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CLIMATE RESILIENT STRATEGIES BY ARCHETYPE-BASED URBAN ENERGY MODELLING

Typical urban context configurations using archetypes

DELIVERABLE 3.1

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1. INTRODUCTION

1.1 Purpose

Global climate change leads to increased ambient temperatures, causing buildings to overheat and demand more energy for cooling while worsening indoor environmental quality. Urban Heat Island (UHI) effects, caused by local warming in urban areas, further exacerbate these challenges. Existing Urban Building Energy Modelling (UBEM) struggles to address UHI due to limited data on microscale climatic conditions and detailed mapping of urban areas. The CRiStAll project aims to address these gaps by creating detailed climatic datasets and exploring different urban configurations at the microscale.

Under the CRiStAll project, three interconnected research lines are developed. These include:

A. building an urban climate model that incorporates the impacts of the Urban Heat Island (UHI) at the microscale, as well as the short-, mid-, and long-term (future weather data) consequences of climate change,
B. putting the archetype-based Urban Building Energy Model (UBEM) into practice using typical urban environment configurations (urban blocks) and
C. evaluating the impact of climate resilience and UHI reducing methods in urban locations.

Work Package (WP) 3, "*Archetypes in urban context*", aligns with research line B, aiming to identify appropriate urban context configurations based on building archetypes for implementation in UBEM tools to assess the impact of future UHI effects. Task 3.1, "*Definition of typical urban context configurations using archetypes and UBEM tool selection*", focuses on utilising Italian building archetypes to establish a connection between representative buildings and districts. After selecting the building envelope archetypes, reference urban contexts are identified using a twofold approach, driven, on the one hand, by the parametric analysis of morphology metrics of urban blocks and, on the other hand, by satellite land surface temperature data able to orient the analysis towards those residential areas of the selected Italian cities which are the most affected by UHI phenomena. Finally, the most used UBEM tools in the literature are compared as part of Task 3.1.

1.2 Deliverable structure

This deliverable is structured into four sections aimed at identifying and characterising representative urban blocks across three distinct Italian climatic zones.

- **Section 1** serves as the introduction, delineating the purpose (1.1), deliverable structure (1.2), and partner contributions to Task 3.1 development (1.3).
- **Section 2** details the methodology for defining typical urban context using archetypes (2.1), the adaptability to the analysed regional capitals (2.2), and the identification of district archetypes (2.3), representative of three Italian building contexts.
- **Section 3** focuses on the methodology for collecting building archetype schemas (3.1) and an example of their application across different climate zones: Turin, Bari, and Rome (3.2).
- **Section 4** provides an overview of the most widely recognised UBEM tools, distinguishing between reduced-order R-C and detailed dynamic models.

1.3 Contribution of partners

POLITO led the task and wrote the deliverable with contributions from the partners involved. It also carried out the collection of building archetypes, prepared the data for characterising the UBEM (Task 3.2), and gathered the georeferenced file and Digital Surface Model (DSM) for the municipality of Turin. unibz collected georeferenced and DSM files for the municipality of Bari performed a morphology analysis for Turin and Bari, collected and analysed satellite Land Surface Temperature (LST) maps for the three Italian cities (Turin, Bari, and Rome), proposed a methodology to identify the typical urban blocks and, after its refinement with POLITO, identified the typical urban blocks in agreement with the POLITO unit. The full methodology was developed and implemented in detail for the city of Turin, which presents the most comprehensive set of input data. Regarding the two other cities, Bari and Rome, which are characterised by lower quality or incomplete datasets, in particular for the DSM and geometrical files, simplified versions of the methodology were implemented by the unibz unit. In particular, more relevance was given to the analysis of LST maps in the identification of the most significant urban blocks. In such a way, flexibility was introduced to facilitate the implementation in those cases affected by the lack of comprehensive data.

2. DISTRICT ARCHETYPE

2.1 Methodology

As briefly summarised in Section 1.1, the proposed methodology aims to identify those urban blocks representative for a study of the UHI phenomena and the identification of suitable mitigation measures. The methodology combines the analysis of the morphology of the city building blocks with the processing of satellite Land Surface Temperature maps collected during the summer period, with particular attention to those days and weeks characterised by heat waves, which further exacerbated the UHI effect. If, on the one hand, the evaluation of the morphology features can allow the selection of those blocks showcasing the most typical configurations, the analysis of the LST maps can facilitate the identification of those which are the most significant for the subsequent UBEM simulations.

Regarding the first part of the methodology, i.e., the one related to the morphological aspects, the preliminary task requires grouping the buildings in the city into *urban blocks* according to their cadastral parcel area. Then, the obtained urban blocks undergo a filtering task aimed to exclude those blocks with less than four buildings (e.g., isolated buildings), a highly irregular shape (e.g., shape factor *SF* lower than 0.1), or very large areas (an area larger than 0.1 km²). The latter ones, in particular, are usually representative of large factories in the city industrial areas, which are out of the scope of the CRiStAll project.

At this stage, 10 urban metrics (Table 1) are estimated for each filtered urban block. These metrics have been selected among the most used ones in literature (Joshi *et al.*, 2022; Javanroodi *et al.*, 2023) and calculated using a plurality of software (GIS and CAD tools) and Python libraries (e.g., Geopandas). Special attention has been dedicated to the Sky View Factor (*SVF*), estimated using the QGIS plugin *Relief Visualization Toolbox* (Zakšek *et al.*, 2011) with respect to a virtual block positioned at half of the minimum distance to the closest blocks (i.e., at the centre of the corresponding street canyon).

Table 1 – Considered urban metrics

Symbol	Metrics	Unit	Formula	Notes
ABD	Average Building Distance	m	$ABD = \frac{\sum_i^n \sum d_i}{n^2}$	*d* indicates the distance between two buildings
ABH	Average Building Height	m	$ABH = \frac{\sum_i^n h_i}{n}$	*h* indicates the height of a building
FAR	Floor Area Ratio	-	$FAR = \frac{\sum A_i * n_i}{A_{block}}$	*A* is the floor area A_{block} is the block area
GR	Green Ratio	-	$GR = \frac{A_{veg}}{A_{block}}$	A_{veg} is the green area A_{block} is the block area
REC	Relative Compactness	-	$REC = \frac{\sum \frac{6V_i^{\frac{2}{3}}}{A_{i_{frontal}}}}{n}$	*V* is the building volume $A_{frontal}$ is the area of the façade towards the street canyon
SF	Shape Factor	-	$SF = \frac{A_{block}}{\pi r^2_{minbounding}}$	*r* is the radius of minimum bounding circle around the block A_{block} is the block area
SVF	Sky View Factor	-	Extracted by GIS	-
SC	Surface Coverage	-	$SC = \frac{\sum A_i}{A_{block}}$	*A* is the building layout area A_{block} is the block area
VtH	Vertical to Horizontal	-	$VtH = \frac{\sum A_{vert}}{A_{block}}$	*A* is the area of the building walls A_{block} is the block area
VAR	Volume Area Ratio	m	$VAR = \frac{\sum V_i}{A_{block}}$	*V* is the building volume A_{block} is the block area

Since the different urban metrics are related to one another, a subset is generally sufficient to describe the urban blocks in a specific city. Consequently, the next phase is based on a statistical correlation analysis performed by means of the Spearman test, considering a statistical significance equal to 0.05. The stochastic distributions are then determined for the selected subset of independent urban metrics. Subsequently, the main statistical values (e.g., minimum, 10^{th} percentile, Q_1, median, Q_3, 90^{th} percentile, maximum) are extracted for each statistical distribution and combined to define a set of representative configurations. Finally, those actual urban blocks showing the closest morphological features to each combination are identified and selected.

Regarding the second part of the methodology, i.e., the study of land surface temperature maps, the first step is the acquisition of satellite thermal images. Specifically, we recommend to consult the database of ECOSTRESS (*ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station*) satellite thermal images by NASA (https://ecostress.jpl.nasa.gov/), i.e., the dataset with the most detailed temperature images of the earth's surface acquired from space up to now.
For each investigated city, the proposed methodology recommends focusing on the summer period and, when possible, on days with heat wave phenomena. Since the analysis of large territorial extent can be complex and resource-demanding, satellite thermal images must be focused on the areas of interest (i.e., the residential district). Furthermore, images must be filtered in order to ensure an acceptable level of quality. Images with an excess of cloud cover or data missing must be removed, as well as those with a quality index provided by NASA lower than 0.75. To ensure robustness to the analysis, a minimum of 12 thermal images per city are prescribed, in agreement with the central limit theorem. Figure 1 shows an example for the city of Turin.
For each one of the urban blocks of the analysed city, an average LST is calculated from the thermal maps of the set of selected thermal images. A new map with the average LST for each block is then generated with GIS tools.

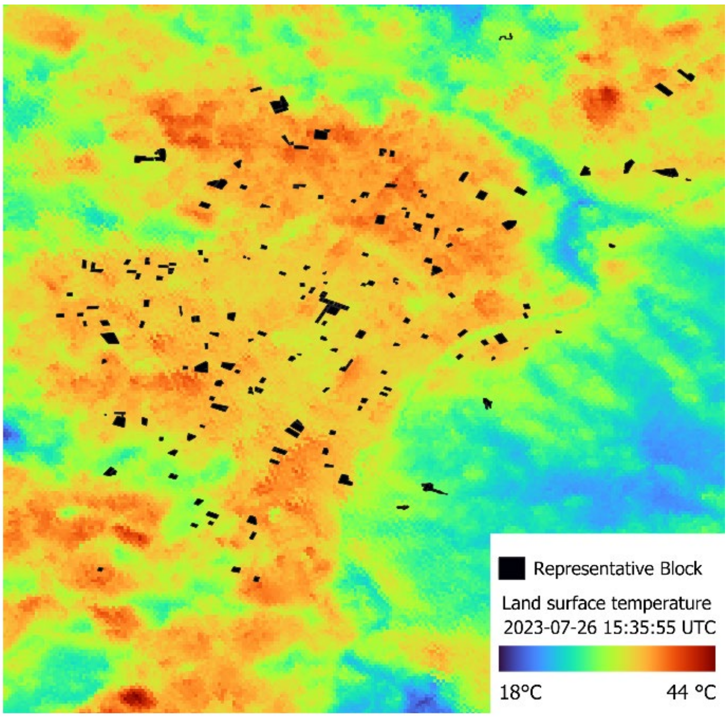


Figure 1: Example of processed ECOSTRESS satellite map of Land Surface Temperature for Turin (July 26th, 2023)

As a final step, parts 1 and 2 of the analysis are combined together. Specifically, the representative urban blocks identified in the morphology analysis are ranked according to their calculated average LST data. Those residential blocks characterised by the highest average LST values are selected as representatives for further UBEM studies aimed at assessing the impact of the UHI effect on district energy performance and identifying the most effective mitigation solutions.

It is worth mentioning that further criteria can be accounted for in a more in-depth analysis. For instance, besides LST data, proximity to urban weather stations can be included among the criteria for the selection of urban blocks for validation purposes.

2.2 Application

2.2.1 Turin

As anticipated above, the city of Turin presents the most detailed and comprehensive set of input data. Consequently, it ensured a detailed implementation of the whole procedure, considering both the complete morphology analysis and the study of the Land Surface temperature maps.

Regarding the morphology analysis performed for Turin, it was included in the paper "*Assessment and mapping of the urban heat island effect: a preliminary analysis on the impact on urban morphology for the city of Turin, Italy*" by Borelli G., Ballarini I., Corrado V., Gasparella A., Pernigotto G., presented in the framework of the conference Building Simulation Applications BSA 2024 (Bolzano, June 26th – 28th 2024).
The 128,144 buildings present in the DSM of Turin were grouped into 4,518 blocks based on their cadastral parcel area. As specified before, the filtering criteria required each block to (1) include a minimum of four buildings, (2) have a *SF* higher than 0.1, and (3) an area lower than 0.1 km². By applying these criteria, the number of blocks was reduced to 2,804. The 10 metrics were then calculated and used as inputs for the correlation analysis according to the Spearman test (Table 2).

Table 2 – Correlation analysis according to the Spearman test

	SF	SVF	GR	SC	Abh	FAR	VAR	REC	Abd	Vth
SF	1	-0.095	-0.037	0.059	0.063	0.058	0.064	-0.023	-0.21	0.24
SVF	-0.095	1	0.2	-0.17	-0.25	-0.26	-0.29	0.32	0.27	-0.34
GR	-0.037	0.2	1	-0.37	-0.099	-0.27	-0.3	0.13	0.5	-0.34
SC	0.059	-0.17	-0.37	1	0.08	0.54	0.61	0.013	-0.032	0.19
Abh	0.063	-0.25	-0.099	0.08	1	0.6	0.73	-0.71	-0.084	0.61
FAR	0.058	-0.26	-0.27	0.54	0.6	1	0.85	-0.4	-0.16	0.63
VAR	0.064	-0.29	-0.3	0.61	0.73	0.85	1	-0.51	-0.13	0.64
REC	-0.023	0.32	0.13	0.013	-0.71	-0.4	-0.51	1	0.22	-0.53
Abd	-0.21	0.27	0.5	-0.032	-0.084	-0.16	-0.13	0.22	1	-0.59
Vth	0.24	-0.34	-0.34	0.19	0.61	0.63	0.64	-0.53	-0.59	1

According to the results, the following four metrics were considered sufficient to proceed with the next steps of the analysis: (1) Green Ratio (*GR*), (2) Surface Coverage (*SC*), (3) Average Building Height (*ABH*), and (4) Vertical to Horizontal (*VtH*). The normalised statistical distributions for those four selected variables are depicted in Figure 2.

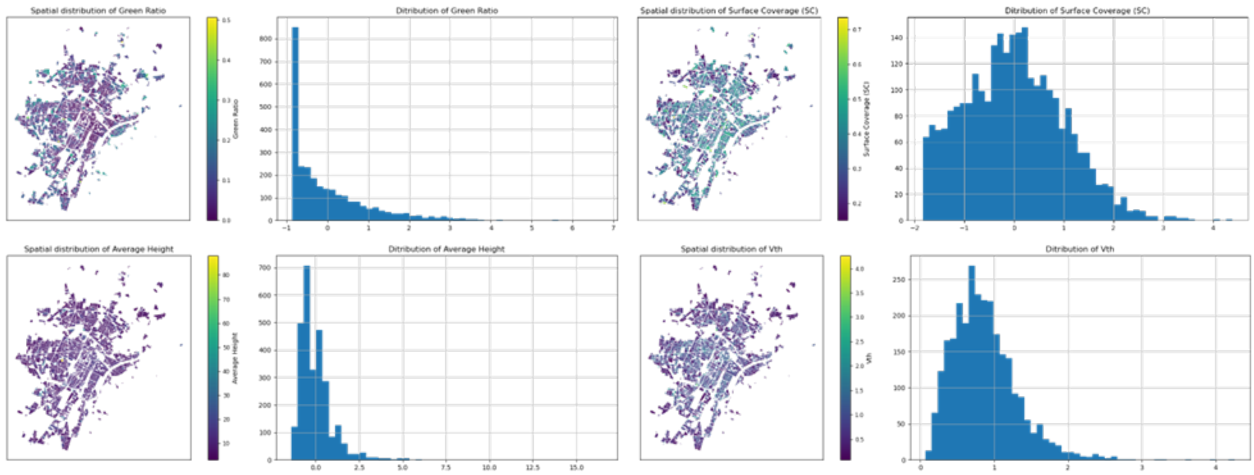
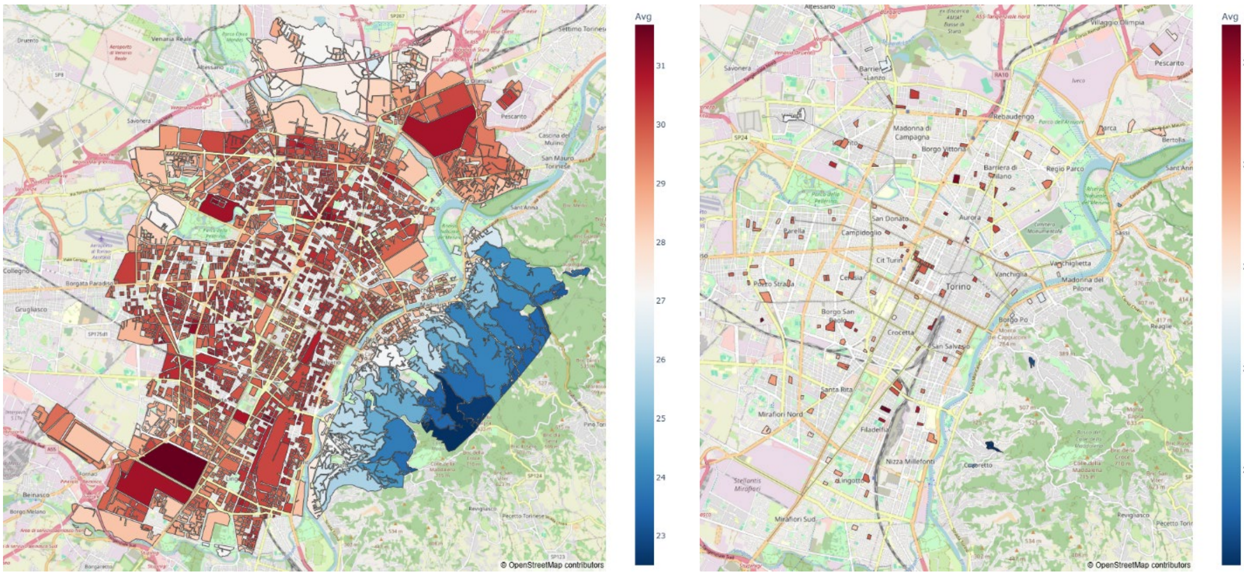


Figure 2: Normalised statistical distributions of the four selected metrics

The main statistical values (minimum, 10th percentile, Q_1, median, Q_3, 90th percentile, maximum) were extracted from the statistical distributions of the four selected metrics, and the actual urban blocks showed the closest morphological features identified. After removing duplicates, 171 urban blocks were identified (i.e., 6 % of the original sample), as shown in Figure 3.

Figure 3: Map of Turin urban blocks with the selected ones highlighted in red

Regarding the LST study, we extracted LST maps from the ECOSTRESS satellite data for the period from 01/06/2023 to 31/08/2023. As mentioned above, data were filtered considering a quality index larger than 0.75 (i.e., removing data with excess cloud cover or missing). In the case of Turin, a dataset with 18 LST images was obtained, and a complete analysis was performed on the entire city. The average LST in each urban block area was calculated, finding a range from 22 °C to 31.7 °C as shown in Figure 4a. At this stage, the analysis focused only on those blocks identified in the first part of the research as representative of Turin (Figure 4b). Due to LST data availability, the number of representative blocks was reduced from 171 to 130, finding a range of LST from 25 °C to 31.3 °C.



(a) **(b)**

Figure 4: Maps of the average Land Surface Temperatures for each urban block, obtained processing a set of 18 satellite maps from summer 2023: depiction of mean LST for the whole city – range 22 °C to 32 °C (a), and for the representative urban blocks – range 25 °C to 32 °C (b)

The candidate urban blocks for detailed UBEM simulations were ranked in decreasing order of average LST values. Among the top 15, the cases described in Section 2.3.1 were selected.

2.2.2 Bari

The case of Bari represents a situation in which, although some input data regarding the urban morphology are available, their level of detail and completeness are not suitable for a full implementation of the proposed methodology. In particular, the data retrieved by the authors lacked (1) usage of the building (residential, commercial, industrial, etc.), (2) cadastral parcel, (3) building construction period, and (4) building height. This data scarcity prevented, first of all, the distinction of residential and non-residential areas directly in the GIS file. Furthermore, the missing inputs regarding cadastral parcels made unfeasible the grouping of buildings into urban blocks and, consequently, the calculation of the urban morphology metrics with the same level of aggregation described in Section 2.1. Finally, the missing data about the building heights hindered the calculation of most of the chosen metrics (i.e., *ABH, REC, SVF, VtH,* and *VAR*). In addition to that, the available

GIS files merged adjacent buildings into a single polygon, leading to 26,809 different building layouts encompassing multiple buildings.

Given all the premises discussed above, it appeared unfeasible to replicate the full methodology for the city of Bari. As a consequence, we considered it more effective to start with the second part of the methodology, i.e., the one related to the LST maps, and, once identified, the districts most affected by UHI phenomena, to focus on the retrieval of the missing information for them.

ECOSTRESS LST images were then collected for the Bari urban region for summer 2023. As done for Turin, a filtering process was implemented to build a dataset of thermal pictures with high quality. Furthermore, in the case of Bari, pictures showing an evident Urban Cool Island phenomenon, often observed in different settlements in the Apulia region, were discarded. Eventually, 17 satellite images were obtained after this filtering task (Figure 5).

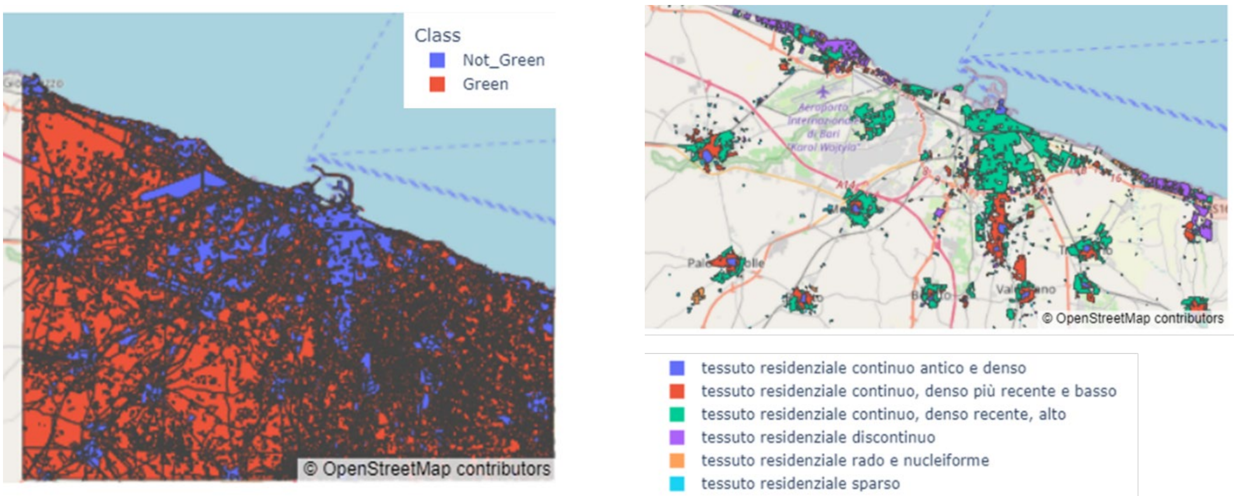


Figure 5: Identification of target areas in the Bari region

The focus was put only on residential areas with an average LST above 29 °C, leading to the identification of the candidate blocks depicted in Figure 6.

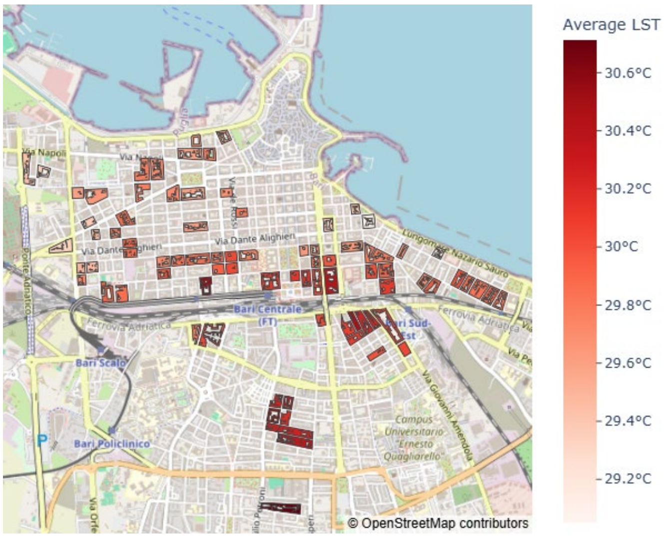


Figure 6: Analysis of average LST for candidate residential urban blocks in Bari

2.2.3 Rome

The city of Rome presents a situation similar to Bari, with a lack of available GIS maps allowing a complete implementation of the proposed procedure. Due to this reason and considering the large size of the municipality of Rome, four residential areas were identified as potential zones for the application of the Land Surface Temperature assessment through satellite thermal imaging (Figure 7): two case studies at the EUR, one in the Garbatella and one in the Salario neighbourhoods. We identified local weather underground stations in these districts with the aim of paving the way for potential further validation studies (yellow dots in Figure 7), and extracted a sub-area with a 500 m radius to ensure diversity in street canyon configurations (blue circles in Figure 7).

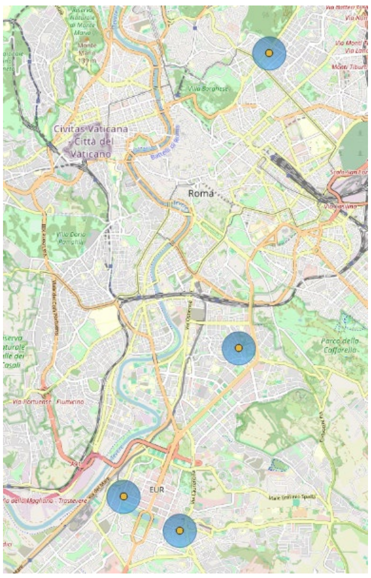


Figure 7: Selected sub-areas in the neighbourhoods of EUR, Garbatella and Salario in Rome

The LST analysis was performed in such areas in agreement with the criteria described in Section 2.1 and exemplified in Sections 2.2.1 and 2.2.2 for Turin and Bari. Examples of average LST maps are reported in Figure 8 for the EUR case studies.

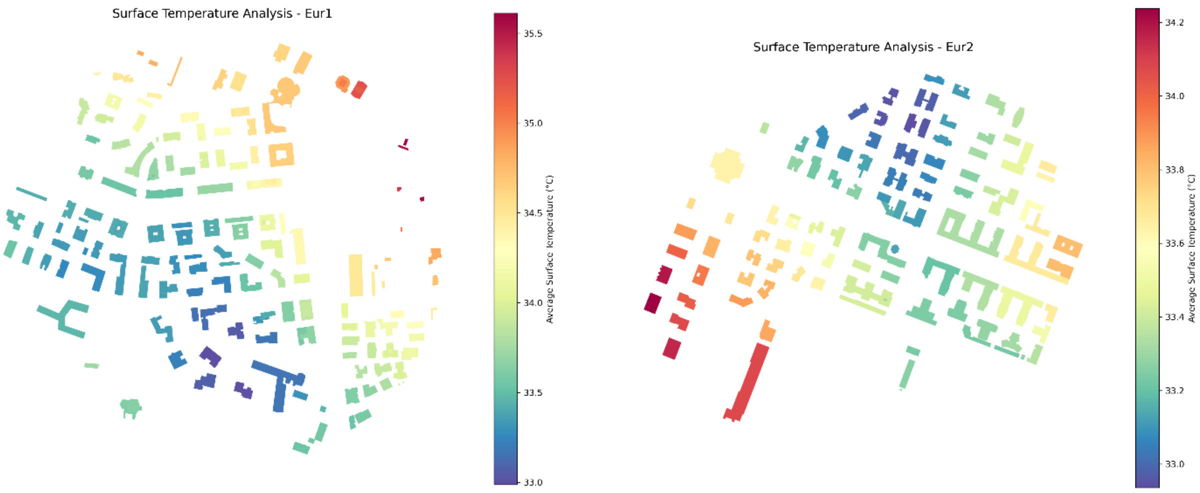


Figure 8: Average LST maps for the two case studies in the EUR neighbourhood in Rome

Due to the lack of 3D maps to perform the subsequent simplified morphology assessment and UBEM simulation, the tasks of providing data and developing 3D models for the identified and agreed upon four sub-areas in Rome have been assigned to an external data provider through a consultancy service. The activity is ongoing, and an update on the present deliverable will be provided. At present, those 3D models are under development in a format compatible with the selected UBEM tool (i.e., CitySim).

2.3 Urban blocks selection: examples

2.3.1 Turin

Those urban blocks depicted in Figure 9 and Figure 10 were selected for the modelling according to UBEM approaches. All three blocks are characterised by the average LST larger than 30.5 °C.

Figure 9: Position of the three selected urban blocks A, B and C in the city of Turin

Figure 10: Google maps pictures of the three selected urban blocks of Turin for UBEM simulations

2.3.2 Bari

Two residential blocks were selected in Bari, as shown in Figure 11.

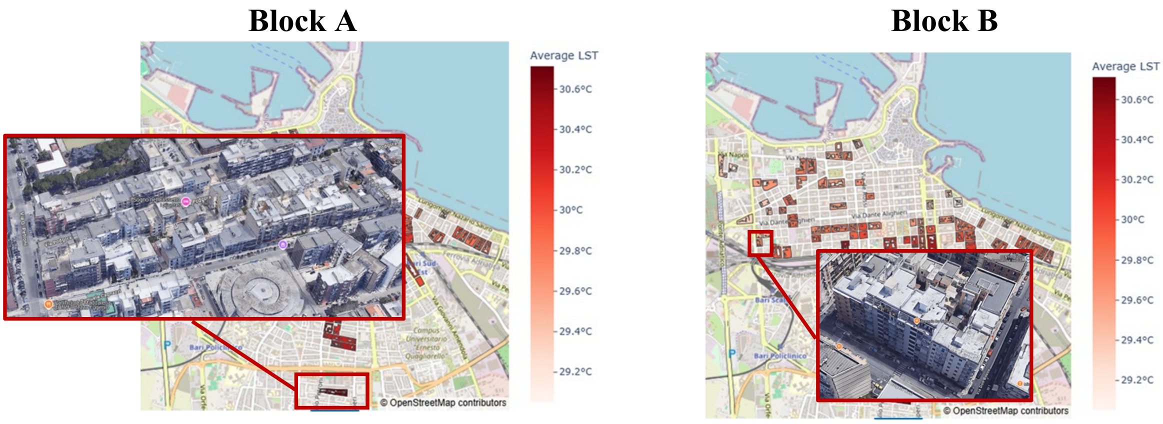


Figure 11: Position and pictures of the two selected urban blocks, A and B, in the city of Bari

2.3.3 Rome

Three residential blocks were selected in Rome, as shown in Figure 12, Figure 13, and Figure 14.

URBAN BLOCK A – EUR

Figure 12: Position and LST map for urban block A - EUR in the city of Rome

URBAN BLOCK B – NUOVO SALARIO

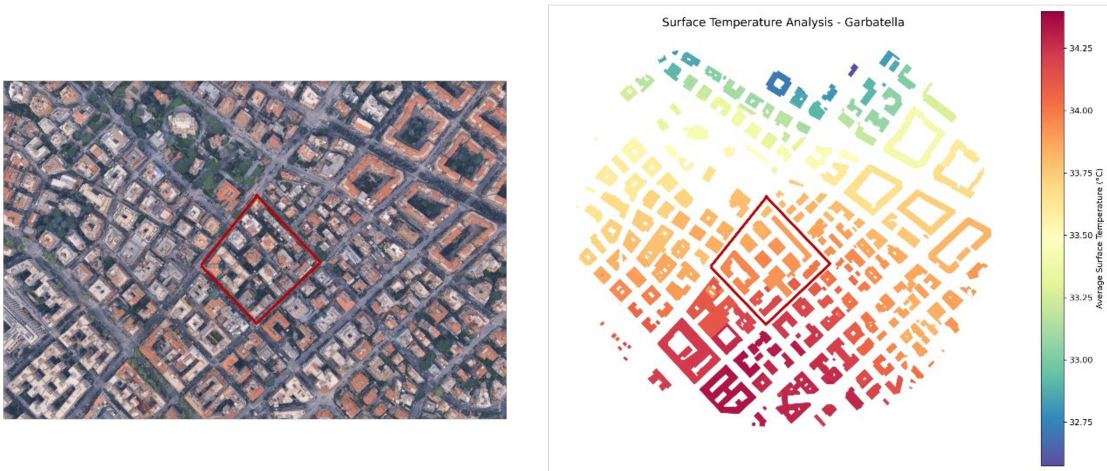


Figure 13: Position and LST map for urban block B – Nuovo Salario in the city of Rome

URBAN BLOCK C – GARBATELLA

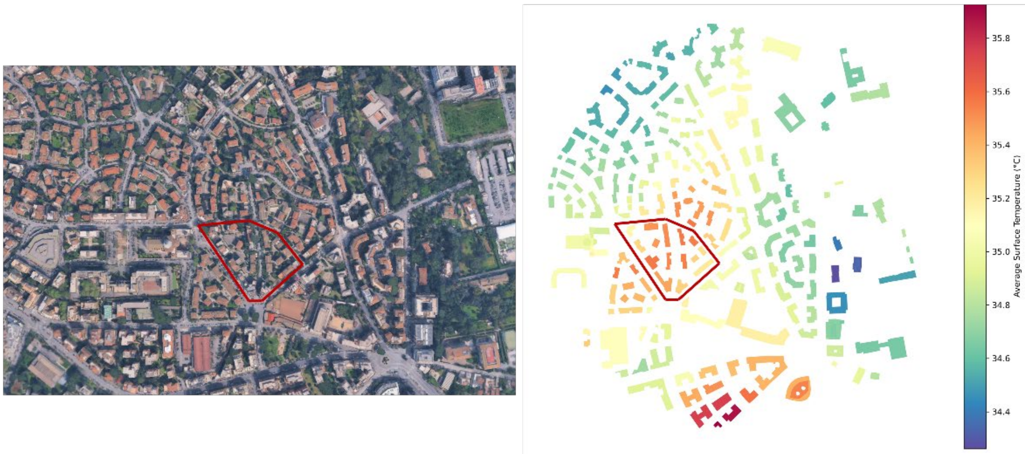


Figure 14: Position and LST map for urban block C - Garbatella in the city of Rome

3. BUILDING ARCHETYPE

The national building renovation plan, as defined in the new Energy Performance Building Directive (EU 2024/1275), is linked to the concept of *building types*, which serves as a key element for assessing the energy performance of existing buildings. The ultimate objective is to transform the urban stock into a decarbonised building sector.

Prototype buildings, building types, or building archetypes (BAs) are virtual buildings that encapsulate the key technological aspects and usage patterns of specific building stocks. BAs are non-geometrical datasets that include information on building envelope components, technical building systems, and operational characteristics. The process of BA generation consists of two phases: segmentation and characterisation.

- The **segmentation** stage involves the classification and categorisation of the building stock's energy performance based on various criteria. These criteria depend on the purpose of the analysis, but the most used include climatic zone, building use category, construction period, and building size and shape.
- The **characterisation** phase provides the assignment of a specific BA schema to the assessed buildings to capture their energy performance. The urban block's geometry is extracted using GIS, then imported and simulated in a UBEM tool.

3.1 Methodology

The BAs are connected to the urban context based on predefined categories. The non-geometric properties of buildings are derived from existing literature sources. The key factors used to classify different building energy performance segments include climatic zone, intended use, and construction period. The climatic zones of the analysed municipalities are clearly defined: climatic zone C for Bari, zone D for Rome, and E for Turin. The analysis focused on identifying and assessing the performance of the residential building stock.

Following the representative geometrical identification of urban blocks in Section 2.3, the methodology consists of the following steps:

1) **Investigation of open-access databases** to gather information on building use categories and construction periods at the building or district level. This information is crucial for assigning appropriate BA schema.
2) **Review and collection of BA schemas** from literature sources adaptable to the analysed building stock.
3) **Assignment of BA** to the real 3D urban scene to characterise its energy efficiency.
4) **Filling data gaps** in BA properties using other recognised references.

Due to privacy concerns and inconsistencies in information structure, the availability and accessibility of data vary across municipalities. As mentioned, the required data range from non-geometrical properties in the BA schema to the construction period of the building stock and building use category. Consequently, the methodology was progressively adapted and simplified for the analysed Italian cities based on their data quality and completeness.

In the three different contexts, given the limited availability of data, the schedule and intensity of internal heat gains—comprising thermal energy produced by occupants, appliances, and lighting—were sourced from the Italian National Appendix of the UNI EN 16798-1 (CTI, 2022).

3.2 Application

3.2.1 Turin

The information regarding the use category and construction period of the real building stock was obtained from the Geoportal of the Municipality of Turin (2025). An example of extractable geodata for an urban area in Turin is shown in Figure 15, where polylines are represented in different colours based on their respective construction periods.

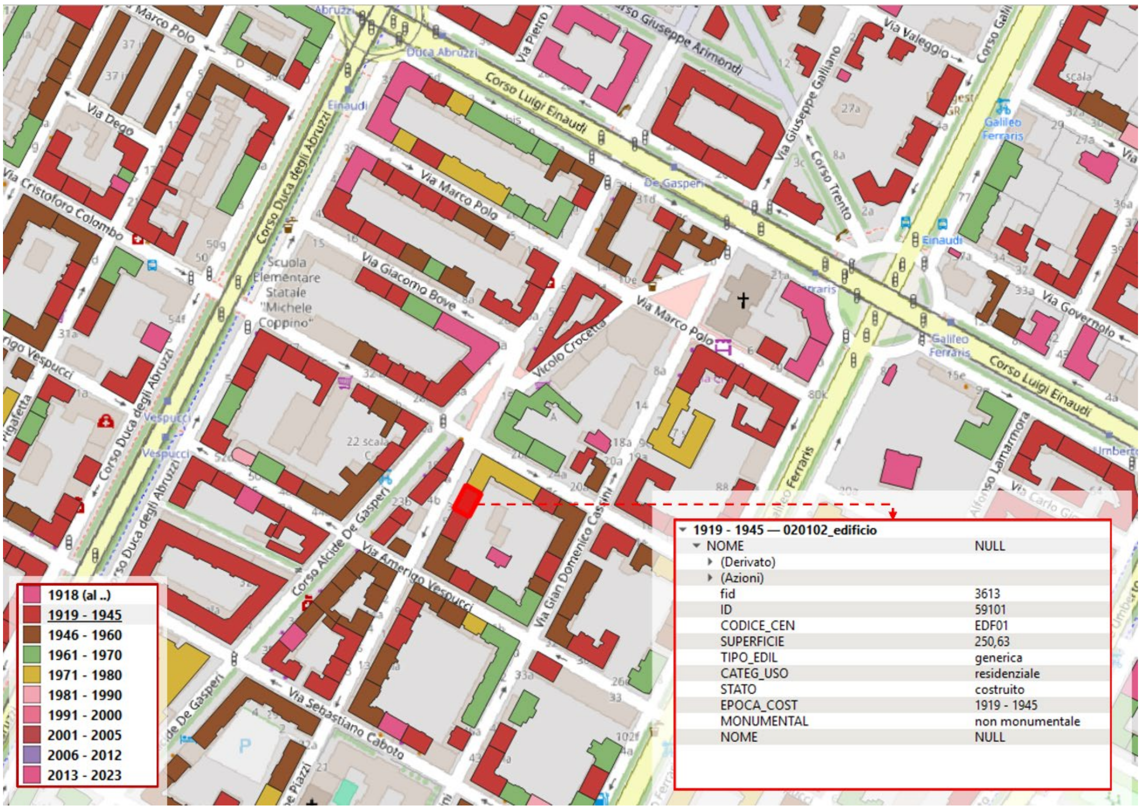


Figure 15: An example of geodata informatisation for an urban block in Turin (Geoportal of the Municipality of Turin, 2025)

The sources utilised to define the BA schema are primarily derived from two references:

- the representative buildings developed within the H2020-TIMEPAC (Towards Innovative Methods for Energy Performance Assessment and Certification), and
- the scorecards from the PRIN-2020 URBEM (Urban Reference Buildings for Energy Modelling) projects.

In both cases, the data utilised originate from statistical analysis of the energy performance certificate (EPC) database of the Piedmont region, specifically for climatic zone E.

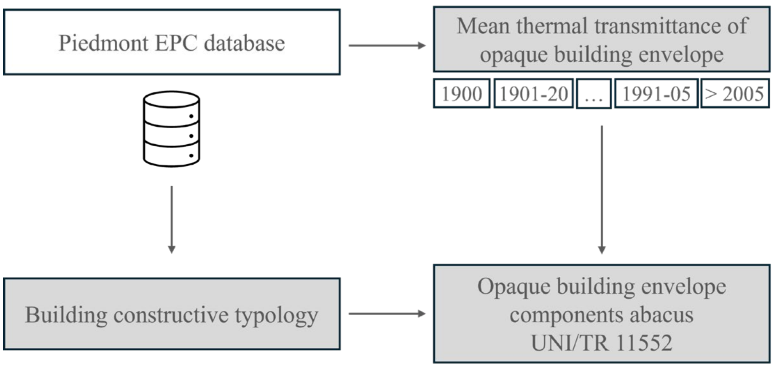


Figure 16: Methodology for the definition of the opaque building envelope components stratigraphy

The methodology for assigning material composition to walls, floors, and roofs is illustrated in Figure 16. Firstly, the building typologies were statistically assessed from the analysis of EPCs of Piedmont (Figure 17). For the periods 1901-20, 1921-45, 1946-60, and 1961-75, corresponding to the simulated buildings in Task 3.2, the most frequent construction styles are:

- **Load-bearing masonry structure**, predominant in 1901-20 (89 %) and 1921-45 (81 %), declined significantly in 1946–60 (31 %) and further dropped to 17 % in 1961–75.
- **Reinforced concrete structure with brick closures**, increasing from 4 % in 1901-20 to 9 % in 1921-45, becoming the dominant style in 1946-60 (54 %) and continued to rise in 1961–75 (69 %).
- **Mixed structure (reinforced concrete and bricks)**, progressively increasing in use from 5 % in 1901–20 to 7 % in 1921–45, reaching 12 % in 1946–60 and remaining relatively stable at 11 % in 1961–75.

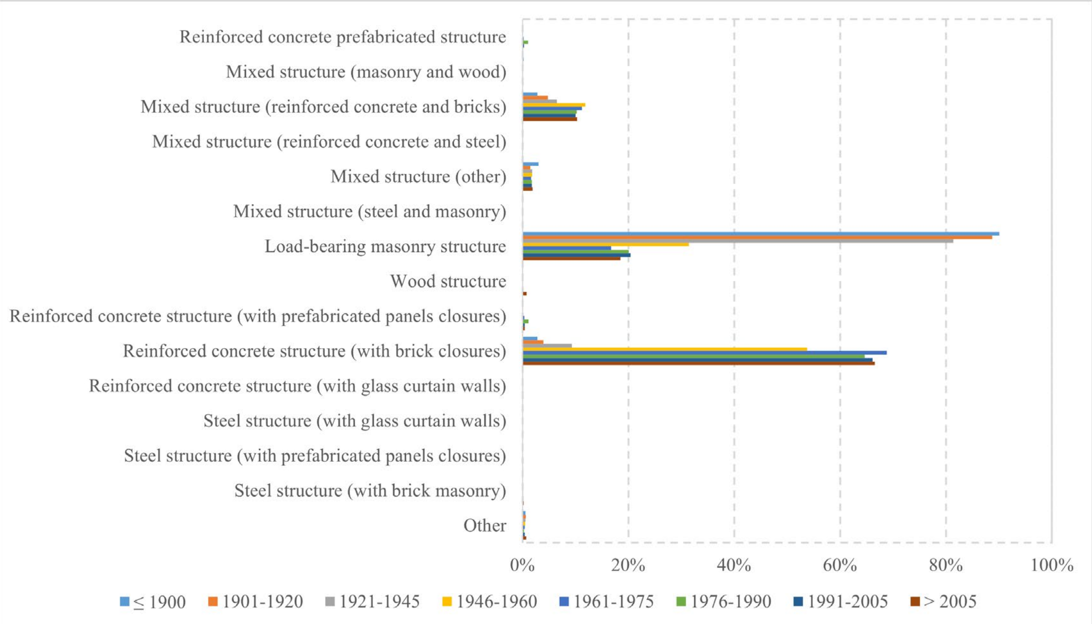


Figure 17: Constructive typologies per construction period

A key limitation of EPCs is the lack of *U*-values specifically distinguished for opaque components, as well as the absence of detailed material layer compositions for walls, floors, and roofs. To address this, weighted thermal transmittances were used as benchmark values for stratigraphy identification. From Piedmont EPCs, the mean *U*-value for both opaque and transparent components was extracted from the TIMEPAC results (2023), subdivided for key statistical indicators: first (Q_1) quartile, median, and third (Q_3) quartile. However, only median values were used as input for calculations. Specifically, the archetypes used were derived from EPCs issued for building units in apartment blocks (code “E_RES_BU(AB)”).

Table 3 reports the window-to-wall ratio (*WWR*) for the different construction periods. Table 4 and Table 5 present the mean thermal transmittance values for various ages, distinguishing between opaque and transparent building envelope components, respectively. Subsequently, using the UNI/TR 11552 standard (UNI, 2014), the stratigraphy of opaque building envelope components was assigned based on target mean *U*-value, territorial affiliation, and building constructive style (Table 4), where the number in brackets indicates the relative position of the stratigraphy within the listed configurations. For transparent components, double-glazing windows were assumed, with a total solar energy transmittance at a normal incidence ($g_{gl;n}$) standard value of 0.75 (UNI, 2018).

Table 3 – Window-to-wall ratio per construction period (TABULA, 2012)

Window-to-wall ratio, *WWR* [%]	
Construction period range	***WWR***
≤ 1900	14 %
1901-1920	16 %
1921-1945	14 %
1946-1960	13 %
1961-1975	10 %
1976-1990	12 %
1991-2005	20 %
> 2005	12 %
	The construction period ranges of buildings are thermally assessed in Task 3.2.

Table 4 – Mean thermal transmittance of opaque building envelope per construction period (TIMEPAC, 2023)

Mean thermal transmittance of the opaque building envelope, U_{op} [W/(m²·K)]			
Construction period range	***Q_1***	***Median***	***Q_3***
≤ 1900	1.000	1.235	1.475
1901-1920	1.018	1.242	1.464
1921-1945	1.030	1.267	1.475
1946-1960	0.943	1.183	1.409
1961-1975	0.929	1.157	1.372
1976-1990	0.848	1.093	1.317
1991-2005	0.627	0.814	1.067
> 2005	0.279	0.439	0.710
	The construction period ranges of buildings are thermally assessed in Task 3.2.		

Table 5 – Mean thermal transmittance of transparent building envelope per construction period (TIMEPAC, 2023)

Mean thermal transmittance of the transparent building envelope, U_w [W/(m²·K)]			
Construction period range	Q_1	*Median*	Q_3
≤ 1900	2.196	2.980	4.244
1901-1920	2.259	3.105	4.383
1921-1945	2.284	3.092	4.356
1946-1960	2.314	3.124	4.480
1961-1975	2.308	3.157	4.573
1976-1990	2.301	2.939	3.745
1991-2005	2.172	2.700	2.981
> 2005	1.458	1.854	2.485
	The construction period ranges of buildings are thermally assessed in Task 3.2.		

Table 6 – UNI/TR 11552 code association for different construction periods

	≤ 1900	**1901-20**	**1921-45**	**1946-60**	**1961-75**	**1976-90**	**1991-05**	**> 2005**
Wall	MLP01 (3)	MLP01 (3)	MLP01 (3)	MCV01 (3)	MCV01 (3)	MCV01 (3)	MCV04 (1)	MCV04 (3)
Roof	COP01 (6)	COP01 (6)	COP01 (6)	COP01 (6)	COP03 (1)	COP03 (1)	COP03 (1)	COP03 (12)
Floor	SOL04 (6)	SOL04 (6)	SOL04 (6)	SOL04 (6)	SOL04 (6)	SOL04 (6)	SOL04 (6)	SOL04 (6)
	The construction period ranges of buildings are thermally assessed in Task 3.2.							

3.2.2 Bari

Unlike the municipality of Turin, Bari does not have a geodatabase with the needed information. The building construction period was derived from the findings of Di Turi (2011). As shown in Figure 18, the construction period range is assigned at the city block level rather than at the building scale. This aspect will also be reflected in the BA schema association, as it is likely that the assessed portfolio of buildings modelled in the UBEM model will share the same non-geometrical properties.

Table 7 summarises the geometrical and thermophysical properties categorised by age ranges, which are used to characterise the energy performance of residential buildings in Bari. Specifically, the *WWR* values are derived from URBEM scorecards for a different Italian region within the same climatic zone (URBEM, 2025). The thermal transmittances of the opaque building envelope components are extracted from Di Turi and Stefanuzzi (2015). The *U*-value of windows for apartment blocks in zone C is reported in Ballarini *et al.* (2017), with the total solar energy transmittance at normal incidence ($g_{gl;n}$) assigned based on the insulation level of glazing elements (UNI, 2018). Then in Table 8 is presented the layer material composition associated with UNI/TR 11552 codes (UNI, 2014), where the number in brackets indicates the relative position of the stratigraphy within the listed configurations.

Figure 18: An example of the historical building evolution for the city center of the municipality of Bari (Di Turi, 2011).

Table 7 – Geometrical and thermal characteristics of the building envelope components (URBEM, 2025; Di Turi & Stefanizzi, 2015; Ballarini et al., 2017; UNI, 2018)

Construction period	***WWR*** [%]	U_{wl} [W/(m²·K)]	$U_{fl;up}$ [W/(m²·K)]	$U_{fl;lw}$ [W/(m²·K)]	U_{w} [W/(m²·K)]	$g_{gl;n}$ [-]
≤ 1920	-	2.19	1.63	1.33	4.90	0.85
1921-45	-	2.19	1.63	1.33	5.70	0.85
1946-60	0.17	2.40	1.27	1.33	4.90	0.85
1961-75	0.17	1.38	0.91	1.33	4.90	0.85
1976-90	0.18	0.89	0.89	1.07	3.70	0.75
1991-05	-	0.56	0.86	1.29	3.40	0.75
> 2005	-	0.40	0.36	0.80	-	-

The construction period ranges of buildings are thermally assessed in Task 3.2.

Table 8 – UNI/TR 11552 code association for the assessed construction periods

	1946-60	1961-75	1976-90
Wall	MLP02 (2)	MCV03 (1)	MCV03 (3)
Roof	COP04 (6)	COP03 (2)	COP03 (3)
Floor	SOL04 (4)	SOL04 (4)	SOL04 (6)
	The construction period ranges of buildings are thermally assessed in Task 3.2.		

3.2.3 Rome

To assign the appropriate non-geometrical properties of the building archetypes, the construction period is an essential parameter. In the absence of a dedicated database identifying the age of buildings within the municipality of Rome, a statistical approach was adopted. Statistical data from ISTAT (2011) are shown in Figure 19. Specifically, for each considered case study—Nuovo Salario, EUR, and Garbatella—the three most frequent construction periods were randomly assigned to the assessed buildings within each urban block. For example, in the Nuovo Salario case study, the following ages were assigned: 1919-45, 1946-60, and 1961-70.

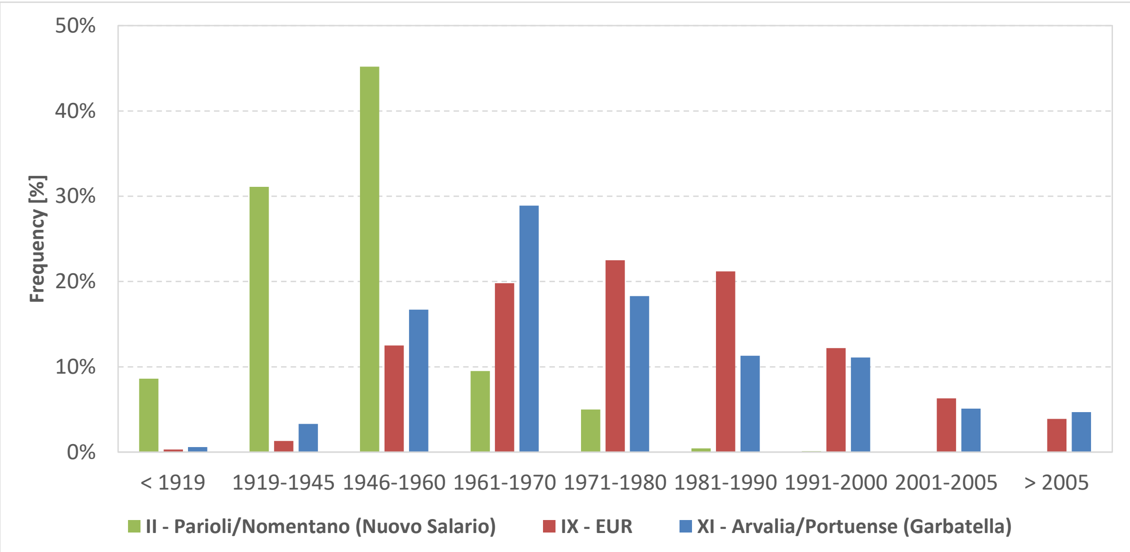


Figure 19: Building construction period distribution for the assessed districts (ISTAT, 2011)

Table 9 provides a summary of the geometrical and thermophysical characteristics of residential buildings in Rome, organised by the construction age range. The *WWR* values are taken from URBEM scorecards pertaining to another Italian region within the same climatic zone (URBEM, 2025). Thermal transmittance values for the building envelope components are sourced from both the URBEM scorecards (2025) and Ballarini *et al.* (2017) to cover construction periods not included in the former. The total solar energy transmittance at normal incidence ($g_{gl;n}$) is assigned according to the insulation level of glazing elements (UNI, 2018).

Table 10 then presents the material layer compositions corresponding to UNI/TR 11552 codes (UNI, 2014), where the number in brackets indicates the relative position of the stratigraphy within the listed configurations.

Table 9 – Geometrical and thermal characteristics of the building envelope components (URBEM, 2025; Ballarini et al., 2017; UNI, 2018)

Construction period	***WWR*** **[%]**	U_{wl} **[W/(m²·K)]**	$U_{fl;up}$ **[W/(m²·K)]**	$U_{fl;lw}$ **[W/(m²·K)]**	U_{w} **[W/(m²·K)]**	$g_{gl;n}$ **[-]**
1919-45	12 %	1.17	2.48	1.81	5.70	0.85
1946-60	12 %	1.50	1.60	1.35	4.90	0.85
1961-75	16 %	1.15	1.56	1.27	3.65	0.75
1976-90	11 %	1.10	1.40	1.25	3.70	0.75
The construction period ranges of buildings are thermally assessed in Task 3.2.						

Table 10 – UNI/TR 11552 code association for the assessed construction periods

	1919-45	**1946-60**	**1961-75**	**1976-90**
Wall	MCO01 (1)	MCO01 (1)	MCV01 (3)	MCV01 (3)
Roof	CIN05	COP04 (1)	COP04 (2)	COP04 (3)
Floor	SOL06 (8)	SOL04 (4)	SOL04 (5)	SOL04 (5)
The construction period ranges of buildings are thermally assessed in Task 3.2.				

4. UBEM TOOL

Large-scale energy analyses are typically classified based on two main methodological approaches: *top-down* and *bottom-up* models (Johari *et al.*, 2020; Abbasabadi and Ashayeri, 2019; Kavgic *et al.*, 2010; Swan and Ugursal, 2009). *Top-down* models, which rely on historical data series, are developed to examine macro-level relationships among the energy, technological, and economic sectors.

In contrast, *bottom-up* models use disaggregated data to estimate the end-use energy consumption of individuals or groups of buildings. *Bottom-up* building stock energy models are commonly subdivided into three categories: engineering (or *physical-based*) models, statistical (or *data-driven*) models, and hybrid models. Although interpretations vary, following the studies by Reinhart and Cerezo Davila (2016) and Johari *et al.* (2020), Urban Building Energy Modelling (UBEM) is generally considered a *bottom-up physical-based* model aimed at determining the energy demands of a block, a district, or the whole city.

Ferrando *et al.* (2020) and Abbasadi and Ashayeri (2019) provide a comprehensive overview of UBEM tools used to assess the performance of building stocks. According to Ferrando *et al.* (2020), *physical-based* tools can be further categorised into:

- **Reduced-order resistor-capacitor** (R-C) models, and
- **Detailed dynamic thermal** models.

Table 11 presents an overview of widely used UBEM tools for assessing the energy performance of urban-scale building stocks, including their references and distinguishing between reduced-order R-C and detailed dynamic thermal models.

Table 11 – Overview of UBEM tool

UBEM tool	Reference	Reduced-order RC	Detailed dynamic
CityBES	Chen *et al.* (2017)		●
City Energy Analyst	Fonseca *et al.* (2016)	●	
CitySim	Robinson *et al.* (2009)	●	
EUReCA	Prataviera *et al.* (2021)	●	
SimStadt	Nouvel *et al.* (2015)	●	
TEASER	Remmen *et al.* (2018)	●	
umi	Reinhart *et al.* (2013)		●
UrbanOpt	El Kontar *et al.* (2020)		●
UBEM.io	Ang *et al.* (2022)		●

According to the research conducted by Kamel (2022), the three most used UBEM tools are umi, CityBES, and CitySim.

umi (Urban Modeling Interface) is a modelling environment developed by MIT's Sustainable Design Lab. CityBES is a web-based platform developed by Lawrence Berkeley National Lab in the United States. CitySim is developed by the Solar Energy and Building Physics Laboratory of EPFL (L'École Polytechnique Fédérale de Lausanne).

The first two tools, umi and CityBES utilise EnergyPlus as their simulation engine, whereas CitySim employs the CitySim Solver, a custom thermal model based on discretising building envelope components into an R-C system with a finite number of nodes (Kämpf and Robinson, 2007).

CitySim was preferred over EnergyPlus-based tools due to its greater flexibility in handling datasets with varying levels of granularity. In contrast, umi and CityBES rely on detailed dynamic thermal energy models and thus require detailed input data—data that is not always available in large-scale analyses. Moreover, CitySim is capable of providing a detailed hourly assessment of short-wave and long-wave radiation exchanges for every surface modelled in the urban scene. This aspect is particularly relevant to achieve the goals of the CRiStall project.

To illustrate this point, Table 12 presents a comparison between the input requirements of CitySim and umi for characterising transparent building envelope components in large-scale energy scenarios.

For this comparison, umi represents the category of EnergyPlus-based UBEM tool, with a specific focus on the *WindowMaterial: Glazing* object in EnergyPlus.

Since EnergyPlus was originally developed for high-resolution single-building analysis, many of its required inputs may need to be assigned default values when applied to large-scale UBEM contexts.

Table 12 – CitySim vs umi inputs for the characterisation of transparent building envelope components

Inputs	CitySim	umi
Back-side IR Emissivity		●
Back-side Solar Reflectance		●
Back-side Visible Reflectance		●
Conductivity		●
Density		●
Front-side IR Emissivity		●
Front-side Solar Reflectance		●
Front-side Visible Reflectance		●
IR Transmittance		●
Solar Transmittance		●
Thermal Transmittance of Window	●	
Thickness of glazing		●
Total Solar Energy Transmittance at Normal Incidence	●	
Visible Transmittance		●

5. CONCLUSION

Task 3.1, titled "*Definition of typical urban context configurations using archetypes and UBEM tool selection*", is a fundamental element of WP3, laying the groundwork for characterising the energy performance of the existing residential urban stock across different Italian climates. Specifically, this task focuses on leveraging building archetypes to establish connections between representative buildings and districts. After selecting the BAs, reference urban contexts were identified through a parametric approach guided by geometric descriptive metrics, incorporating typical values and examples from Bari, Rome, and Turin. Lastly, a comparative analysis of the most widely used UBEM tools in the literature was conducted.

The findings of this deliverable serve as the foundation for the subsequent tasks within WP3, ensuring a structured and cohesive workflow:

- **Task 3.2**, "*Implementation of UBEM tool with the urban context configurations*", builds upon identified urban context by integrating them into the CitySim environment. This step involves modelling urban blocks across three Italian climate zones, assigning thermophysical inputs to buildings, and incorporating non-geometrical properties from the BA schema into the archetype-based UBEM.
- **Task 3.3**, "*KPI assessment of the typical urban context configurations*", evaluates the energy footprint of the existing building stock based on different construction periods. Additionally,

future weather files, accounting for UHI effects, will be analysed to assess their impact on energy performance.

A conclusion from this deliverable is the evident disparity in the level of information on Italian building data across different cities. These inconsistencies extend beyond energy-related data to georeferenced attributes, such as construction period, intended use, and building height. For instance, in Bari, many city blocks are not discretised into individual building footprints, limiting the granularity of available data. This lack of harmonisation presents challenges for UBEM developers, increasing uncertainty in input data, undermining model accuracy, and determining the adaptation of the methodology.

Addressing these data gaps highlights the broader significance of informatising the building stock—i.e., creating structured and harmonised digital databases of urban buildings. This process offers substantial benefits for municipalities, including improved urban planning, enhanced interoperability with other systems, and greater energy efficiency. By ensuring a standardised and comprehensive approach to building data management, cities can leverage UBEM more effectively to drive sustainable urban development.

NOMENCLATURE

Symbols

A	area [m^2]
ABD	Average Building Distance [m]
ABH	Average Building Height [m]
d	distance [m]
FAR	Floor Area Ratio [–]
g	total solar energy transmittance [–]
GR	Green Ratio [–]
h	height [m]
r	radius [m]
REC	Relative Compactness [–]
SC	Surface Coverage [–]
SF	Shape Factor [–]
SVF	Sky View Factor [–]
U	thermal transmittance [W/(m^2·K)]
V	volume [m^3]
VAR	Volume Area Ratio [m]
VtH	Vertical to Horizontal [–]
WWR	window-to-wall ratio [%]

Subscripts

fl	floor
gl	glazing, glazed element
lw	lower
n	normal to surface
up	upper
veg	vegetation
w	window
wl	wall

Acronyms

BA	Building Archetype
DSM	Digital Surface Model
EPC	Energy Performance Certificate
LST	Land Surface Temperature
UBEM	Urban Building Energy Model/Modeling
UHI	Urban Heat Island

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