Space			
Vd	[m^2/m^2]	Vertical density	1,91	2,05	1,30
VOSR	[m^2/m^2]	Vertical open space ratio	6,12	5,97	4,47
VAr	[m^3/m^2]	Volume-Area ratio	12,04	10,98	8,51
rSA	adim.	rapport with Surrounding Aggregates	7	10	7
rTM	adim.	relation to the Territory Morphology	3	7	3
AT	adim.	Altimetric Trend	7	7	3
MVld	adim.	Mountain-Valley levels difference	7	7	3
		Analysis-oriented			
TCl	adim.	Typological Commingling level	5	5	3
STS	adim.	presence of Specific Typological Structures	7	5	5
TAd	adim.	Typological Alteration degree	10	5	7
Sd	adim.	Stratification degree	10	5	7
SF	adim.	Sky Factor	25,2	22,0	30,2
SVF	adim.	Sky View Factor	21,4	19,0	24,7

METHOD: Performance evaluation

SEISMIC PERFORMANCE

We refer to “**relative vulnerability**” of the aggregates, because the normalization is carried out on the dataset of the whole historical city of Rieti.

Given the typological-observational nature of the vulnerability assessment methodology, the results have a greater relevance for the urban management in order to understand **the vulnerability level of different portion** of the urban texture.



SOLAR PERFORMANCE

The **solar irradiation on building façades** (kWhm^{-2}y) has been assessed for the selected urban aggregates of each digital model, considering **urban obstructions** during the **whole year**. We focus on the solar performance of the vertical surfaces since they are directly related to the building's solar gains which
account for the most part of the energy demand in the Mediterranean latitudes.

Heliodon2 software and Heliodon2plus data post-processor have been used for simulations.
Heliodon2 calculates the spatial and temporal distribution of solar energy on building façades, considering a cloudless sky condition during a given period; the associated postprocessor use climate data to obtain **direct and diffuse solar radiation**.

Calculations have been carried out on the base of the **latitude** of the city of Rieti (42°24' N 12°51' E).

Results: (1) seismic performance

Seismic vulnerability: the most critical situations for the cases with **higher Sd** or **TAd**, which is usually reflected also on **articulated** geometric configurations **(I)**, and for **irregular aggregates** with high values of **PT, PTis and AT**, located in complex urban fabric.

The latter due to the relation with the surrounding aggregates (**rSA**) increasing the induced vulnerability **(II)**.
On the contrary, **case III emerges as relatively less vulnerable** as described by lower **PT** (regular linear trend) and lower **TAd** (mainly composed of building with a high degree of typological homogeneity).

Table 1. Structural characteristics parameters and total values, TI total values and vulnerability index.

	I	II	III
Average conservation status of vertical structures	5	3	3
Average conservation status of horizontal structures	5	3	3
Average state of conservation of the roofs	5	3	3
Synthetic index of masonry quality	7	7	7
Presence of particular structural elements	5	5	0
Offset of floors between adjacent buildings	7	7	10
Slenderness of the wall	3	3	3
Pushing elements (arches, vaults, roofs)	7	10	7
Masonry discontinuities	7	7	5
Discontinuities or singular elements in vertical structures	1	5	1
Discontinuities or singular elements in horizontal structures	1	5	1
Discontinuities or singular elements in roof structures	1	5	1
Regularity in the arrangement of openings	3	3	7
Total indicator of structural characteristics	**57**	**66**	**48**
Total TI	**70**	**71**	**51**
Overall vulnerability index	**127**	**137**	**99**
Overall vulnerability index (normalized)	**8**	**9**	**3**

Results: (1) solar performance

Solar energy, irradiation on façades (kWhm^{-2}y) is directly related to a combination of:

- **high- density-related values** (GSI, VOSR, Vd) and **low SF/SVF values**.

In historical urban textures, reasons for **better solar access compared to observed tendencies**, are due to specific morphological features: **lower urban density combined with optimal façades orientation (III).**

- Solar performance is in general **poor for cases with high urban density.** Even though similar surface exposure and lower SF/SVF, **case II** receives more solar radiation **compared to I**. This result is reliably represented by UM (**FSI, GSI, VOSR** and **VAr**).
- Considering the most reliable metrics for solar analysis as indicated in previous studies, **II and III performs better than the average**. The former, due to the **presence of several courtyards and higher ratios of façade surface/built volume**. The latter thanks **to favourable texture orientation in relation to façade exposure**.

Table 1 Value of solar energy over a one-year period regarded to case studies.

	Unit	I	II	III
Solar radiation	kWh*	2.748.809	2.283.577	2.107.196
Façade energy density	kWh/m^2*	269,1	320,2	369,0
Direct solar radiation	kWh	662.113	550.052	507.566
Diffuse solar radiation	kWh	1.315.029	814.776	850.469
Global solar radiation	kWh	1.977.142	1.364.828	1.358.035
Direct façade energy density	kWh/m^2	64,8	77,1	88,9
Diffuse façade energy density	kWh/m^2	128,7	114,3	148,9
Global façade energy density	kWh/m^2	193,5	191,4	237,8
Direct solar radiation fraction		33%	40%	37%

** Considering cloudless sky condition*

Results: (2) UM + MTI

- **The purpose of the diagrams** is to visualize the urban scale performance: the higher the value of an indicator, the worse the behaviour of the aggregate in term of solar availability and seismic vulnerability (we use reciprocal value for SF and SVF).
- By grouping different types of UM and MTI is possible to highlight urban form features of each case:
  - Case III values clearly reflect differences in urban layout and morphology of the island.
  - The difference between I and II appears: II has higher values in most of the Plan and Space metrics, while I has higher values in all the Analysis-oriented metrics.
  - The case I and II are the aggregates with lower performances, while case III always covers the smaller areas of the graphs, showing as in a regular urban texture exist more favourable condition.

First-stage evaluation of seismic vulnerability and façade solar availability at urban scale can be obtained making use of the diagrams: **the smaller the area on the proposed diagrams, the greater are the intrinsic capacities of the urban aggregate to perform at both levels.**

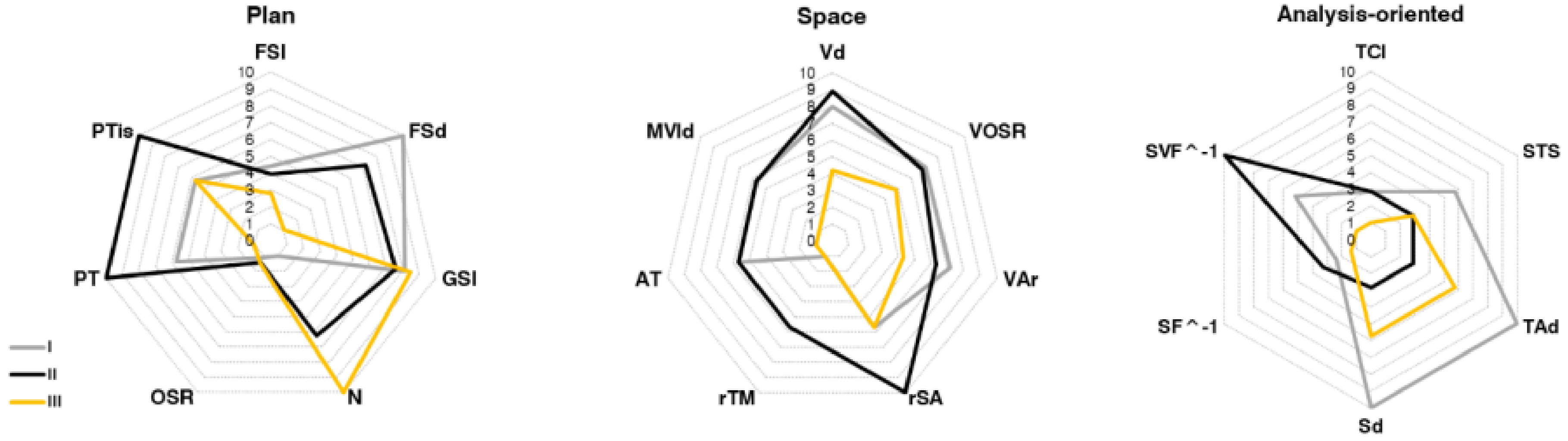


Figure 1 Comparison of normalized UM and MTI (grouped into Plan, Space and Analysis-oriented)

Conclusions

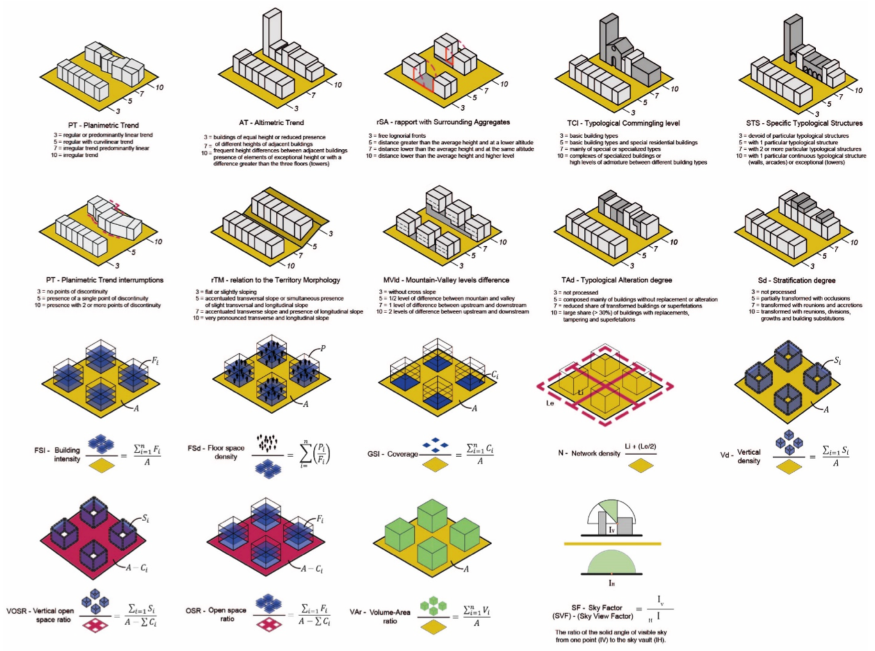
Our paper presents an investigation on the capability of a multi-criteria analysis based on UM and MTI to predict urban seismic vulnerability and solar availability in the historical city located in Mediterranean climate.

- The proposed method is useful to
- The **Plan indicators** highlight intrinsic criticalities of urban texture and very hard to transform without invasive action that could compromise the historical value.
- The **Space indicators**, are suitable to describe renovation strategies based on urban acupuncture and geometric regularity, taking into account the interaction with the **urban surroundings**.
- The **Analysis-oriented indicators** are suitable to control urban form and typology implications of solar and seismic performance and to improve them through **solar and seismic sensitive design**.

LIMITATIONS AND FUTURE DEVELOPMENT

- To select common basic variable among for urban form analysis
- To define quantitative indicators for the seismic performance assessment
- Interaction with GIS

The proposed multi-criteria analysis model has been structured with several purposes. On one hand, it can support **policy maker decisions** according to the performances of urban aggregates, in order to **differentiate public investments and incentives**; on the other hand, it should be **integrated in the early stage of design process**, taking into account the solar façade availability and seismic vulnerability of urban areas to guide **urban renovation strategies**.



Thanks for your attention

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