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# A Geographical Abacus of the Urban building heritage based on Volunteered Geographic information (VGI)

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**Abstract.** This paper describes the preliminary result of the research project "Urban Abacus of Building Energy performances (Abaco Urbano Energeticodegli Edifci – AUREE)" aimed at supporting the renovation and energy efficiency enhancement of urban building heritage financed by Ricerca Sistema Elettrico (MISE) program. The AUREE concept is a Web – GIS GeoBlog portal with some customized interfaces aimed to share the knowledge on urban building heritage and promote the participation of the stakeholders of the urban community. The methodological approach is specifically addressed to small and medium Mediterranean urban contexts that are characterized by a lack of baseline data. It is characterized by the implementation of a simple analytical Urban Building Energy Model (UBEM) based on spatial Open Data, typological study of the local building heritage and a web-based participative framework. After a touch on the theoretical context, the paper presents the general framework of the AUREE project and then focuses to the methodological approach for some participative interfaces. Via an experimentation on the city of Carbonia (Sardinia, IT), the paper presents an archetypes approach based on historical information that provides an exhaustive segmentation and classification of the urban building stock. They are the necessary basis for the UBEM and for the knowledge structure for the Geographical Abacus aimed to support homeowners on the early step of a building renovation decision.

**Keywords:** Building Energy Retrofit, UBEM,VGI, GIS.

## 1 Introduction: theoretical context

Energy efficiency enhancement of urban areas is a major key point of the EU 2020 objectives in the new climate package for 2030 because the European building stock is responsible of about 40% of emissions. New buildings and new energy retrofitting

technologies are characterised by high performances, but, due to the high presence of old and inefficient buildings and the growing of the consumption the average energy need value of the European building stock is still about 200 kWh/m² per year [1].
Developing an urban strategy is considered essential to increase the efficiency of the building heritage because could channel the private investments and public financial resources on a holistic urban transformation design programs. But generally, the renovation of this huge and old building stock is only managed by the homeowners, supported by more or less effective national incentives that not consider the local building heritage peculiarity.

There are many literature exempla of guidelines or quality protocols about building heritage renovation and a lot of them focuses on energy efficiency enhancement [2] [3]. These are generally documents developed for a purely technical audience, that often, due to their intrinsic specificity, have difficulty in spreading even among operators in the construction industry and are almost unknown to non-technical citizens. The lack of shared knowledge between construction industry operators and non-technical actors about the building heritage is considered one of the main barriers in the recovery process [4].

In order to overcome these barriers, the development and testing of methodologies and supporting tools are becoming increasingly important. They include methodological procedures and technical tools aimed to link the perspective of the single building design process with the strategies at urban or neighbourhood scale and to promote the participation of all the local actors involved on the building stock renovation process. Thanks to the growing of geographic open data availability, examples of methodologies for supporting urban energy planning are increasingly numerous. Most of these are Urban Building Energy Modelling (UBEM) approaches [5] aimed to define the buildings stock energy needs and estimate the potential (theoretical, technical, and exploitable) of various efficiency technologies and/or design scenarios. In general, complex models could obtain more reliable results but require more data and onerous results analysis activities. Less complex models adopt several simplifying hypotheses, therefore they require fewer resources, and have usually more repeatable procedures. However, the uncertainty of the initial assumptions could, in this case, burden the results. One of the most used simplifying approaches is the "archetype", which involves a study of a representative sample of the heritage, in order to explicate some elements that characterize the energy need, and the use of appropriate methods (analytical, statistical, etc.) to extending the results of the sample to all similar buildings in the city. Some recent UBEM bottom – up approaches addressed to urban scale [6] adopt appropriate statistical calibration technique based on energy consumption data to improve the reliability of the results of the energy simulation. These tools focus on the energy demand estimation and, in order to limit the burden of the pre-processing activities, the physical input data on building heritage are highly typological. This approach could miss some important knowledge on architectonic characteristics and uses that are important to define reliable retrofitting hypothesis linked to local market. Moreover, although the spreading of smart metering systems, the energy consumption data generally are not easily available with a proper spatial and temporal details for all the cities contexts. The UBEM approach must be consistent to the tool purpose, to base data availability and economic

and human resources, therefore the developments and testing of methodologies and new application that could be exported also on the more common urban planning practice is still an open field of research.

The aim of the AUREE Project (Urban Energy Abacus of Buildings) project is to develop and test a tool to support energy efficiency and renovation process of the building heritage based on a portal (Web - GIS, GeoBlog) which contains some specific interfaces aimed at sharing the knowledge of the building stock and promoting the participation of the local stakeholders.

Via the development of the Carbonia's case studio, the objective of this work is to develop and archetypal study , based on historical information, that provides an exhaustive segmentation and classification of the building stock. It will be the basis to create an interactive, spatial based and self updating Abacus of the building heritage. The descriptive approach of the heritage proper of the definition of construction guidelines is coupled with an easy urban energy model that could calculate the performances of more common building retrofitting scenarios also taking to account Volunteered Geographic information (VGI) provided by the stakeholders interactions trough the portal.

The paper presents first the general framework of the AUREE project that encompasses some layers about public building, residential heritage and others addressed to interact to local stakeholders. Then the peculiarities of the Carbonia's case study and the methodology for the archetypal segmentation are presented. The result section describes the structure of the Abacus interfaces and the relationship to the archetype definition and the participative based data. The methodology experimentation has been carried out on the city of Carbonia because it is a fascist's new town (1938) characterized by a rather homogeneous built heritage that is well documented on local urban planning tool and literature. At the end of the paper, the main critical aspects and the further step of the research project are pointed.



## 2 The AUREE general framework

The methodology is mainly designed for small and medium-sized Italian cities and is based on information sources commonly available in the national territory such as: geographical OPEN data (regional GeoDB, ISTAT data, ...), knowledge of the building heritage linked to local urban planning and thematic disciplinary references (technical regulations, scientific studies and gray literature, ..). These data may be integrated with expeditious urban survey activities that are commonly implemented in the modern urban planning practices.

The methodology consists of an analysis and representation protocol of the building heritage on a geographical basis, combined with a tool for communication and involvement of local actors developed on the WEB GIS portal organized in three main sections that contain the information bases of the portal and some specific interfaces for interaction with local actors (see fig. 1):

- Public buildings: it constitutes a support tool for energy management of the public buildings but also a tool for sharing the values of the public buildings heritage and to promote the transparency of energy uses;

– Residential heritage: contains the spatial representation of the energy performance of the building heritage and aims to directly involve the occupants in providing information on their home in order to have suggestions for specific retrofits in exchange;
– Geographical Abacus: collects and reorders knowledge on recurring elements of the building heritage on a GIS framework ,favouring its dissemination among construction industry operators but also to a non-technical audience.

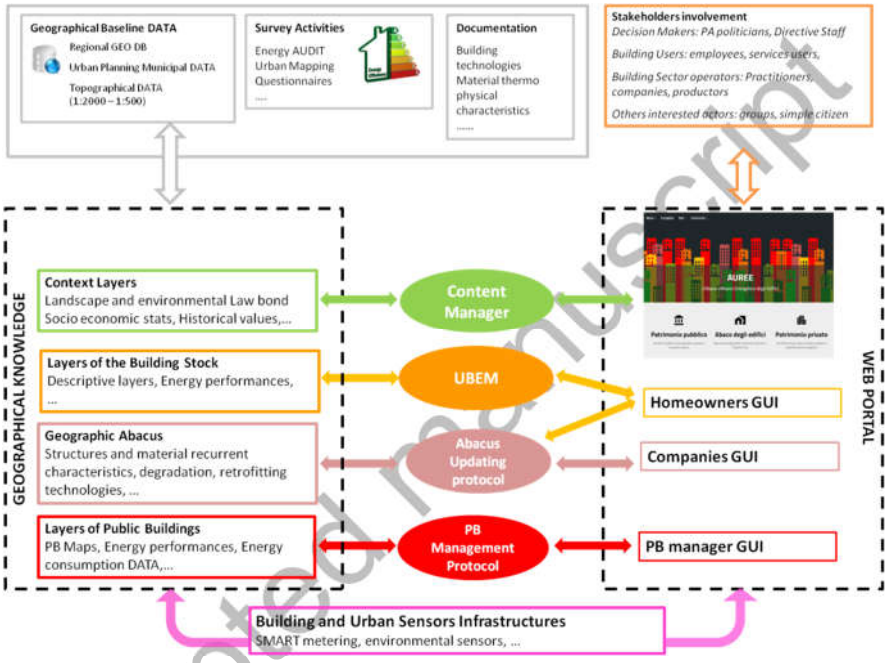


**Fig.1.** AUREE general framework

In addition to these sections connected to specific interfaces, it is then possible to consider all the context layers, even if not directly linked to the aspects of energy efficiency, which can however influence the renovation potential (regulations, demography data, ...). This is not a simple collection of regulatory constraints, it is an open set of themes that creates a shared background knowledge among decision makers and other stakeholders to direct towards the development of holistic approaches to urban planning.

In the case of public buildings, a protocol based on energy audit procedures and sensors monitoring is proposed. This approach aims to geographic representation and sharing of energy data and building values (transparency of Public energy uses), and at supporting the phases of project, construction, monitoring and management through BIM approaches.

For residential built heritage, an approach based on the study of building typologies and its recurring elements is proposed, coupled with the development of an Urban

Building Energy Model (UBEM), useful for assessing the energy retrofit potential of the building heritage.

The abacus is a spatial database that contains the typological information of the recurring elements of the building heritage (structures, systems, usage profiles, and retrofit interventions) linked to the geographical reference element (the building footprint). It aims to support the project activities and the preliminary evaluation of various alternative of building renovations through the geographical representation of the most widespread architectures and the proposal of adequate technologies related to the local market.

The research purpose is therefore to define in detail the procedures and tools that connect the different thematic contents (public buildings layer, building heritage layer, geographical abacus, context layer, data collected by the sensors) to the representation and interaction with local actors through the portal (see fig.1.).

This article focuses to the methodological approach developed for the Abacus of the residential building heritage with its relations with the participatory interfaces, leaving the description of the UBEM algorithms and of the other elements of the AUREE project to furthers publications.

## 3 Carbonia case study

Carbonia (about 27000 inh. ISTAT 2020) is a southern Sardinian (Italy) company town, founded starting from 1937 by fascist regime (see fig.2). It has a very peculiar building stock, mostly designed and built in a few decades, an emblem of 1930s industrial modernization in Sardinia.

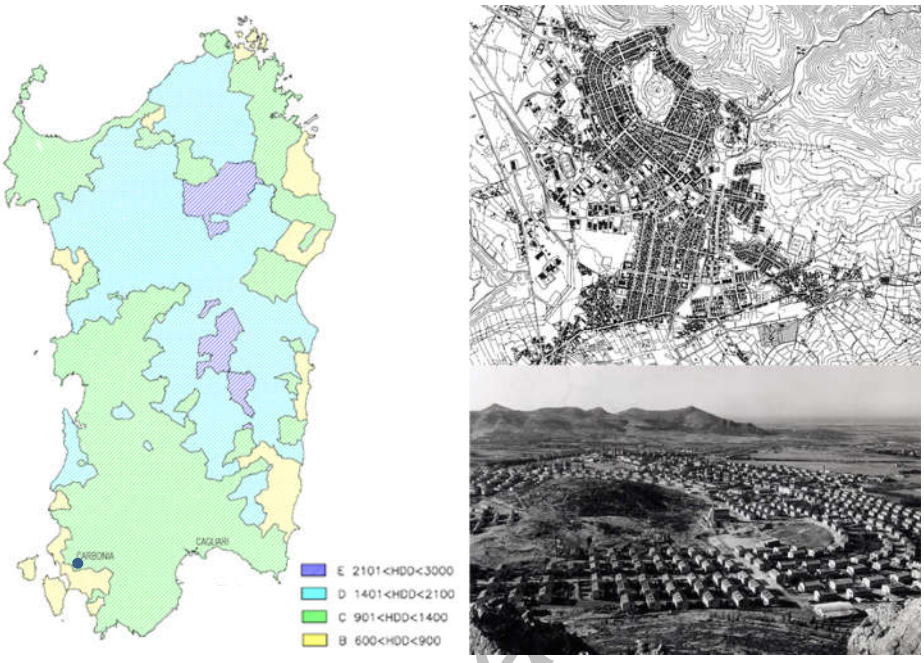


**Fig. 2**. Left: Geographical position of Carbonia and climate classification of Sardinian territory. Right: Current plan of Carbonia (up) and historical view of the foundation period (down).



The reasons for the foundation of Carbonia was the discovery of the massive coal deposits in Serbariu, and more upstream in the regime's desire to build an autarkic coal district able to answer the nationwide issue of energy sources. Before the discovery of Serbariu's mine, the only settlements present in the area were sporadic nucleuses of rural houses called "medau". Their construction probably dates back to the eighteenth century, when the occupation of Sardinia by the Duchy of Savoy favoured a repopulation of the countryside. One of the biggest aggregations of medau was precisely in Serbaiu [7].

The construction of the company town can be divided in two phases. The project of the first one provides for a population of 12,000 inhabitants, began in 1937 and concludes at the end of 1938. Shortly afterwards the inauguration, it started the construction of the second-phase project that was expected to welcome 50,000 residents and would have ended in the immediate post-war period. The outcome is a company town at the mouth of the mine, formed by the serial repetition of few building types, still inhabited nowadays.

In the first phase, a series of workers' lodging types was built. They consist mainly of two-storey four-family homes surrounded by a garden and designed in the forms of "autarkical rationalism", a sort of local version of the typical English cottage.In the second phase, on the other side, prevailed more intensive multi-storey buildings.

The peculiarity of the "autarkic project" emerges in the construction techniques. Masonries are always realized with local volcanic stone, called (inappropriately) trachyte, with only one example of reinforced concrete frame, in some of the buildings of the

late typologies. Different technologies of horizontal enclosure were adopted, ranging from vaulted floors with cement bricks produced on site, to concrete floor of "Sap-type" or "Rex-type", both made of prefabricated beams with few steel reinforcements [8].
After the fall of fascist regime, the property of the built heritage was transferred from the coal company to the public building institutes. From that moment the evolution of the urban settlement reflects the one of every other Sardinian small town. The areas surrounding the company centre are characterized by private buildings that can be classified within the most common types of the period 1950-2000. The historical typologies of foundation period have been partially sold to the original tenants and now represents a problematic mixture of public and private property.

The peculiarity of Carbonia requires an adaptation of the standard model of buildings stocksenergy classifications by archetypes. Generally, they follow four steps: segmentation, characterization, quantification, and validation of the final energy demand for a reference year.In the segmentation process, the number of archetype buildings required to represent the building stock of the country is determined. The number of archetype buildings is obtained from the combination of the different segmentation criteria, such as building type, construction year, main HVAC system and climate zone. In the characterization step, each archetype is described by its technical characteristics. The quantification step determines the distribution of archetype buildings in order to be representative of the building stock. To validate the building stock aggregation, the final energy demand is calculated using the defined archetype buildings as input to the model and comparing the results with corresponding values of energy use found in national and international statistics for a particular reference year [9] in case of a single urban centre the climate characterization is unique.

The choice of archetype for the segmentation phase can follow three criteria: the use of real buildings, the creation of example buildings and the creation of a synthetical average building. In the first, it is required the selection of a real existing building representing the most typical buildings in a specific category. The selection process is performed through a statistical analysis to find out the real building with characteristics like the mean geometrical and construction features of the statistical sample. In the second, it is necessary the creation of a virtual building which for each relevant parameter includes the most used material and systems based on expert inquiries and other sources of information. It is used in case of no statistical data are available. The third approach foresees the creation of a virtual building which for each relevant parameter includes the most used material and systems using basic statistical data. It is a statistical composite of the features found within a list of buildings in the stock [10]. The results of segmentation and classification of Carbonia's building stock are presented in the following section.



## 4 Results and discussion

The case of Carbonia required a specific approach that is a synthesis of the previous ones. Due to its particular history, the age of the buildings is very characterizing. At the moment, only the residential buildings segmentation phase has been carried out. Three

periods have been identified: pre foundation (1700-1937), foundation (1937-1950) and post foundation (1950-now). The choice of archetypization methodology differs by age of construction. In the first period only one type (medau) have been identified. It is an example building. Its features have been derived by historical studies [9]. The typization of buildings from the foundation period is quite peculiar. Each building is a model repeated numerous times. The models are real building types that not only represent the building stock but are the whole building stock themselves. Fifteens models have been identified. The studies conducted on the heritage to ensure its conservation are precious sources for its constructive features [10]. For the residual part of the urban stock, i.e. the post foundation, an example building methodology has been chosen. The most common post war types have been identified. They are semi-detached or isolated houses, detached houses, linear multi-storey, block multi-storey and tower multi-storey. For the definition of constructive features an experts based approach has been adopted. The proposed technologies have been verified with the limits imposed by Italian energy performance legislation, starting from 1976.

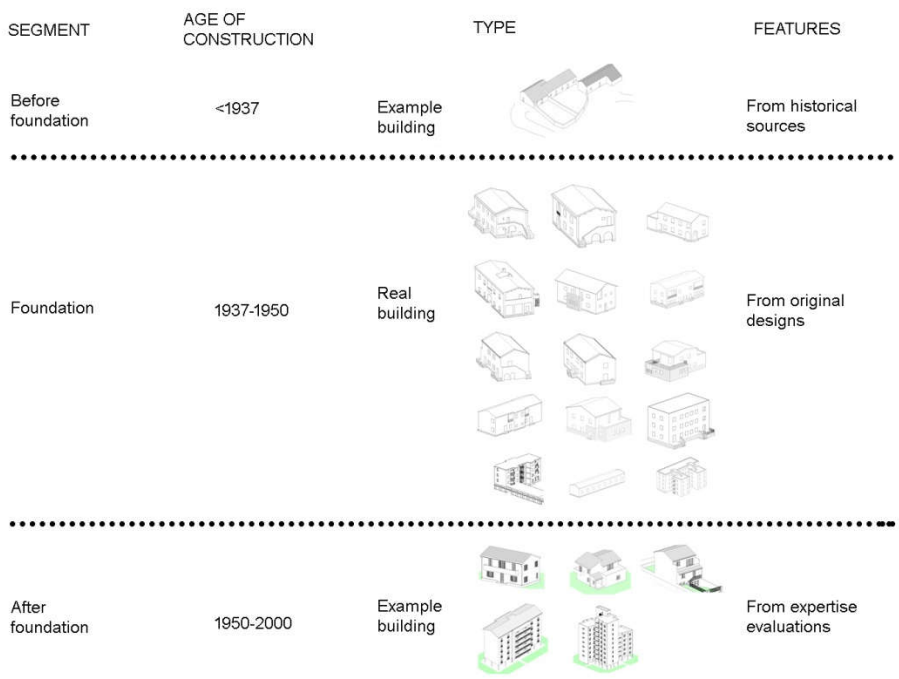


**Fig.3.**Framework of the archetypal approach

The representation of the energy characteristics of the residential built heritage is based on the study of building typologies and its recurring elements (Abacus) coupled with the development of an energy model at the urban scale (Urban Building Energy Modeling - UBEM), useful for preliminary evaluation the retrofit potential of the building stock. The Abacus and the Residential Heritage sections are strongly linked, in fact they are different representations of the same set of information based on: typological

studies, UBEM results and data from participatory interfaces. Thanks to the processing capabilities typical of the GIS environment, an engineering UBEM has been set up which adopts anarchetype approach capable of calculating the energy performance of each building on the basis of:

- the geometries obtainable for each building from the topographic basis (dispersing surfaces, volumes, ..);
- the typological characteristics of the building envelope and of the more common plant systemson the local context adopted to classify the entire residential heritage;
- a simplification of the calculation algorithms proposed by current technical standards (UNI TS 11300 series) [11]

In this way, thematic maps relating to the energy performance of the heritage are obtained, the occupants of the homes, aftera profile registration, could use it to access a specific interface. The interface shows the information of the typological study and the preliminary results of UBEM, but asks the user to answer a questionnaire concerning some characteristics of his real estate unit and his profile of use (presence, time, comfort, ..). These answers will be combined to UBEM results both to generate advice for specific energy retrofit actions and to modify the statistics that are the basis of the UBEM itself and the contents of the Abacus (for more detail on questionnaire see https://www.auree.it/).

As already mentioned, the Geographical Abacus is a spatial information database that collects and represents the knowledge on the recurring elements of the building heritage that are also at the basis of the development of UBEM, favouring its dissemination among operators in the sector and non-technical recipients, facilitating the link between market offer and demand. On this section the users can consult the map of building archetypes and learn through a structure organized by successive levels of knowledge detail (see fig. 4.): from the essential notions inherent to building efficiency and retrofit technologies up to the technical requirements addressed to a technical user. In other words, the disciplinary contents of the Abacus are similar to those of a technical and / or construction guideline, structured however as a spatial based multimedia hypertext that facilitates consultation. In fact, the information contents of the Abacus derive largely from typological knowledge approach carried out on the local context, but also integrate some UBEM results, and voluntary information deriving from the feedback from portal users. In order to fulfil the privacy regulatory framework, the complete answers of the questionnaire will be visible only to the user who completes it, only statistics by type and reprocessed representations by value classes will be included in the Abacus.

The first page, accessible to all users of the portal, presents a map of the study area where it is possible to select a building of interest, and access to a summary page dedicated to the archetype of the selected element (level 1). In the home, may also be present layers directly dedicated to the building elements (roof, wall, ..) that allow you to go directly to level 2 of knowledge. Level 2, still mainly dedicated to non-technical users, acts as a hub to explore the various issues related to the efficiency of building. Some contents that are characterized by less variability in context of study, are directly

linked to the typological studies (structures of the building envelope). For the others that show more variability (as: type of windows, plants, profile of uses, ..) the interface report typological information improved with the statistics from the questionnaire for the selected archetype. From the thematic pages (level 2) it will then be possible to access to others interfaces (level 3) with more technical content such as in-depth information on retrofit technologies and typological efficiency scenarios, as well advice addressed to the occupants. From level 2 onwards, it will be possible to access a menu to contact local companies registered on the portal, linked to some specific services.The construction industry operators will be able to register on the portal by filling a profile form in a specific section where they can list the services offered and enter any local success stories in the use of innovative technologies or design approaches. If contacted by the owner, they will be able to access a summary sheet of the essential characteristics of the building and through the portal they will be able to develop a more in-depth knowledge of local services demand in order to better calibrate their offer.

The experimentation in a case study of excellence, that is so rich in information on the building heritage, will allow to define in detail the procedures and tools that connect the different thematic contents, to refine the representation aimed at interacting with local actors through the portal. The approach is developed for the theme of energy efficiency, however once the information structure and the communication tool will be tested, thanks to the modular structure of the GIS environment it will be possible to integrate on a spatial basis also other themes even not directly related to the original one in order to explore the theirs relationships.

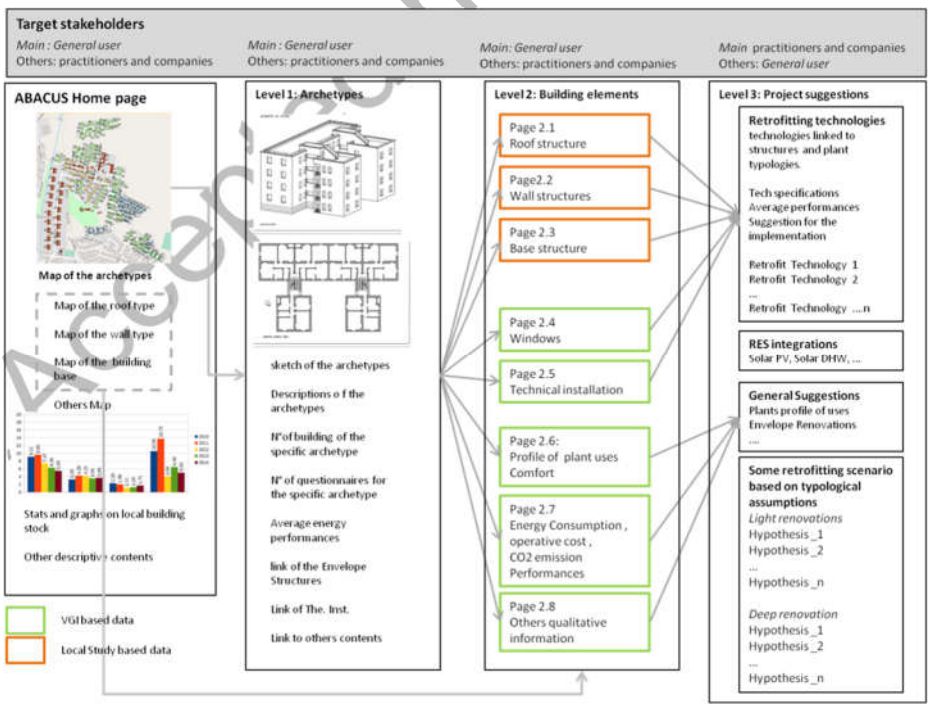

**Fig.4.**Framework of the Abacus section

## 5 Conclusion and further research

The AUREE project is still in progress, but a partial version of portal is already available that contains a beta of the house occupant interface with the questionnaire (https://www.auree.it/ ). This paper shows how common available base date could define a local based archetype that could be used as a framework for the development of a web based sharing tool. During the next year, all the interfaces will be implemented and tested and the informative materials of the guidelines for the collection of assets will be loaded. In order to improve the effectiveness of the methodology, a key point will be the analysis of the flow of the VGI based data (quality, number, spatial distribution, …). The aspects that will have to be tested will mainly concern the following topics:

- appropriateness and effectiveness of the disciplinary contents integrated in the abacus;
- functionality of the interfaces of the Abacus and addressed to houses occupants;
- refinement of the procedures that link Abacus, UBEM and questionnaire

## 6 Acknowledgment

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