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Building archetype characterization for mass-housing energy efficiency through a UBEM approach

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Abstract. Building archetypes characterization is one of the main sources of inaccuracy in Urban Building Energy Modelling (UBEM). This study aims to implement an effective approach to developing a building archetype for estimating energy efficiency in social housing districts. The goal is to support researchers and decision-makers analyzing strategies for similar buildings, evaluate energy use in buildings, and design different retrofit scenarios. UBEM is a practical approach in large-scale building energy modeling used by researchers and stakeholders to analyze and develop different design and retrofit scenarios for buildings with similar construction features and occupancy. The archetype approach requires a subset of buildings representing a cluster with similar properties (e.g., building type, construction features, occupancy, and age), which is used to extrapolate the total energy consumption at the urban scale. The research focused on clusters of four in-line multi-story building types in Rome to conceptualize the study, characterized by reinforced concrete structures. The most diffused systems are the traditional building systems using a gas boiler and radiators for domestic hot water and heating. The model was implemented following a UBEM approach, relying on Urban Modeling Interface (UMI), a tool allowing the creation of building templates to evaluate their energy use at neighbourhood and city-scale. The overall results obtained in this study are described to characterize the archetype for the mass-housing building that researchers and administrations can use to evaluate different strategies for buildings with similar characteristics.

1. Introduction

Buildings significantly contribute to energy consumption in urban areas worldwide, and reducing energy usage in the built environment has become a critical objective in the face of climate change [1]. In recent decades, extensive research has focused on developing building archetypes, which is considered one of the most significant challenges in creating Urban Buildings Energy Models (UBEM) [2]. This study conceptualizes the archetype of mass-housing residential buildings in Italy, precisely, the linear multi-story building type. Mass housing neighbourhoods were widespread in the European peripheries between the 1950s and 1980s in the post-World War II urban expansion. The roots of the mass housing development can be traced to the process that ignited a rapid increase in housing demand: population growth and a shift of the population from rural areas to industrialized cities [3]. These buildings represented the face of a modern planning paradigm based on standardized and fast construction methods, envisioning the utopias of self-sufficient and experimental urban communities with high-density buildings integrating all the services for the inhabitants. However, the fast construction resulted in a vulnerability concerning the construction material's durability, often causing the energy inefficiency of the building envelope [4]. Mass housing in Italy has been mainly limited to public housing constructions, with notable experimental projects like Tor Bella Monaca and Corviale in Rome (1200 apartments for 4500 dwellers), Vele in Scampia (1192 apartments for 6500 dwellers), or the Rozzol Melara complex in Trieste (650 apartments for 2500 dwellers). For this article, we focus on four examples in Rome: Tor Bella Monaca, Tor Sapienza, Quartaccio, and Laurentino 38 (Fig.1) to characterize an archetype of the linear multi-story building produced in the mass housing's scope for urban energy modeling.

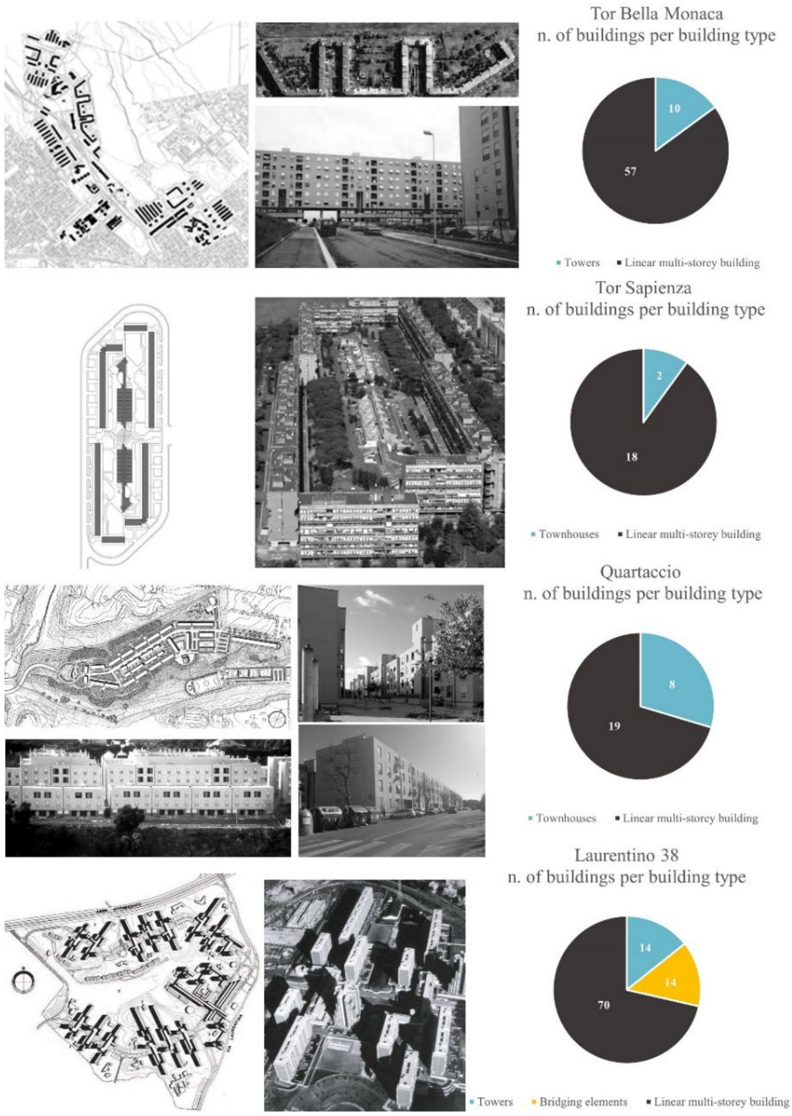


Figure 1. Case studies used to characterize the archetype

In Rome approximately 400.000 inhabitants live in low-cost social housing schemes constructed in the same period of the considered cases, hence the reason to focus on social housing and a fortiori, on the linear multi-story building that represents a considerable share, as expressed in Figure 1.

2. Methodology: characterization of the building archetype

Once the building type has been identified, the subsequent step is to collect data on several buildings belonging to the same building type to develop an archetype [5]. This involves collecting data on building systems, building materials, energy consumption, and occupancy. For this study, we relied on the workflow in Fig.2 to characterize the archetype of linear post-war mass social housing. Specifically, we gathered the above-mentioned necessary data for Tor Bella Monaca, Tor Sapienza, Quartaccio, and Laurentino 38. The data were analyzed using statistical methods to identify patterns and relationships between different variables and key factors influencing the archetype design. For example, regression analysis can be used to identify the relationship between building size and energy consumption, while cluster analysis can be used to group buildings according to construction materials or design characteristics. For the archetype in this study, the principal components were analyzed to assess the most recurring characteristics statistically, as suggested by the consolidated methodology to build archetypes. Drawing from real data, we conceptualized two tables regarding the characteristics of the cluster of buildings used in the statistical analyses (Table 1; Table 2). The first table contains information related to the architectural and urban aspects, while the latter contains data related to energy consumption.

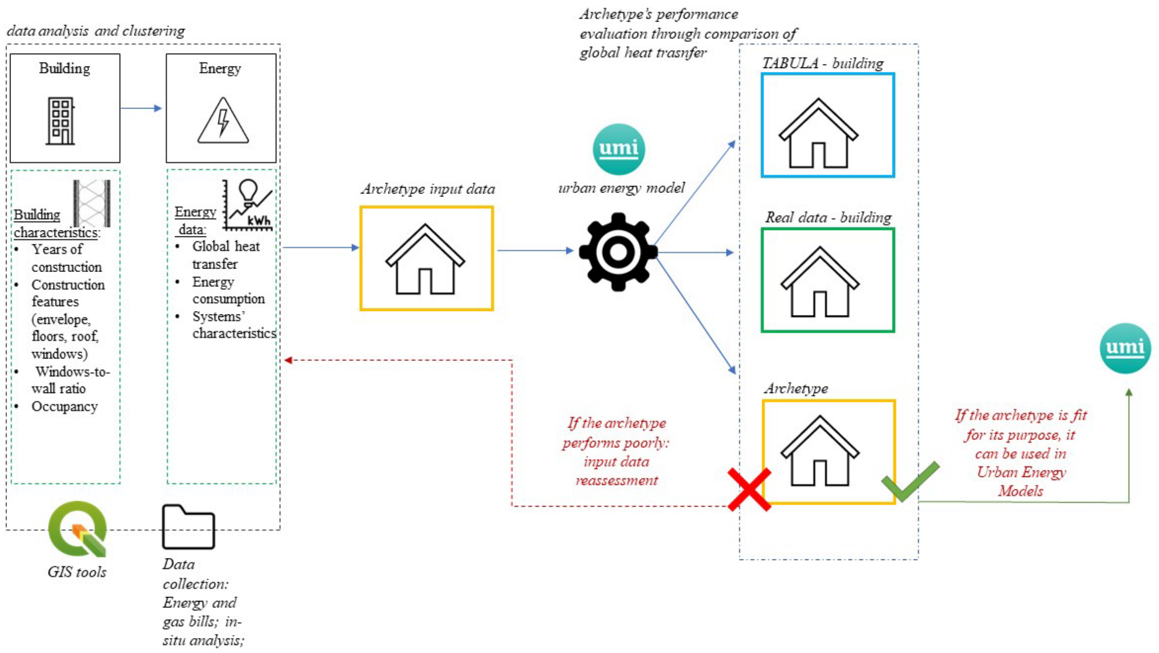


Figure 2. Proposed methodology workflow

Thirty-six building transects were analyzed from the selected cases; the building module represents the portion of the building that includes all the apartments that access the same stairway. In detail, for Tor Bella Monaca, fourteen building modules composing the R5 compartment were studied; for Tor Sapienza, seven modules and for Quartaccio and Laurentino 38, six modules each. The architectural and urban data table includes information such as the building's height, number of floors, total area, and usage type. This data was obtained through on-site surveys and a review of relevant documentation. The energy data was collected using a combination of on-site measurements, energy bills, and analysis of the building's mechanical systems. The table includes data related to the building's energy sources, such as electricity, gas, and oil, as well as information on the building's overall energy consumption. Although the comprehensive data collection process, including every data point in the tables, was impossible due to practical constraints, only a single representative building was included in the tables. The data can identify trends, benchmark performance, and inform policy decisions related to energy efficiency and sustainable urban development.

Table 1. Architectural and urban data[1]

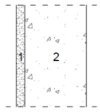
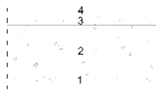
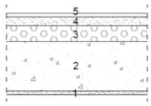
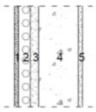
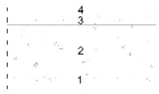
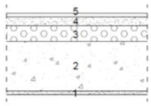
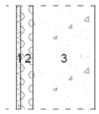
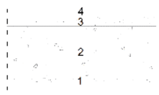
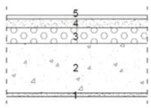
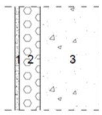
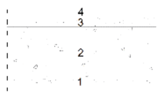
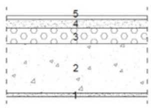
Urban Area	Construction years	Floors	n° of dwelling	Average size [m^2]	Area [m^2]	Occupancy [people/ dwelling]	Wall type	Floor type	Roof type
Tor Bella Monaca	1981 – 1983	7	34	58	1972	4			
Tor Sapienza	1974 – 1979	6	24	95	2280	5			
Quartaccio	1985 – 1988	4	25	73	1825	4			
Laurentino 38	1976 – 1984	8	29	65	1885	5			

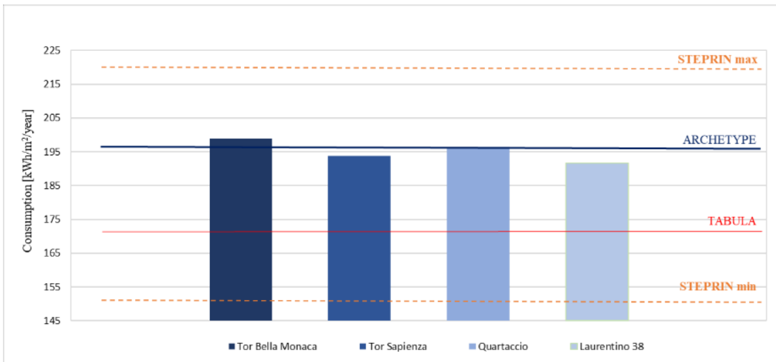
Table 2. Energy data

Wall heat transfer coefficient [kWh/m^2/ year]	Tabula value [kWh/m^2/ year]	Normative value [kWh/m^2/ year]	Glass heat transfer coefficient [kWh/m^2/ year]	Glass surface [%]	Energy system	Consumption [kWh/m^2/ year]	Energy label kWh/m^2/ year	STREPIN kWh/m^2/ year
0.65	0.66	< 0.36	6.3	48	Natural gas boiler, radiators	198.9306	G < 160	160 < x > 220
0.70	0.66	< 0.36	6.3	38	”	193.7456	”	”
0.72	0.66	< 0.36	6.3	37	”	196.3862	”	”
0.62	0.66	< 0.36	6.3	33	”	191.6587	”	”

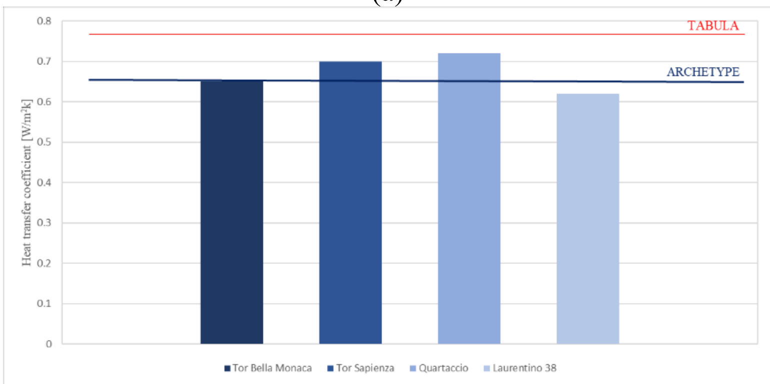
In order to obtain a representative archetype from an energy standpoint through data analysis, a weighted average was calculated to evaluate the average energy consumption [kWh/m^2/year] of the urban areas

[1] **Wall type**:Tor Bella Monaca: (1) plasterboard [2cm], (2) cast-in-place reinforced concrete [15cm]; Tor Sapienza: (1) plaster [1cm], (2) concrete mortar [3cm], (3) polystyrene [2cm], (4) cast-in-place reinforced concrete [10cm], (5) plaster [1cm]; Quartaccio: (1) plaster [1cm], (2) polystyrene [3cm], (3) cast-in-place reinforced concrete [15cm]; Laurentino 38: (1) plaster [1cm], (2) polystyrene [5cm], (3) cast-in-place reinforced concrete [15cm]. **Floor type:** (1) plaster [1cm], (2) cast-in-place reinforced concrete [18cm], (3) self-levelling scrab [2cm], (4) tiles [1cm]. **Roof type:** (1) plaster [1cm], (2) cast-in-place reinforced concrete [15cm], (3) rigid insulation [4cm], (4) self-levelling scrab [2cm], (5) external tiles [1cm].[1]

under analysis. The resulting archetype falls under the G energy label due to its construction characteristics and the use of technologically obsolete systems. As an innovative step, we compared the archetype with the standard issued by the Ministry of Environment and TABULA [6] data; the consumption is found to be within the average of residential buildings in the same climate zone and built during the same period (Fig. 3a). A similar approach was applied to the global heat transfer analysis (Figure 3b). We considered the representative envelope stratigraphy of each building to structure the building template. As a result, the average value of the archetype's global heat transfer is slightly lower than the values in TABULA for buildings with similar characteristics.



(a)



(b)

Figure 3.(a) Energy consumption analysis for the case studies (b) Global heat transfer analysis

Thus, even if the envelope of the proposed archetype performs better than the TABULA archetype, the latter manages to consume less energy annually, expressed in kWh/m^2. The more accurate outcomes are derived from the occupational study and the use of heating and hot water systems. In order to obtain such accurate data, multiple bills were examined to assess global consumption. This survey showed that the heating radiators are centralized and switched on simultaneously throughout the building for a preset time duration. The usage and occupancy parameters were used to input information into the UMI building template for the archetype setting to reflect the urban energy situation.

3. Results and discussions

Based on the data of the analyzed buildings, we compared the archetype drawn from the analyses, analysis, the Tabula archetype, and a building characterized by the real data from a case study through UMI [7]. Tabula provides different types of residential buildings for each European country, classifying them according to the year of construction, typical energy consumption values, and architectural characteristics. The building in this database that best represents the building typology in this research is the archetype "IT.MidClim.AB.06.Gen"; in terms of plant systems, it is similar to the analyzed buildings but has fundamental differences concerning energy consumption and architectural characteristics of the building envelope. The following table (Table 3) compares the Tabula archetype with the proposed archetype and actual building data.

Table 3. Energy comparison between archetypes and real data

	Tabula IT.MidClim.AB.06	Archetype	Real data
Global heat transfer [W/m^{2}k]	0.76	0.67	0.65; 0.60; 0.72; 0.62
Consumption of DHW [kWh/m^2/a]	49.61	55.95	56.58; 55.11; 55.86; 54.51
Consumption of Heating [kWh/m^2/a]	91.4	103.17	104.33; 101.61; 102.99; 100.52
Consumption Elecrticity [kWh/m^2/a]	33.39	37.61	38.02; 37.03; 37.54; 36.63
Total Consumption [kWh/m^2/a]	174.4	196.73	198.93; 193.75; 196.39; 191.66

This further comparison provides valuable insights as the archetype in this study is more punctual than the reference building on the online web tool for the Italian building stock. The reason lies in the in-depth definition of a very specific building typology, where the constructive and energetic characteristics were explored in depth. Representative archetypes are crucial to aid planners and decision-makers in simulating different energy retrofit scenarios in each climatic context to reduce overall energy consumption and global CO2 emissions following the targets imposed by Europe [8].

4. Conclusions

In conclusion, this study presents a generally applicable method to characterize building archetypes and provide more accurate insights into specific building typologies' energy and architectural characteristics. Despite the comparison to assess the fitting of the archetype being performed with Italian regulatory references, it can be reproduced by replacing them with local references, while TABULA serves as a general source for the European building stock. Indeed, the proposed digital methodology can be replicated at different scales to define a new archetype - having available real input data - or to simulate the energy behaviour of an urban context in different climate zones. Furthermore, the present study highlights the necessity of implementing a more detailed national database of reference buildings to reduce uncertainties in UBEM simulations. Additionally, a current limitation is the lack of precise data concerning energy consumption; institutions should promote data exchange to decarbonize the outdated building stock.

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