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CLIMATE RESILIENT STRATEGIES BY ARCHETYPE-BASED URBAN ENERGY MODELLING

Atlas of the typical urban context configuration: model features

DELIVERABLE 3.2

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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 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 3.2, "*Implementation of UBEM tool with the urban context configurations*" focuses on modelling of the identified urban contexts with the UBEM tool selected in the framework of Task 3.1. This task is a direct follow-up of Task 3.1 and implements the proposed methodology while taking into account the peculiarity of the UHI assessing method defined in the work package WP2. Task 3.2 is also crucial for the completion of Task 2.3 to generate the future urban weather files accounting for UHI effect. Furthermore, results of Task 3.2 are necessary for the development of climate resilient strategies in Task 4.2.

1.2 Deliverable structure

This deliverable is structured into three sections aimed at modelling in CitySim 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 3.2 development (1.3).
- **Section 2** details the general simulation settings and common features of the districts implemented in CitySim.
- **Section 3** focuses on modelling peculiarities within the chosen UBEM tool across the three municipalities: Turin (3.1), Bari (3.2), and Rome (3.3).

1.3 Contribution of partners

The unibz unit took care of modelling the geometry of the urban blocks selected in the context of Task 3.1 and sent them to the POLITO unit. POLITO, in agreement with what described in the deliverable D3.1, performed a detailed modelling in the selected UBEM, CitySim, and generated the results for the analysis of the KPIs as part of Task 3.3. Both unibz and POLITO contributed to the drafting of the present deliverable. All the partners reviewed and finalised the deliverable.

2. GENERAL SIMULATION SETTINGS AND COMMON FEATURES OF THE DISTRICTS IMPLEMENTED IN CITYSIM

This section discusses the general simulation settings and shared characteristics of the districts implemented in CitySim. Specifically, these similarities range from the preparation of the urban geometry to the thermophysical characterisation carried out within CitySim.

The level of detail (LoD) of the urban geometry scenes corresponds to LoD1, i.e., buildings modelled as mono-zone simplified shoebox volumes. The geometries were imported into the UBEM tool using different methods. For the municipalities of Turin and Bari, the urban scenes were developed using GeoPackage formats. This approach allows for the differentiation across layers: “buildings”, “shadings”, and “grounds”. The “buildings” layer includes the assessed objects; “shadings” comprises elements that obscure the sky vault; and “grounds” includes meshes representing the street level. For the “buildings” and “shadings” layers, it is important to assign height attributes necessary for extruding the volumes into CitySim. Following the right-hand rule, the surface normal were oriented: clockwise for buildings and shadings, and counterclockwise for grounds. The street level was modelled using equal triangular meshes with a spatial resolution of 10 x 10 meters. An example of GeoPackage preparation within QGIS environment is illustrated in Figure 1.

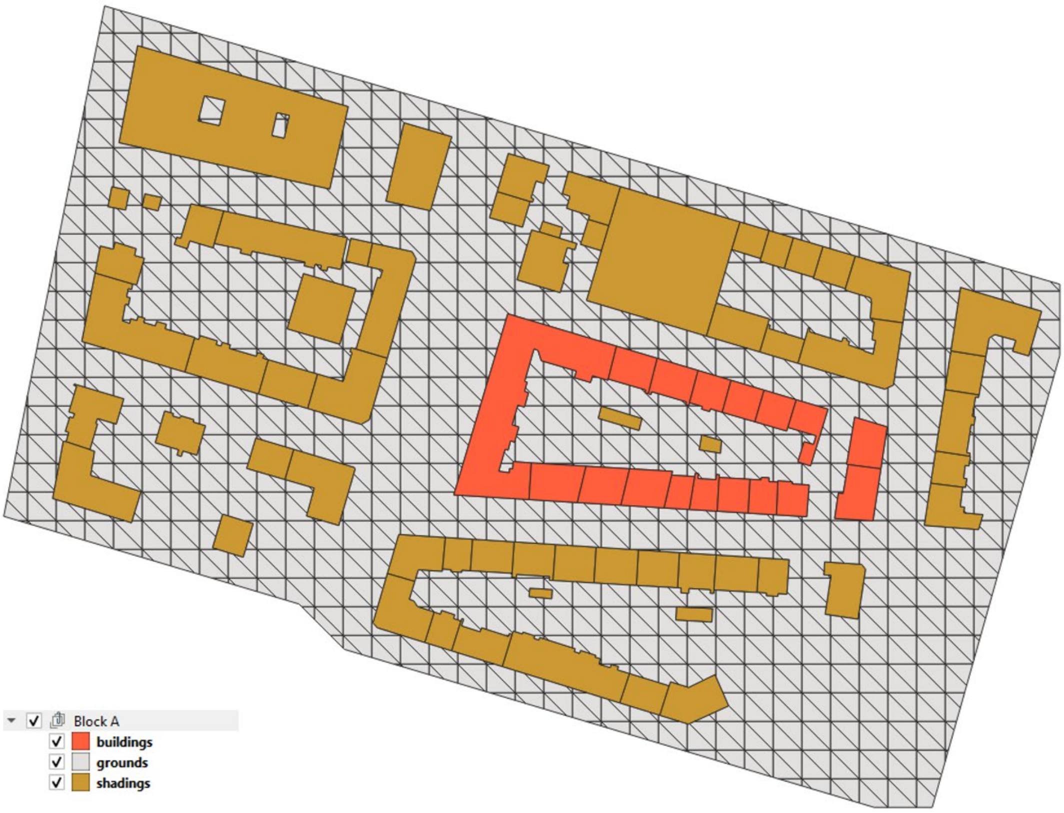

Figure 1: Preparation of the GeoPackage subdividing into buildings, shadings, and grounds layers in QGIS environment

The urban blocks of Rome, modelled at a larger extent as described in deliberable D3.1, were imported into CitySim using an AutoCAD 2000 DXF file via SketchUp (*Figure* 2). In AutoCAD, the surfaces were created using 3DFACE elements and organised into layers following the naming convention: *bldg_code#FACADE*, *bldg_code#ROOF*, and *bldg_code#FLOOR*. This convention is fundamental for proper data importation and for correctly enclosing the volumes to be thermally assessed.

The DXF file was then imported into SketchUp for geometry correction and modification, preparing the models for import into CitySim Pro through the Ruby-based plugin. The use of SketchUp was a crucial step due to its better integration with CitySim, offering an intuitive interface and simplified export options. Ground meshes were subsequently added in SketchUp using an automatic triangulation algorithm.

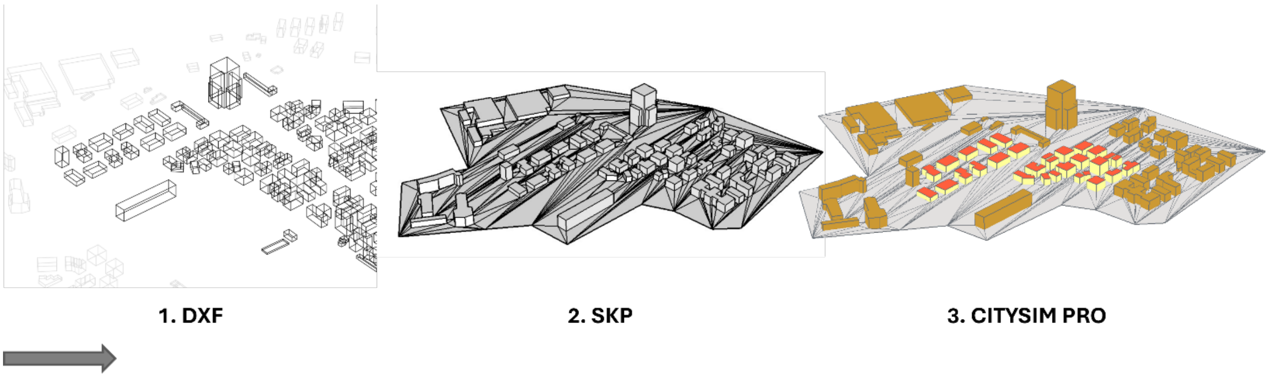

Figure 2: City block geometry importing: from AutoCAD 2000 to CitySim Pro via SketchUp

The thermophysical properties of the opaque and transparent components were assigned to the assessed buildings based on building archetype schema, defined in Task 3.1 "*Definition of typical urban context configurations using archetypes and UBEM tool selection*". The thermal losses due to thermal bridges were neglected. The infiltration rate was assumed equal to 0.50 h^{-1}. Internal heat gains schedules and intensities (occupants, appliances, and lighting) were derived from the draft of the Italian National Annex of UNI EN 16798-1 (2022).

Table 1 summarises the short-wave reflectance (ρ) values for the various surfaces considered in the UBEM scenes. Building walls and roofs were considered light and medium-coloured, respectively (UNI, 2018). All shading objects used a default value of $\rho = 0.20$. Based on ASHRAE Fundamentals (2021), the short-wave reflectance values for ground and green surfaces were matched to weathered asphalt and green grass, respectively.

Table 1 – Short-wave reflectance per assessed surface

Assessed surface	Short-wave reflectance, ρ [–]
Building walls	0.70
Building roofs	0.40
Shading objects	0.20
Ground surfaces	0.10
Green surfaces	0.26

Regarding the operation of solar shading system, and as described by UNI EN ISO 52016-1 (2018), manual operation was assumed with the following rule: shadings are closed if solar irradiance exceeds 300 W/m^2 and open if it drops below 200 W/m^2. In CitySim, blind behaviour is modelled using a sigmoid function that transitions between fully open and closed states. To comply with the standard, this operation was translated into CitySim by assigning an irradiance cut-off of 250 W/m^2 and a smooth transition value of 0.10. Figure 3 shows the sigmoid function, where the *x*-axis represents solar irradiance expressed in W/m^2 and the *y*-axis reports the window open percentage.

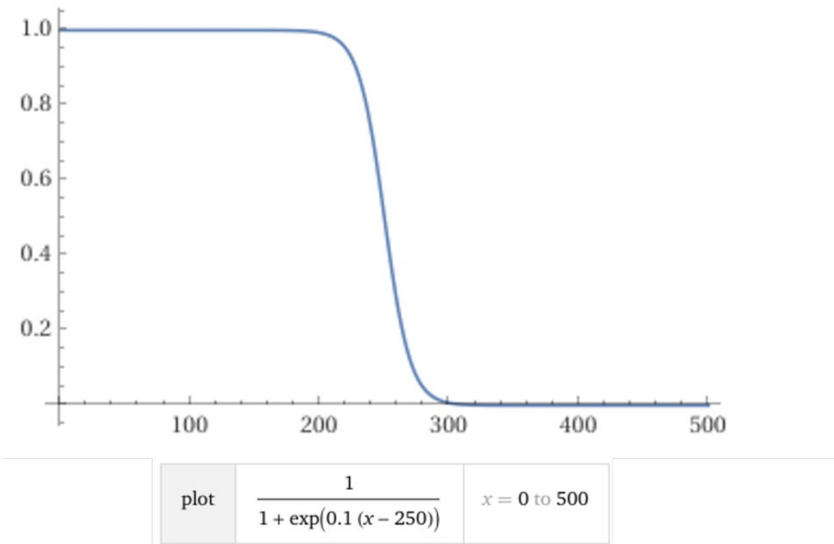

Figure 3: Sigmoid function for solar shading system operation in CitySim

3. EXAMPLES OF SPECIFIC FEATURES OF THE DISTRICTS IMPLEMENTED IN CITYSIM

This section provides the geometrical and thermophysical description of the analysed urban blocks, subdivided into Italian climatic zones: Turin, Bari, and Rome. For each city block, the assigned building codes and geometrical characteristics are presented, including bulding floor area (A_{fl}), total thermal envelope area (A_{env}), volume (V), window-to-wall ratio (WWR), compactness ratio ($A_{env} \cdot V^{-1}$), and mean thermal transmittance for opanque (U_{op}) and transparent (U_w) elements.

3.1 Turin

Figure 4: Urban block A (Turin) visualised in CitySim Pro

Table 2 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block A (Turin)

Bldg. code	Constr. period	A_{fl} [m^2]	A_{env} [m^2]	V [m^3]	WWR [%]	$A_{env} \cdot V^{-1}$ [m^{-1}]	U_{op} [W/(m^2·K)]	U_w [W/(m^2·K)]
A_1	1921-45	524	648	1917	14 %	0.338	1.45	3.09
A_2		776	1357	2654		0.511	1.42	
A_3		371	671	1508		0.445	1.47	
A_4		748	1045	2860		0.365	1.47	
A_5		639	743	2364		0.314	1.46	
A_6		13200	11126	45540		0.244	1.43	
A_7		1387	1315	5086		0.258	1.46	
A_8		877	954	3244		0.294	1.47	
A_9		849	880	2943		0.299	1.45	
A_10		980	949	3409		0.278	1.48	

Bldg. code	Constr. period	A_{fl} [m^2]	A_{env} [m^2]	V [m^3]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m^{-1}]	U_{op} [W/(m^2·K)]	U_w [W/(m^2·K)]
A_11		875	937	3227		0.290	1.47	
A_12		689	707	2480		0.285	1.48	
A_13		775	868	2964		0.293	1.49	
A_14		665	713	2380		0.300	1.47	
A_15		351	480	1321		0.363	1.51	
A_16	1946-60	587	661	2085	13 %	0.317	1.28	3.12
A_17		1401	1680	5044		0.333	1.27	

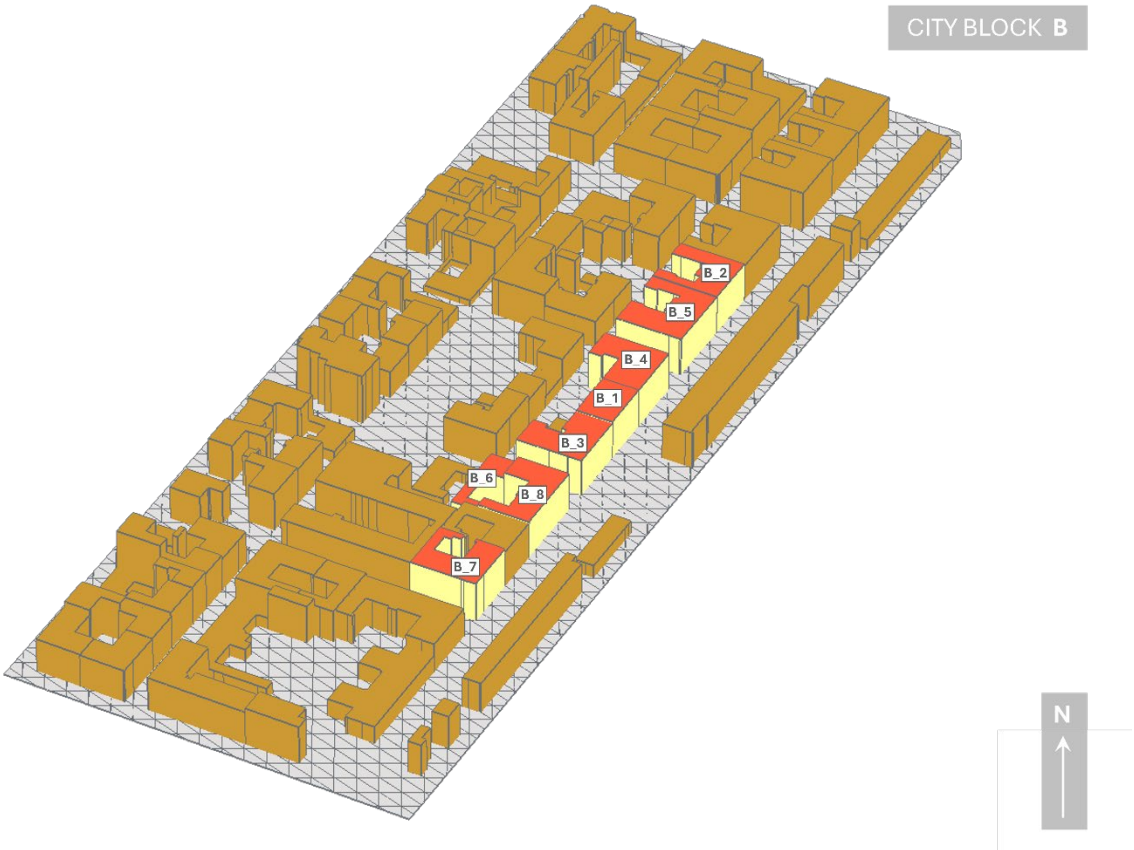

Figure 5: Urban block B (Turin) visualised in CitySim Pro

Table 3 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block B (Turin)

Bldg. code	Constr. period	A_{fl} [m^2]	A_{env} [m^2]	V [m^3]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m^{-1}]	U_{op} [W/(m^2·K)]	U_w [W/(m^2·K)]
B_1	1901-20	2909	2103	10179	16 %	0.207	1.50	3.10
B_2		4018	3558	14197		0.251	1.47	
B_3		4698	3969	15816		0.251	1.48	
B_4		4701	3922	16298		0.241	1.48	
B_5		5738	5050	19988		0.253	1.47	
B_6	1921-45	1804	2370	6351	14 %	0.373	1.45	3.09
B_7		4434	4036	15963		0.253	1.47	
B_8		4569	3968	15838		0.251	1.47	

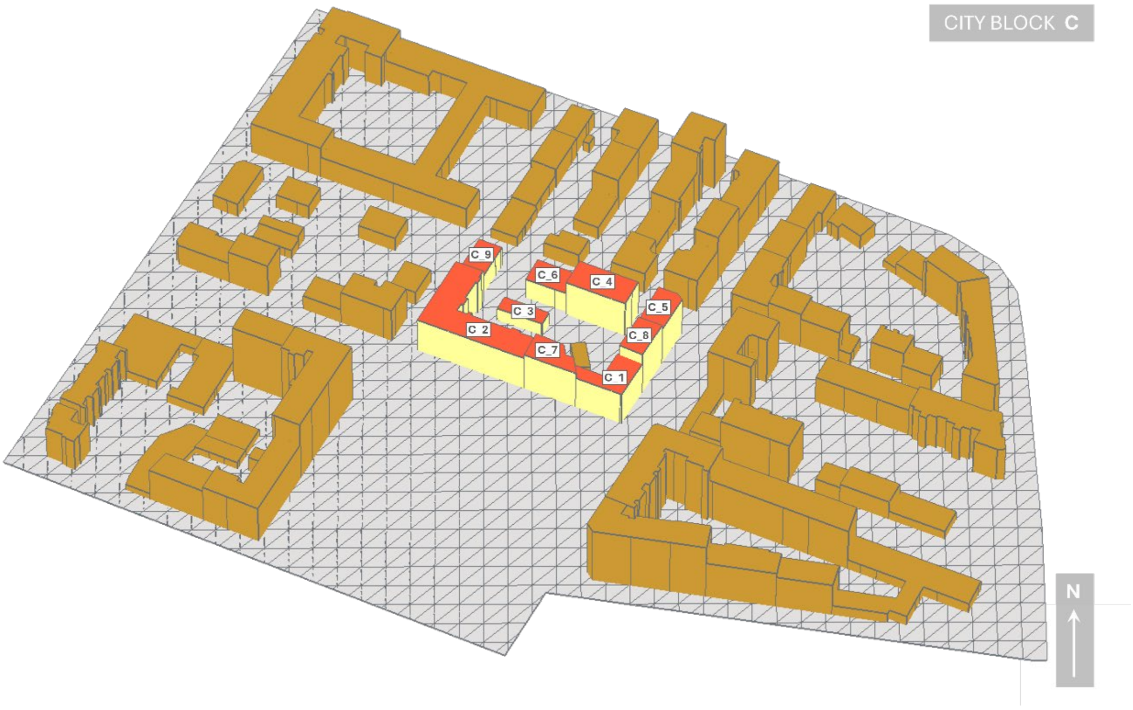

Figure 6: Urban block C (Turin) visualised in CitySim Pro

Table 4 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block C (Turin)

Bldg. code	**Constr. period**	A_{fl} [m²]	A_{env} [m²]	V [m³]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
C_1	1901-20	1440	1819	5328	16 %	0.341	1.45	3.10
C_2		5310	4854	17081		0.284	1.47	
C_3		278	682	1027		0.664	1.48	
C_4	1946-60	2103	2197	7149	13 %	0.307	1.30	3.12
C_5		1373	1584	5013		0.316	1.28	
C_6		678	1043	2645		0.394	1.36	
C_7		1355	1521	4854		0.313	1.28	
C_8		1312	1327	4593		0.289	1.27	
C_9	1961-75	681	1063	2589	10 %	0.411	1.25	3.16

3.2 Bari

Figure 7: Urban block A (Bari) visualised in CitySim Pro

Table 5 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block A (Bari)

Bldg. code	Constr. period	A_{fl} [m^2]	A_{env} [m^2]	V [m^3]	WWR [%]	$A_{env} \cdot V^{-1}$ [m^{-1}]	U_{op} [W/(m^2·K)]	U_w [W/(m^2·K)]
A_1	1976-90	595	3353	8922	18 %	0.376	0.93	3.70
A_2		233	1436	4655		0.308	0.92	
A_3		216	1474	5395		0.273	0.92	
A_4		124	533	1865		0.286	0.94	
A_5		148	660	2225		0.297	0.93	
A_6		604	3261	12075		0.270	0.93	
A_7		633	3756	12670		0.296	0.92	
A_8		311	2662	7778		0.342	0.91	
A_9		472	1453	4722		0.308	0.95	
A_10		305	1726	4580		0.377	0.93	
A_11		185	702	2768		0.254	0.94	
A_12		168	647	2515		0.257	0.94	
A_13		140	545	2107		0.258	0.94	
A_14		150	579	2247		0.258	0.94	
A_15		136	523	2039		0.257	0.94	
A_16		420	2570	8398		0.306	0.92	
A_17		100	472	1506		0.313	0.93	
A_18		102	685	2040		0.336	0.92	
A_19		147	648	2208		0.293	0.94	
A_20		274	1528	5485		0.279	0.93	
A_21		120	441	1200		0.367	0.94	
A_22		398	2615	7964		0.328	0.92	

Bldg. code	Constr. period	A_{fl} [m²]	A_{env} [m²]	V [m³]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
A_23		289	1209	5771		0.209	0.94	
A_24		723	4158	18074		0.230	0.93	
A_25		563	2254	14065		0.160	0.94	
A_26		620	2917	15493		0.188	0.93	
A_27		357	1762	5355		0.329	0.93	
A_28		177	791	1774		0.446	0.93	
A_29		336	2700	10081		0.268	0.92	
A_30		122	822	1836		0.448	0.92	
A_31		328	1799	6554		0.274	0.93	
A_32		408	2058	8153		0.252	0.93	
A_33		338	2777	10131		0.274	0.92	
A_34		595	3353	8922		0.376	0.93	

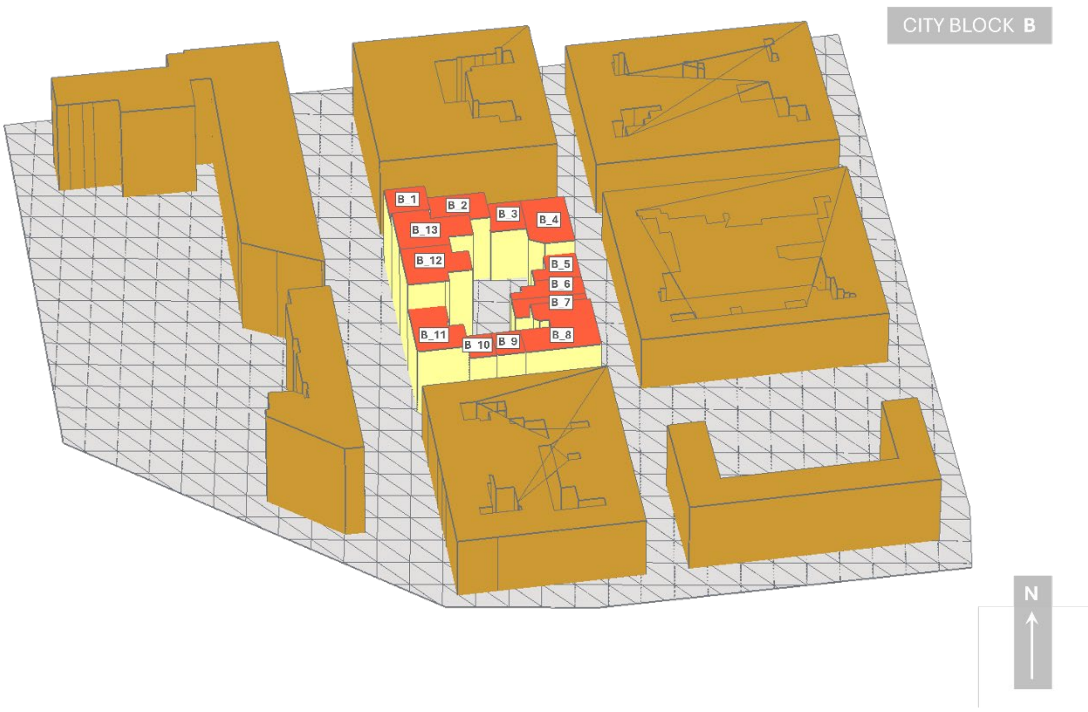

Figure 8: Urban block B (Bari) visualised in CitySim Pro

Table 6 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block B (Bari)

Bldg. code	Constr. period	A_{fl} [m²]	A_{env} [m²]	V [m³]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
B_1	1946-60	209	1576	6272	17 %	0.251	2.07	4.90
B_2		220	1456	5489		0.265	2.02	
B_3		148	772	2969		0.260	1.93	
B_4		287	1529	5733		0.267	1.94	
B_5		141	700	2113		0.331	1.91	
B_6		154	667	2311		0.289	1.84	
B_7		196	714	2933		0.243	1.75	

Bldg. code	**Constr. period**	A_{fl} [m²]	A_{env} [m²]	V [m³]	WWR [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
B_8	1961-75	438	2363	8760	17 %	0.270	1.27	4.90
B_9		92	541	1842		0.294	1.28	
B_10		88	521	1764		0.295	1.28	
B_11		272	1869	6807		0.275	1.29	
B_12		296	2378	10360		0.230	1.31	
B_13		323	2595	11322		0.229	1.31	

3.3 Rome

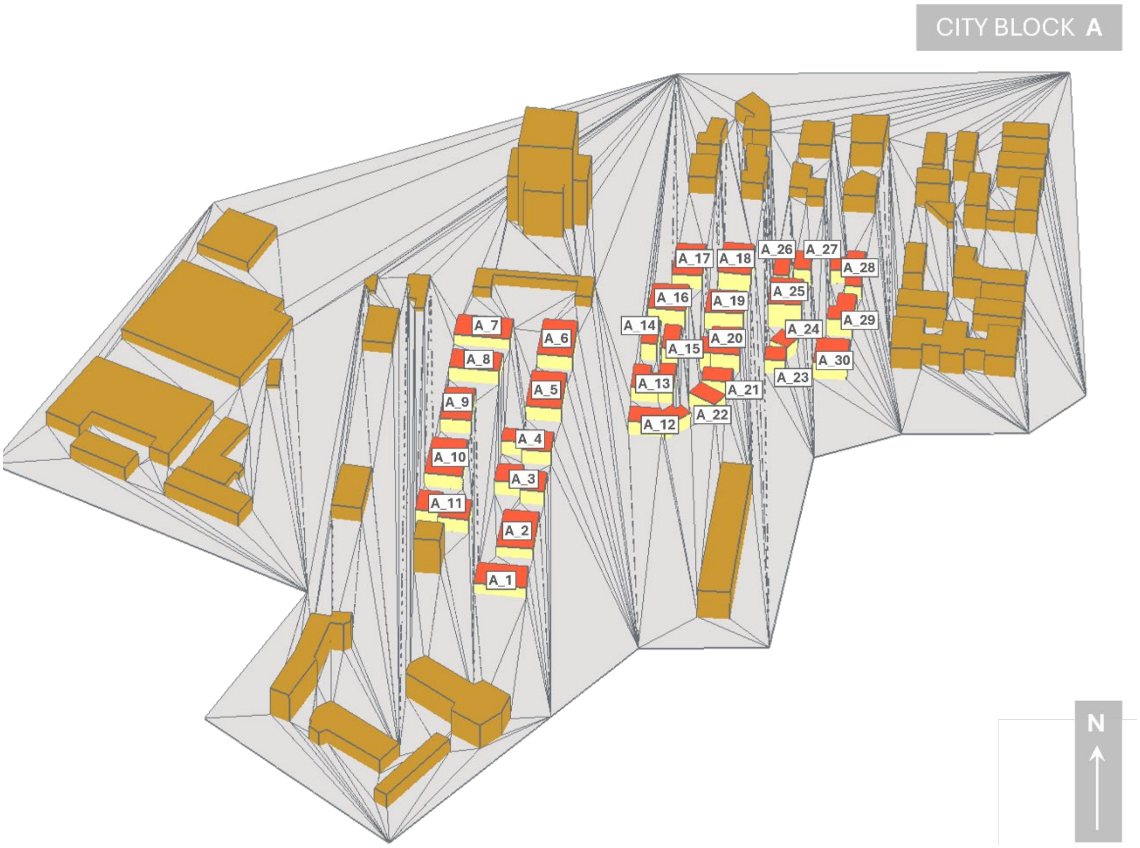

Figure 9: Urban block A (Rome, EUR district) visualised in CitySim Pro

Table 7 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block A (Rome, EUR district)

Bldg. code	**Constr. period**	A_{fl} [m²]	A_{env} [m²]	V [m³]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
A_1		1826	2141	5477		0.391	1.312	
A_2		2254	2506	6761		0.371	1.320	
A_3		1606	2372	6424		0.369	1.281	
A_4		1451	2174	5803		0.375	1.279	
A_5	1961-70	2915	2776	8746	16 %	0.317	1.301	3.65
A_6		2915	2776	8746		0.317	1.301	
A_7		2002	2316	6005		0.386	1.314	
A_8		1587	2224	6348		0.350	1.288	
A_9		2205	2254	6615		0.341	1.291	
A_10		3046	2867	9138		0.314	1.226	
A_11		1802	2562	7206		0.356	1.212	
A_12		1912	2269	5736		0.396	1.201	
A_13	1971-80	2248	2507	6744	11 %	0.372	1.207	3.70
A_14		1131	1416	3394		0.417	1.178	
A_15		1131	1416	3394		0.417	1.178	
A_16		2208	2515	8279		0.304	1.205	

Bldg. code	Constr. period	A_{fl} [m²]	A_{env} [m²]	V [m³]	WWR [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
A_17		2205	2254	6615		0.341	1.217	
A_18		2864	2599	8592		0.303	1.206	
A_19		2002	2351	7508		0.313	1.202	
A_20		2230	2616	8361		0.313	1.202	
A_21	1981-90	899	1189	2698	11 %	0.441	1.191	3.70
A_22		682	1205	2729		0.441	1.191	
A_23		475	922	1901		0.485	1.183	
A_24		439	874	1754		0.498	1.181	
A_25		3031	2901	10607		0.273	1.184	
A_26		917	1445	3439		0.420	1.177	
A_27		910	1196	2730		0.438	1.174	
A_28		1424	2253	5698		0.395	1.201	
A_29		1357	1892	5087		0.372	1.187	
A_30		2342	2237	7027		0.318	1.201	

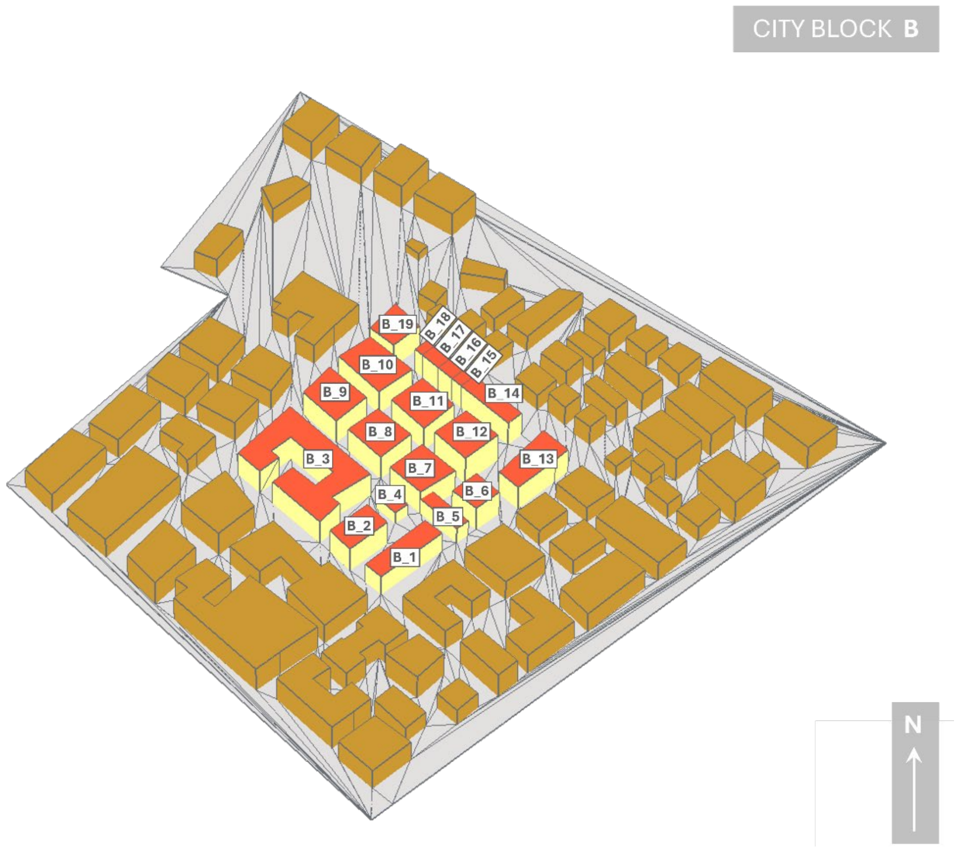

Figure 10: Urban block B (Rome, Nuovo Salario district) visualised in CitySim Pro

Table 8 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block B (Rome, Nuovo Salario district)

Bldg. code	**Constr. period**	A_{fl} **[m²]**	A_{env} **[m²]**	V **[m³]**	*WWR* **[%]**	$A_{env} \cdot V^{-1}$ **[m⁻¹]**	U_{op} **[W/(m²·K)]**	U_w **[W/(m²·K)]**
B_1	1919-45	2523	2646	7570	12 %	0.349	1.572	5.70
B_2		2088	2353	7516		0.313	1.545	
B_3		11524	9501	34571		0.275	1.595	
B_4		250	666	1124		0.593	1.565	
B_5		641	1172	2566		0.457	1.555	
B_6		1682	1768	5047		0.350	1.507	
B_7		3258	2671	9774		0.273	1.597	
B_8	1946-60	2657	2727	9564	12 %	0.285	1.489	4.90
B_9		3017	2989	10861		0.275	1.489	
B_10		3504	3340	12614		0.265	1.489	
B_11		3332	2811	9996		0.281	1.489	
B_12		3706	2993	11118		0.269	1.490	
B_13		3548	3078	10644		0.289	1.490	
B_14		1706	2129	6140		0.347	1.491	
B_15		330	380	1189		0.320	1.491	
B_16		604	580	1811		0.320	1.491	
B_17		572	660	2057		0.321	1.491	
B_18	1961-70	314	474	942	16 %	0.503	1.217	3.65
B_19		1860	2138	6695		0.319	1.253	

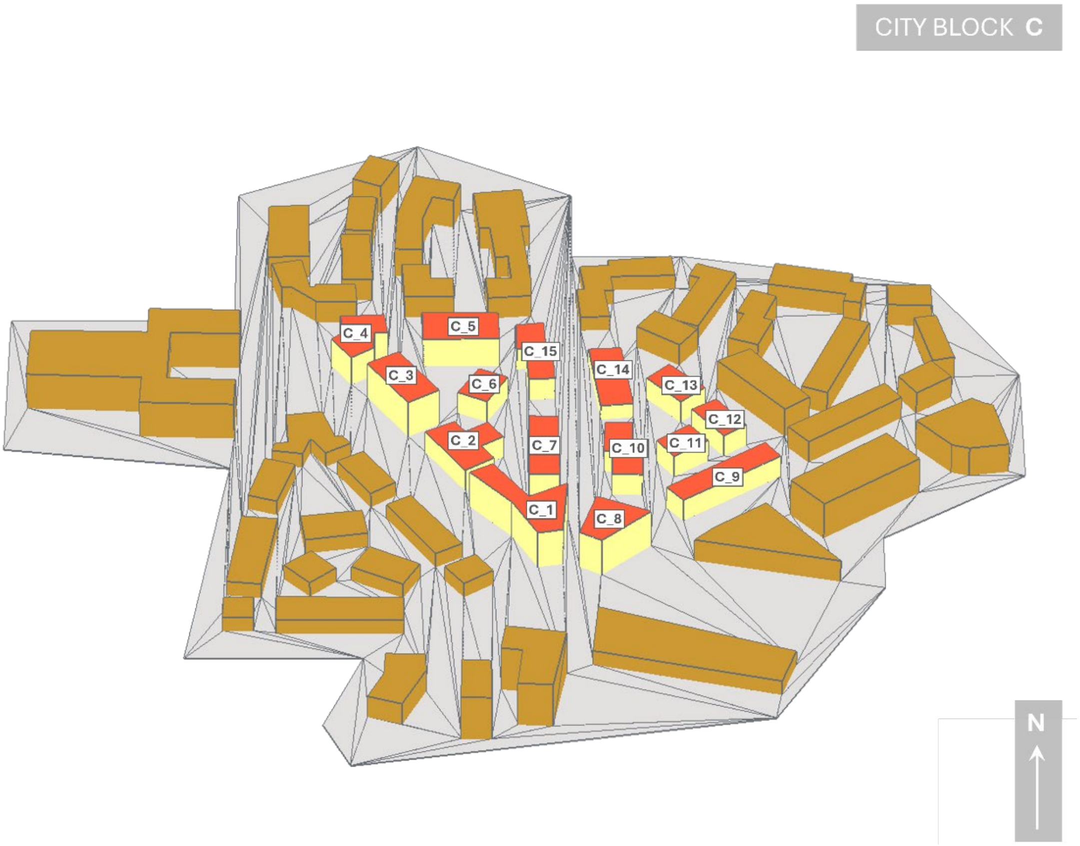

Figure 11: Urban block C (Rome, Garbatella district) visualised in CitySim Pro

Table 9 – Geometrical and mean thermal characteristics for opaque and transparent components for urban block C (Rome, Garbatella district)

Bldg. code	Constr. period	A_{fl} [m²]	A_{env} [m²]	V [m³]	*WWR* [%]	$A_{env} \cdot V^{-1}$ [m⁻¹]	U_{op} [W/(m²·K)]	U_w [W/(m²·K)]
C_1	1946-60	1844	2695	6914	12 %	0.390	1.491	4.90
C_2		1099	1541	3298		0.467	1.487	
C_3		1589	1773	4766		0.372	1.490	
C_4		1128	1451	3385		0.429	1.490	
C_5	1961-70	1151	1748	4606	16 %	0.380	1.278	3.65
C_6		330	798	1486		0.537	1.271	
C_7		635	1382	2859		0.483	1.283	
C_8		1158	1646	4344		0.379	1.254	
C_9		1098	1634	3294		0.496	1.280	
C_10		553	1291	2487		0.519	1.275	
C_11		443	739	1330		0.556	1.267	
C_12	1971-80	516	836	1549	11 %	0.540	1.199	3.70
C_13		389	904	1751		0.516	1.203	
C_14		347	1201	2082		0.577	1.236	
C_15		855	1334	2566		0.520	1.203	

4. GENERAL REMARKS AND CONCLUSIONS

This deliverable reports the main settings implemented in the framework of Task 3.2 as part of the modelling activity dedicated to build UBEM models in agreement with the methodology developed as outcome of Task 3.1. UBEM models were prepared in CitySim, i.e., the chosen Urban Building Energy Modelling code, and focused on the urban blocks selected in Task 3.1. This deliverable is also meant to provide guidance to replicate the implementation phase for additional case-studies, intended to progressively enrich and expand the atlas of typical urban configurations of interest for the study of the Urban Heat Island effect and the definition of mitigation strategies. Although the focus is put on the three selected Italian case-studies, future developments can indeed be based on other national locations, as well as on case-studies abroad of particular significance for the study of this urban phenomenon and the implementation of mitigation measures.

The second part of the deliverable includes the series of urban blocks in the cities of Turin, Bari, and Rome chosen in the Task 3.1 as representative and relevant for the study of the Urban Heat Island phenomena on these two municipalities. For each modelled block, the main features of the building envelope are reported for each encompassed building. Specifically, vintage, floor area, building envelope area, volume, compactness ratio, window-to-wall ratios, and average thermal transmittances of both opaque and transparent building envelope are described. Furthermore, each case is provided with a CitySim 3D picture meant to give an overview of the surrounding context and highlighting the street canyons bordering the analysed urban blocks. As a whole, reported building metrics and 3D models constitute the core part of the atlas of urban configurations to expand in the framework of the project and beyond.

NOMENCLATURE

Symbols

A	area [m^2]
U	thermal transmittance [W/(m^2·K)]
V	volume [m^3]
WWR	window-to-wall ratio [%]
ρ	reflectance [–]

Subscripts

env	envelope
fl	floor
op	opaque
w	window

Acronyms

BA	Building Archetype
LoD	Level of Detail
UBEM	Urban Building Energy Model/Modeling
UHI	Urban Heat Island

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