Article

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Web-Based Management of Public Buildings: A Workflow Based on BIM and IoT Sensors Integration with a Web-GIS Portal

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Abstract: The paper presents the final results from 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 the "Ricerca Sistema Elettrico (MISE) program". The crux of AUREE project is a Web – GIS GeoBlog portal with customized semantic dashboards aimed at sharing information on urban built environment and promoting the participation of local stakeholders to its improvement. As the latest development of this research, a workflow integrating the AUREE portal with BIM authoring and an open source IoT platform has been implemented and applied to an experimental case study concerning a public building in Carbonia (Italy). The headquarters of the sustainable energy research center Sotacarbo was selected as case study. The presented results proved that it was possible to create an open system, which could be easily consulted by "non-expert" users as well, to make available real-time monitoring data obtained from IoT sensors measuring the energy consumption, the indoor environmental conditions and the usage profiles of public buildings. The proposed open system could also be suitable to be later used as an effective tool to support the rising "energy communities".

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Introduction

In July 2021, the European Commission, in the pursuit of its 2050 decarbonization objectives, adopted a proposal for a recast of the Energy Efficiency Directive as part of the European Green Deal package. As an intermediate step it contains legislative proposals to meet the EU objective of at least 55% reduction in greenhouse gas emissions by 2030. In May 2022, within the "REPowerEU plan", the European Commission proposed an increase to the binding of energy efficiency target from 9% to 13% compared to the 2020 Reference Scenario, aimed at making the European Union independent from third countries fossil fuels [1]. The energy system will therefore experience a profound transformation, in terms of lower final consumption, induced by growth in efficiency concentrated in particular on the public and private building stock. The electrification share of the system will gradually tend to exceed 50% [2]. The acceleration of renewable energies becomes a crucial factor: their contribution to electricity generation should reach at least 72% by 2030 and cover shares close to 100% of the overall primary energy mix by 2050, in compliance with the other main values of the transition process [2].

To address these challenging goals, it is necessary to promote the integration between systems and technologies according to a multi-scalar and inter-sectoral approach. With the aim of making citizens and businesses protagonists of the energy transformation, it is urgent the development of support tools for efficiency interventions and for the promotion of self-consumption and energy communities, the increase of technologies based on Renewable Energies (RES), and the adoption of systems for the efficient management of buildings.

It is widely reported in literature [3] that lack of shared knowledge between the stakeholders is one of the main barriers for the energy transition, in particular for the urban context. Urban systems are very complex because they are characterized by a plethora of buildings with quite various physical elements and by a mix of stakeholders with often divergent interests: Public Administration (PA) policy makers, companies, homeowners, citizens, etc. The PA should lead the process aiming to make citizens and businesses protagonists of the energy transformation adopting and experimenting best practices and tools for building heritage energy management and valorization [4].

Developing effective support tools to share knowledge about energy efficiency and RES technologies, policies and measures for the promotion of self-consumption and energy communities based on RES technologies is still a prominent issue on EU agenda [5]. These types of tools are often based on web interfaces and portals open to the public or restricted to a group of actors; they could be aimed at supporting first design-planning phases of a decisions making process or more likely in just sharing and spreading knowledge and awareness for general citizens or specific kinds of stakeholder [6]. Some type of portals, as the official Italian portal that show the EPC stats at the national and regional level [7] collect and represent information about energy performance and/or energy consumption aiming mainly to communicate and share best practices [8,9]. Some portals need more interaction with the users asking to fulfill forms sometimes quite complex but can perform basic energy calculation [10] also with commercial purposes [11]. With the aim to create a platform to share building energy retrofit potential to also involve companies and investors, some EU projects develop handy geographical interfaces to make scenarios and comparisons between building of the same context [12]. Other tools are targeted to more technical audience as for supporting urban solar planning [13] or territorial energy planning [14] or feasible assessment of energy communities grid configuration [15,16].

One of the most critical aspects of these web-based tools is balancing the simplification of concepts and procedures aimed at sharing knowledge with the targeted stakeholders and limiting cost for the implementation, with the reliability and significance of the results. In literature there is still a lack of methodology and tools, in particular those addressed to and tested in contexts characterized by scarcity of resource (economical and human) and lack of base data, as could be widely considered the Mediterranean average sized cities. In these contexts, some practical approaches based on open data and commonly available technologies and expertise should be developed balancing reachable results and resources.

The energy transition of the built environment could not be done without taking advantage of the latest Industry 4.0 technologies (like Internet Of Things devices, cloud computing, digital twins *etc.*) as well as of the Building Information Modeling (BIM) methodology and related tools, in order to more effectively monitor and optimize buildings energy consumptions. Chen *et al.* [17] investigated the potential for Construction 4.0, Industry 4.0, and BIM to contribute to sustainable building development towards smart cities advancement. In this regard, the latest literature contributions proposed effective workflows for BIM and IoT integration. Panteli et al. [18] investigated BIM applications and research trends in different life cycle stages by presenting a comprehensive overview of the state-of-the-art in the field, structured in the pre-, the during and the post-construction stages of buildings. Tzortzopoulos *et al.* in [19] proposed a BIM-based protocol intended for supporting decision making by social housing owners by simulating alternative retrofit options. The combined use of BIM and IoT technologies is playing a key role in the digital transformation of the Architecture, Engineering, Construction and Operation (AEC/O) industry occurring in recent years. This is proved by the increasing interest in this research field, even though BIM and IoT integration investigation is still in an early stage. Di Giuda *et al.* in 2018 in [20] focused on the concept of the “cognitive building” adopted as ideal man-building interface to allow real-time adaptation of indoor conditions and provided services based on users. More specifically, the authors of the paper [20] presented a new approach aimed at enhancing energy audit procedures by adopting Building Information Modeling (BIM) to gather, spread, filter, and analyze measured data indicative of the envelope energy performance of a real building. The work [21] of Di Giuda, Pellegrini, Schievano *et al.* provided instead a state of the art of the research on BIM applications for Post-Occupancy Evaluation (POE) of existing buildings, by mainly focusing on the use of IoT sensors and Machine Learning. Desogus *et al.* proposed a plan for sensor equipment of the “Mandolesi Pavillon”, an iconic building part of the University of Cagliari Campus, in order to monitor indoor thermo-hygrometric conditions and identify compatible retrofit interventions oriented at improving the building energy performance, by also making use of a BIM model of the case study to store and manage real-time monitored data [22]. Considering the value of Building information modelling in supporting all phases of retrofit process, Sanna *et al.* focused on implementing an efficient integration between BEMS (Building Energy Management System) and BACS (Building Automation and Control System) to monitor the indoor comfort of existing buildings [23,24]. The effectiveness of BIM-based approaches in storing and managing data coming from sensors was also proved by the study [25] conducted by Rogage *et al*. concerning real-time post-occupancy assessment of residential buildings performance. Similarly, in the context of the final experimental stage of the PRELuDE[3] project [26], Desogus *et al.* tested an integrated use of BIM and low-cost IoT sensors on a real case study (*i.e.* the aforementioned "Mandolesi Pavilion") by also making use of a common data platform to visualize and manage data related to building indoor conditions (e.g., temperature, luminance etc.) and of energy consumptions [27]. The research contribution [28] showed a newly developed integrated solution based on a BIM platform and Internet of Things (IoT) to create a self-updating BIM model to monitor thermal conditions in real time.

In this context, the Sotacarbo Sustainable Energy Research Center and the Department of Civil Environmental Engineering and Architecture (DICAAR), Department of Electrical and Electronical Engineering (DIEE), Department of Mechanical, Chemical and Materials Engineering (DIMCM) of the University of Cagliari cooperated in the "Urban Abacus of Building Energy performances – Abaco Urbano Energetico degli Edifici (AUREE) research project, funded by the 2019-21 Triennial Plan for the fulfilment of the Agreement between Ministry for Economic Development and Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) – Project 1.5 "Technologies, techniques and materials for energy efficiency and energy saving in the electrical end uses of new and existing buildings".

The project fits into the framework of those tools aimed at creating a fundamental knowledge that can be exploited to accelerate the processes of intelligent integration of renewable energy, energy efficiency, and different sustainable solutions. It can help to achieve decarbonization at the lowest possible cost, on the one hand by accompanying end user toward the choice of a conscious energy behavior and on the other by supporting public administration and decision-makers in the planning of energy measures.

The concept of the AUREE project is a web–GIS GeoBlog portal with customized interfaces aimed at sharing information on the urban built environment and promoting the participation of local stakeholders in its improvement. The methodological approach is specifically addressed to small and medium urban centers, characterized by the low availability of basic data on buildings' energy performance. The town of Carbonia is selected as a relevant case study.

The portal is implemented with an Urban Building Energy Model (UBEM) [29–31] based on spatial open data, a typological survey of the built heritage, and a participative web framework, as extensively described in [32]. It represents the main tool on which the collection and sharing of data on the energy performance of the built heritage of the city of Carbonia are based. The developed 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.

There are also some other sections not directly linked to heritage physical characteristics, but important to define regulation bonds and technological innovation opportunities: territorial context data section and companies' section. The territorial data are 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 in order to develop a holistic approach to urban planning.

The Companies section is an open geo database framework addressed to companies and practitioners that work on construction and building renovation local markets, it aims to promote best practices and facilitate demand and offer matching.

This work focuses on content and procedures of the public building section, for more information on other sections some other papers have been published before [32–34].

The aim of the paper is describing the part of the system that manages the data on public buildings. A protocol based on energy audit procedures and sensor monitoring is proposed. The approach aims to collect, represent and share the energy-related data on public buildings. A key role

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is played by energy management interfaces based on BIM and sensors integration that are developed and tested in the research.

Tools and Methods

The last stages of the AUREE research are aimed at implementing an effective workflow to handle and make available real-time monitoring data concerning existing public buildings. It is centered on the integration between a sensors platform, BIM models and a web-GIS portal. The proposed methodology leads to the provision of a monitoring and representation protocol for public buildings management, based on the combination of BIM, IoT, GIS and web technologies (**Error! Reference source not found.**).

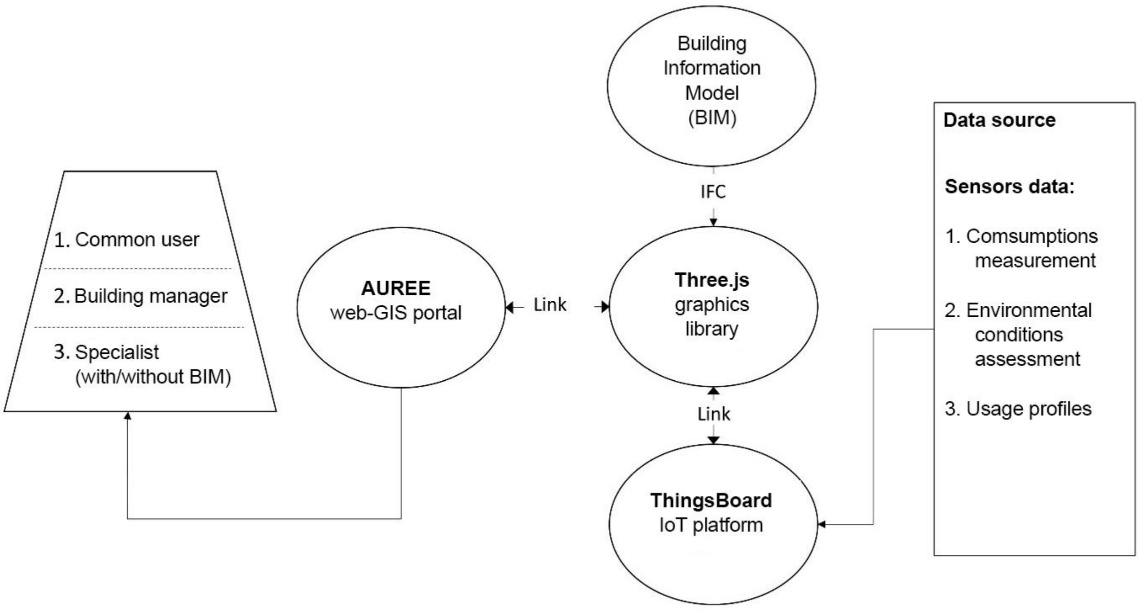

Figure 1. Workflow of information exchange between the monitoring system, the BIM model and the web-GIS portal.

Arrangement of the information sets concerning public buildings

The involved information sets are organized according to the following categories:
1. general information
2. building envelope
3. systems
4. usage profiles
5. energy performance (from certificates)
6. actual energy consumption (data acquired from energy suppliers)
7. real-time monitoring
8. improvement proposals.

More specifically, the "general information" category includes buildings information regarding their position, construction age, main use, historical characterization, planning restrictions, visualization (pictures) and dimensional features (areas, volumes etc.). Information regarding dimensions, materials properties and thermal performances of vertical and horizontal building components are incorporated in the "building envelope" set. Detailed information about technical components and efficiency are included in HVAC, electrical, lighting and renewable energy "systems" information (see the **Error! Reference source not found.**). Information regarding "usage profiles" of spaces and systems are also considered, as well as energy performance indicators and classes obtained from "Energy Performance Certificates".

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By way of example, **Error! Reference source not found.** and **Error! Reference source not found.** show the schematic organization of the information sets respectively related to usage profiles and real-time data monitoring concerning environmental conditions and energy consumptions.

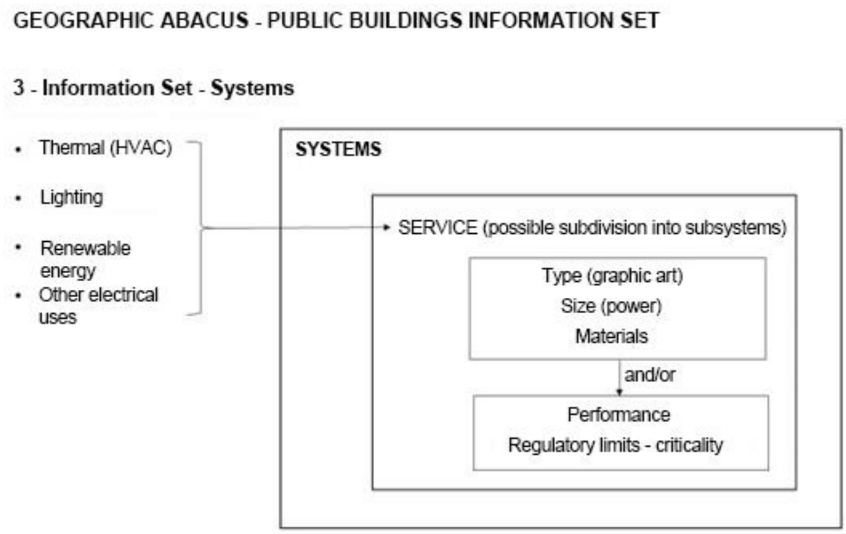

Figure 2. Systems information set for a geographic abacus of public buildings.

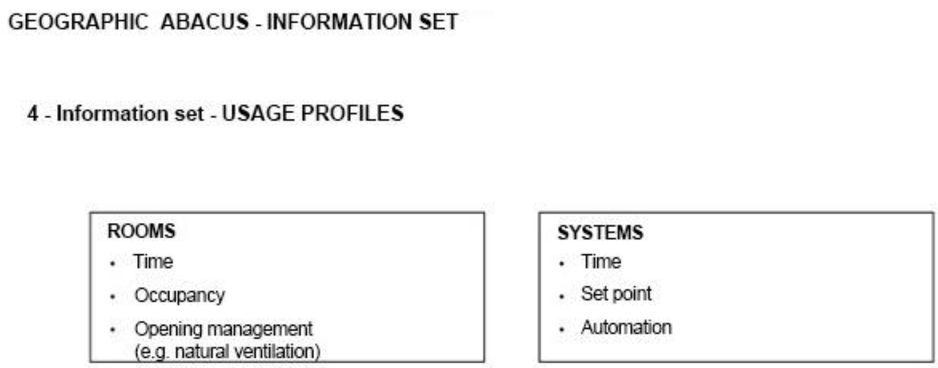

Figure 3. Usage profiles information set for a geographic abacus of public buildings.

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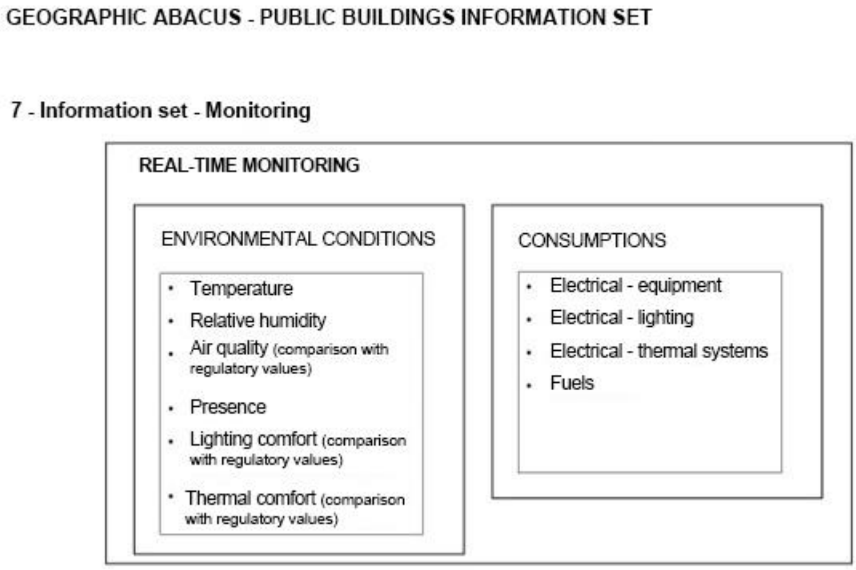

Figure 4. Monitoring information set for a geographic abacus of public buildings.

Building Information Modeling (BIM)

As shown in **Error! Reference source not found.**, the proposed methodology provides for the use of the Building Information Modeling (BIM) to store and show some specific data deriving from real-time monitoring systems. In this specific case, the methodology workflow is conceived considering the use of Autodesk Revit as BIM authoring software, nevertheless it could be contemplated a future integration of this framework with different BIM authoring tools.

The use of the BIM methodology aims at implementing three-dimensional parametric and informative models of the buildings which will be object of experimentation. Virtual components in BIM models must accurately represent geometry and information of structural, architectural and system elements of real buildings. For this purpose, the proposed methodology also provides for a rational selection of informative attributes to be collected (*i.e.* the information requirements) as parameter values in BIM models before the model implementation, in accordance with the Level Of Information Need (LOIN) [35] of BIM components for the project goals.

It is important to emphasize that the use of the BIM methodology in the framework herein presented is not directed at using the model as a tool for information exchange between the responsible parties, but rather it is simply aimed at easing display and identification of building components. The introduction of the BIM approach for geometric and information modeling is also directed at supporting a digitization process of public building stocks, also in view of the imminent legislative obligations [36] for which, starting from 1 January 2025, the use of the BIM methodology will be mandatory for new public constructions and interventions on existing buildings for an amount greater than or equal to 1,000,000 euros.

WebGL graphic library

In agreement with the further aim of this work of making the information database accessible also to non-technical users, an integration with an open-source Web Graphics Library (WebGL) is introduced in the workflow. Graphics libraries allow to create 3D visualization scenarios accessible via browser. In this specific case, the use of the Java-based graphics library "Three.js" [37], implemented by the MIT (Massachusetts Institute of Technology), has been integrated in the proposed framework, as it allows to import and read information of BIM models through IFC formats [38].

Before exporting BIM models to IFC standards, proper exportation and visualization filters have been created, to make the models navigable and allow objects selection in the WebGL platform by browser. Moreover, making appropriate simplifications to the BIM model before importing it into the graphics library has been necessary to make its visualization easier and clearer.

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Therefore, once an IFC simplified model is imported, the WebGL platform also allows to link model components to real-time monitoring systems, in accordance with one of main goals of this work.

This workflow section thus ensures the important advantage of making information models accessible by technicians not expert in BIM by not entailing any information loss and not requiring any subsequent verification of data quality.

IoT sensors and platform for real-time data monitoring and processing

As anticipated above, the proposed workflow also includes the integration of the WebGL-based 3D scene with a platform for real-time monitoring data. More specifically, the "ThingsBoard" open-source IoT (Internet of Things) platform has been selected to read, analyze and collect sensors data, as "ThingsBoard" is in line with the digitization policies of Industry 4.0 by allowing the users to collect and visualize data from sensors and assets, to control devices through remote procedure calls, to design dynamic and responsive dashboards etc. [39].

The integration of the proposed workflow with the "ThingsBoard" IoT platform is directed at simultaneously acquiring data concerning the air concentration of carbon dioxide (CO2) and volatile organic compounds (VOC), the air temperature (T) and relative humidity (RH), as well as the human presence in indoor environments [40]. The implemented methodology envisages that sensors data could be sent to "ThingsBoard" via WI-FI or wired web network and stored through the platform cloud service.

The "ThingsBoard" IoT platform allows the users to manage and integrate any "smart" object, *i.e.* equipped with enabling technologies that interact with the surrounding environment ensuring the data exchange in real time. The platform enables the collection, processing and analysis of data, to produce useful information for supporting decisions making and processes optimization, from energy efficiency to comfort control and safety.

As far as IoT sensors are concerned, among the different available technologies, wireless products are widely used as they make it possible to avoid expensive system modifications imposed by wired solutions. Those that use the "Z-Wave" radio standard, are widespread internationally. The "Z-Wave" is a wireless communication protocol through which it is possible to generate a "mesh network" made up of all mutually communicating devices by using low energy for the information exchange within the network [27,41,42].

Although the measurement uncertainty is much higher than microclimatic monitoring devices, IoT sensors are increasingly adopted to collect data on hygro-thermal indoor conditions and air quality as these devices are characterized by small dimensions and they ensure continuous data monitoring of environmental parameters [27].

Web-GIS portal

The AUREE portal is a cloud-based architecture (WEB gis, Geo Blog) that have some customer-based interfaces aimed to share knowledge about urban building heritage and improve participation between more common typology of local stakeholders involved on building renovation and energy retrofitting process: real estate occupants, Local Administration Decision Maker, construction companies and practitioners or other actors with a more generic interest.

The web portal has been structured on some recognizable sections that have in common the baseline data but shows different representations with specific contents and procedures: residential building section, typological section, public building section, companies' section and other parts with some relevant thematic geographical layer and documentation.

The residential building section contains a spatial representation of the energy performance of the building heritage provided from an easy UBEM methodology [32] and aims to directly involve the occupants, Public Decision makers and companies by defining a shared knowledge framework. The building typologies section is a different representation of the same baseline information about residential heritage energy performances grouped by building typologies. This representation provides a dynamic knowledge summary of envelope and technological systems recurrent characteristics of local building typologies but also tries to define the more common real estate profile of uses.

The public building section has been designed to be a supporting tool for public buildings facility management but also to promote the transparency of energy uses and enhance citizen awareness about energy efficiency and heritage historic qualities and values.

The AUREE architecture is based on GeoNode [43] service, an OpenSource Content Management System (CMS) for geographical data that mixes the typical CMS capabilities with some native functions such are: catalog of documentation and geodata, layers and maps publication and sharing, spatial layers management and metadata editing, multi-user.

The GenoNode environment allows the interoperability of spatial data (Vector, Raster, 3D model *etc.*) consistent to Open Geospatial Consortium (OGC) guideline and INSPIRE standard through the more common sharing protocol (WMS, WFS, WFS – C *etc.*). The AUREE portal can share geographical data with the more important institutional Regional and National Spatial Data content manager and, moreover, data can be used into the more common open-source GIS desktop systems (QGIS, gvSig, uDig *etc.*) but also on the licensed ones like ESRI ARCGIS. The portal architecture is based on a cloud server with Ubuntu 20.04.02 LTS Linux Operative System equipped by Docker where has been installed and settled the portal components: PostGIS (spatial database); GeoServer (map server with OGC standard services); pyCSW and Django with Wagtail and Survey modules. The GeoNode plug-in-based systems allowed to create some fully customized tools and procedure related to the portal sections:

- residential building tool, that manages database and UBEM procedure to calculate a represent building energy performance data;
- building typologies tool, that support building typologies creation, and represent some summary stats and graphs from questionnaire based data;
- Building Audit tool, that supports home occupants on questionnaire compilation and provide suggestion for real estate renovation;
- public building management system, that is the focus of this paper;
- help template tool, that is a simplified management tool for multi - medial contents of the custom interfaces of the portal.

The structure of the AUREE portal is designed to guide the user through a process of deepening knowledge organized into some progressive levels that define the user experience. The section of the portal focused to public buildings follows the underlying idea of the project by articulating itself into successive levels of deepening knowledge (see the **Error! Reference source not found.**). After the home page, ideally targeted to a generic and not specifically interested user, by clicking on the link "public buildings" the user could moves to a page that constitutes the first level of knowledge aimed at non-technical but interested audience in the subject. This page could serve as a hub to access other subsequent levels of knowledge dedicated to more specific users: page of documentations; building summary sheet; BIM interface.

At the moment the methodology is focused on the following aspects:

- developing and testing protocols to provide and pre-process baseline data for building sheet, focusing on the integration with the normal activities carried out by public buildings management services;
- developing and testing procedures for loading base data into the portal, with special attention to the support interfaces aimed at the building managers;
- evaluating the effectiveness of the contents with a selected group of stakeholders.

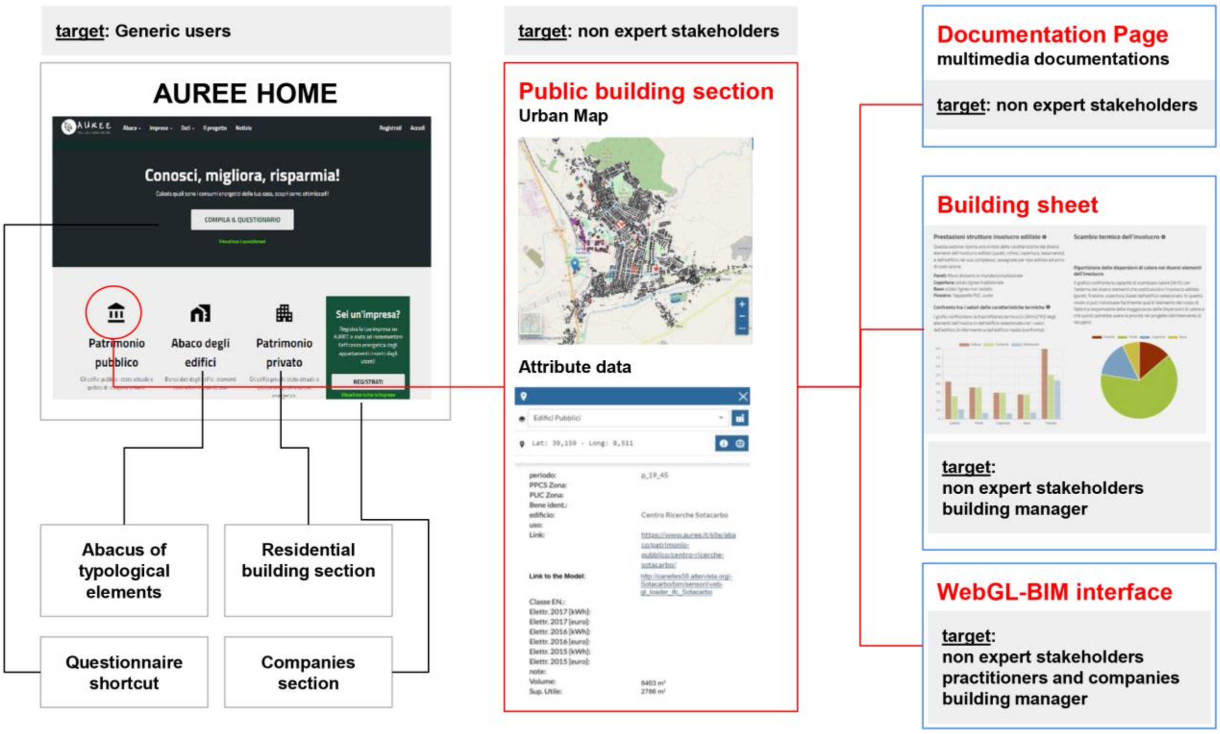

Figure 5. AUREE web-GIS portal: structure and target users.

The case study

Carbonia public buildings

Carbonia (about 27000 inh.) is a southern Sardinian (Italy) company town, founded by the fascist regime starting from 1937 in an area close to the coal mine of Serbariu. Before the discovery of Serbariu's mine, only sporadic nucleuses of rural houses could be found in that area [44,45].

The first urban plan designed for the city by the architect Gustavo Pulitzer-Finali in 1937 included a central spatial layout of neighboring and connecting squares and public buildings near residential areas [44,45]. The square known as "Piazza Roma" should be considered as the main historical public space of the town as the most representative public buildings (*i.e.* the Church of San Ponziano, the Fascist headquarters, the Town Hall, the Post Office, the Movie-Theatre and the Recreational Club) were arranged around three of the four sides of its rectangular perimeter.

The public building heritage of Carbonia must be distinguished between the buildings dating back to the city's establishment and those provided by subsequent urban plans. The public building heritage dating back to the Carbonia establishment can be classified by the building function as follows:

1. Buildings for culture and fascist propaganda
2. Religious architecture
3. School buildings
4. Public services.

The Fascist Headquarters (*i.e.* the so-called "Torre Littoria"), the Office Workers' Recreational Club and the Movie-Theatre are representative of the historical buildings for culture and fascist propaganda. Although these buildings, all designed by Pulitzer-Finali, are characterized by different sizes, shapes and finishing materials, they can be considered only apparently dissimilar as a few detailed designs and peculiar distribution layouts allow them to be related to the Pulitzer-Finali's purpose of typifying the urban space in Carbonia through harmonious and non-monotonous forms [44,45].

The religious architecture was designed by the architects Ignazio Guidi and Cesare Valle that also worked to an urban project for Carbonia in continuity with the Pulitzer-Finali's work. The religious buildings of Carbonia can be related to the historicist modern trend which characterized a

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part of the Italian architecture of the twentieth century by a modern and expressive use of reinforced concrete structures. It is worth mentioning the Church of San Ponziano, the Municipal Cemetery and the Church of "l'Addolorata" as the most representative religious architecture in Carbonia [44,45].

The architects Guidi and Valle had the chance to better experiment with a modern and rational language in school buildings design, by recalling the architecture of Gropius in the arrangement of volumes around a central nucleus, as well as in their rational layouts and in the use of large windows [44,45].

The north side of "Piazza Roma" in Carbonia is characterized by the presence of historical buildings for public services like the Town Hall, the Post and Telegraph Office and the so-called "case INA" houses, which architecturally communicate with the square through arcades, loggias and pavements variations. Moreover, according with the original rational urban plan, other public services (*e.g.* schools, healthcare services, food shops, hotels for employees and workers, buildings for recreational activities) were integrated into the urban areas of working-class housing estates [44].

It is worth mentioning among the public buildings erected after the Carbonia company-town establishment several schools from nurseries to lower secondary level, neighborhood and city sports facilities, libraries, several public houses and culture buildings like the archeological museum "Villa Sulcis" [46].

Since the early 2000s, the company town Carbonia was subjected to a relevant urban and architectural regeneration plan, financed by European funds, concerning the functional and environmental restoration of a new strategic urban infrastructure for sustainable mobility and accessibility to the historical center, the restoration of the industrial archeology building "la Torneria", the renovation of one of "the hotels for bachelor workmen" to be reused as student house [47]. Moreover, the architectural and urban regeneration plan, had considered a redevelopment strategy for the building complex of the abandoned Serbariu mine, which was acquired by the municipality of Carbonia in 1991. The mining site has been then recovered and converted to an important cultural and Research Center for clean energy technologies. The Serbariu mining site currently hosts the headquarters of the Italian Center for Coal Culture, as well as the Coal Museum inaugurated in 2006 in the premises of the former lamp factory (*i.e.* the so-called "Lampisteria") [48].

However, it should be noted that, following the performed extensive survey of the public buildings of Carbonia, only one building was selected as a pilot case for the application of the whole workflow presented in this paper.

Focus on the Sotacarbo Headquarters

The Sotacarbo Research Center, built between 1938 and 1939, was originally a Materials Warehouse serving the Serbariu Mine, owned by A.Ca.I. (Italian Carbon Company), which used to take advantage of the Sulcis coal basin. The building was enlarged in the 1950s with three new bays for additional warehouses in the courtyard.

The building was originally characterized by a main façade in exposed trachyte masonry with a large iron gate leading to a courtyard through a wide corridor. The other building facades were only characterized by a trachyte wainscoting.

In 2000 the building structures and finishes appeared considerably deteriorated due to a state of abandon. The building was therefore renovated to make it functional and appropriate to its new use as research center but also respecting its historic testimonial value of industrial archeology [47].

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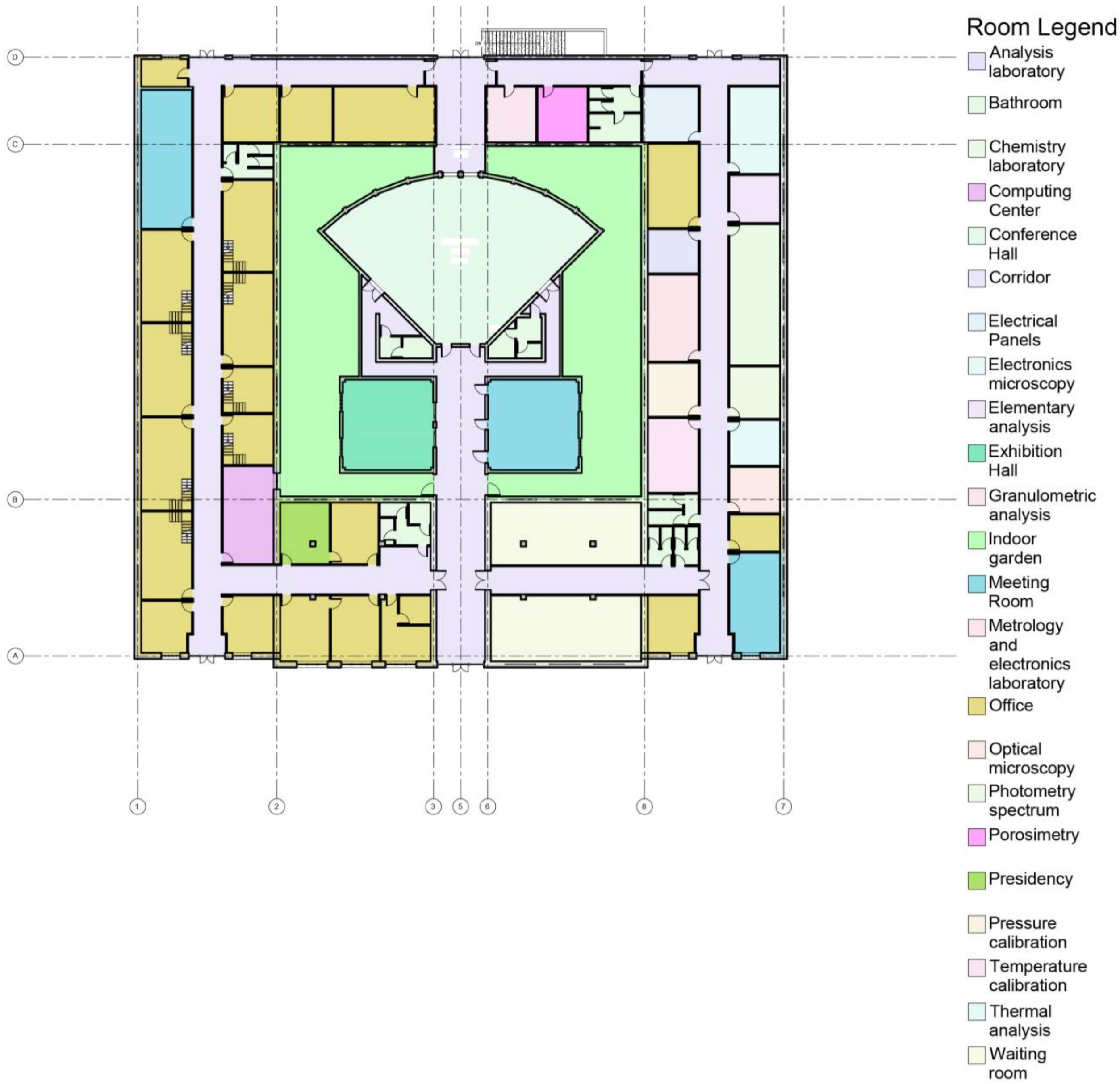

Figure 6. Sotacarbo Research Center – Ground floor plan with room uses.

Currently the building occupies a rectangular footprint area 54 meters long and 50 meters wide. All buildings are arranged around an internal courtyard measuring approximately 29 x 30 meters, inside which the two longest sides are connected by a more recent structure (**Error! Reference source not found.**).

The two shortest parallel wings of the building are characterized by sloping roofs, with eaves height of about 6 meters, also provided with double-pitched skylights protruding on the roof top. The six skylights originally ensured an optimal lighting and natural ventilation system, whereas they have currently lost their natural function, being now completely closed through a corrugated sheet (**Error! Reference source not found.**).

The structure supporting the sloping roofs is composed by a peculiar system of reticular reinforced concrete beams, with a triangular thin section, covering a span of approximately 13 meters, built on site and subsequently assembled with an interaxle spacing of about 3 meters. It was not possible to inspect the roof pitch decks, which were originally made of large brick hollow tiles with smooth reinforcement bars placed between the main beams, according to the Perret patent. The roof covering, that currently appears as a simple corrugated sheet on the beams, originally consisted of a layer of Marseilles tiles lying on a lightweight concrete slab. The flat roofs structures are supposed to consist of traditional masonry-concrete slabs supported by a framework of reinforced concrete beams, based on similar structures nearby such as the “former workshops pavilion”.

The buildings composing the Sotacarbo Research Center headquarters can be divided into three blocks based on their use. The first main building block hosts offices, laboratories, an archive, meeting and conference rooms (as shown in **Error! Reference source not found.**). The offices are double-height rooms, with partially transparent mezzanines covering two-thirds of the surface in adherence to the external perimeter walls, placed at a height of 2.5 m from the floor surface. A second block consists of a new building, made of precast reinforced concrete components, designated as a mechanical workshop. The third and last functional block includes open areas, such as the area of a pilot platform, which hosts experimental systems and services connected to it, the car parks, as well as access and green areas. The internal courtyard hosts an Auditorium (see the **Error! Reference source not found.**), with a capacity of about 100 people, with relative services, an exhibition hall and a meeting room, all surrounded by a small green area. The Auditorium, the exhibition hall and the meeting room are characterized by more recent construction systems as they dated back to the aforementioned relevant renovation occurred in the early 2000s. In particular, the Auditorium structure is made of exposed reinforced concrete columns, infilled with exposed brick rubble-filled masonry, ventilated roof supported by glulam beams and a corrugated sheet. The exhibition hall and the meeting room are characterized by the same construction systems as the auditorium structure. The latter three buildings are linked with the entrance corridor by a covered way, laterally transparent, made of iron and glass elements supported by small brick walls. The south-east wall, dating back to the renovation, is instead made of porous brick and has a thickness including internal and external plaster of thirty centimeters.

As far as the building envelope is concerned, the perimeter north-east and south-west walls, sixty centimeters thick, were built with a double layer of irregular trachyte ashlars with mixed earth and lime grout, according to the Sardinian building tradition, and plastered both inside and outside (see **Error! Reference source not found.** and **Error! Reference source not found.**). The northwest trachyte wall is fifty centimeters thick and plastered only on the inside in order to leave visible the outer surface of the trachyte masonry. The south-east external wall, dating back to the renovation, is instead made of porous bricks and only thirty centimeters thick including internal and external plaster. The walls facing the courtyard, again in trachyte, have a thickness of between fifty and fifty-five centimeters including internal and external plaster. The wall structure characterizing the most recent buildings is instead composed by an outer layer, twenty centimeters thick, of exposed brick masonry, an approximately four centimeters interlaid layer of air, a four-centimeters layer of extruded expanded polystyrene, a further brick masonry stratum by eight centimeters and an inner layer of premixed gypsum plaster by one and a half centimeter.

As regards the building systems, it is equipped with:

1. a lighting system
2. a system for hot water production including three electric water heaters
3. a winter and summer air conditioning system, composed by two electrical air-water heat pumps, placed outside the building and fan coils as terminal units.

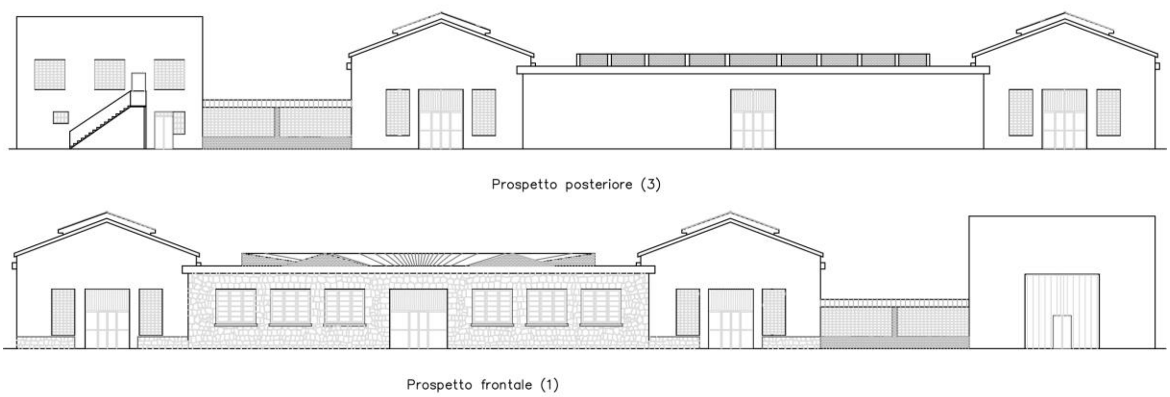

Figure 7. Sotacarbo Research Center – Front (down) and back (up) views.

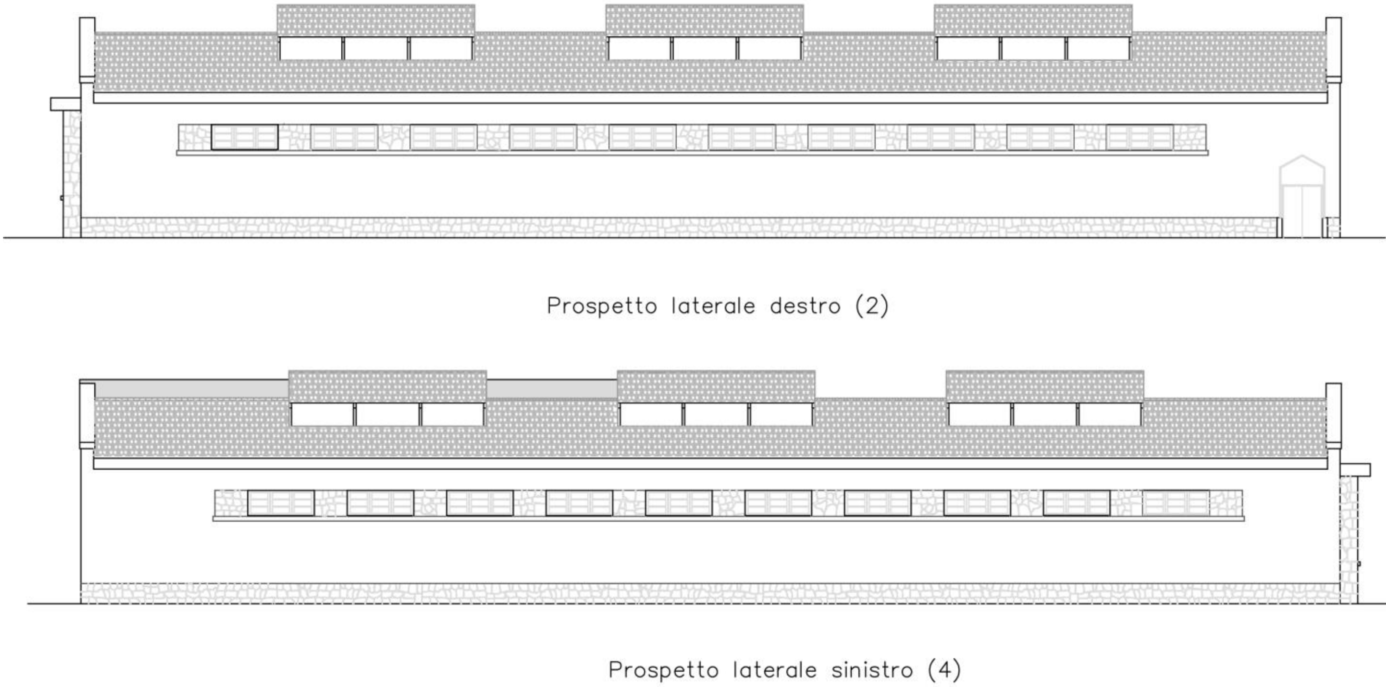

Figure 8. Sotacarbo Research Center – Right (up) and left (down) views.

Results

Provision of a Carbonia's public buildings abacus

The public building stock of Carbonia currently counts about 120 public buildings. However, only an abacus of most relevant public buildings was composed by classifying the building heritage based on the relevance of size and use.

An abacus concerning most significant public buildings in Carbonia is composed (see Table 1) including the Town Hall and other buildings for municipal offices, some buildings for culture like a theatre, a cinema and a library, public schools from nurseries to lower secondary level, the intermodal center etc.

The public buildings included in the abacus are georeferenced by identifying them in a Geographic Information System (GIS) environment (see the related map in Figure 1), likewise what was done for the private building stock during the previous stages of the AUREE project [33,34]. For each building, an information sheet is arranged, by means of a system of interconnected tables (called "dictionaries") similar to a relational database.

Table 1. Abacus of selected Carbonia public buildings

Building Name	Building Use	Building tag[1]	Construction period
Town Hall	General affairs	001_AMM	1919-1945
The "Littoria" Tower	General affairs	002_AMM	1919-1945
Council Room	-	-	-
"Ex-ENAL" offices	General affairs	003_AMM	1919-1945
Ex-Courthouse	General affairs	004_AMM	1981-1990
"The old's man house"	Social services	005_AMM	1919-1945
Central Theatre	Culture	006_AMM	1919-1945
Central Cinema arena	Culture	007_CLT	1919-1945
Library	Culture	008_CLT	1991-2000
"Deledda" primary school	Public education	009_CLT	2006-2010
"Ciusa" primary school	Public education	010_SCL	1946-1960
"Via Mazzini" primary school	Public education	011_SCL	1961-1970
"Satta" lower secondary school	Public education	012_SCL	1946-1960

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"Don Milani" lower secondary school	Public education	013_SCL	1991-2000
"Via Dalmazia" nursery school	Public education	014_SCL	1991-2000
"Santa Caterina" nursery school	Public education	015_SCL	1991-2000
"Via Lubiana" district	General affairs	016_AMM	1991-2000
The "Sulcis Villa"	Culture	039_CLT	1919-1945
Ex-"Via Dante" secondary school	Heritage	041_AMM	2001-2005
Intermodal centre	Public transport	042_AMM	2006-2010
"Via Mazzini" municipal offices	Local police	044_AMM	1919-1945
"Via B. Sassari" nursery school	Heritage	047_AMM	1919-1945
Employment office	Heritage	-	1971-1980
"Piazza Cagliari" minimal houses	-	-	-
"Via Trieste, 21" houses	Public housing	-	1946-1960
Ex-classical high school	Heritage	-	1919-1945

[1] Municipal alphanumeric code

Figure 1. Carbonia public buildings represented on AUREE Web-GIS portal

AUREE portal: The public buildings section

As illustrated in the methodology section, the portal is primarily addressed to non-technical users. It aims at presenting the main characteristics of the building stock in order to facilitate the involvement of various local actors in the field of energy retrofitting and renovation of public and private buildings.

The first page is obviously the home page Figure 2, with the links to the main sections of the portal: residential buildings, typologies and public buildings. The Home page also includes a direct link to the questionnaire that allows the simulation of the energy retrofitting potential of a residential unit or building, plus a news section, a link to the section dedicated to local companies, and a repository of other layers and documentation that may be related to the main subject of the portal (technical regulations, local urban planning, etc.).

Currently, not all sections of the portal are fully operational and freely accessible online, some are still being tested. The section focused on public buildings, which is the subject of this work, is currently being developed in beta version and shows the contents of some buildings that have been analyzed in the context of the research.

The map that constitutes the first level of knowledge is directly accessible from the home link. It mainly contains the map of the urban center with the layer of Carbonia's public buildings, which collects a summary of the most relevant information. The navigator (**Error! Reference source not found.**) allows to explore the map by activating some spatial themes based on the general characteristics of the building. The attributes data can be grouped into general information, historical series of energy consumption, and other typological energy performance information Table 2. At present, only the buildings analyzed in this work has been implemented on the layer, but procedures and tools are being defined to allow PA building managers to update the geographic database while performing their usual activities. From the map, through some direct links, it is possible to be headed to the other sub-sections of the public buildings page.

Figure 2. Home page of the AUREE portal

The link in the map allows to access the environment dedicated to the visualization and interaction with the BIM model and with the sensors, described in detail in this work. This interface goes into more detail on the building's energy management activities and it could constitute a background knowledge for the development of a design activity. Therefore, it constitutes the level of information with the highest technical content in the section of public buildings and it is primarily aimed at the technical managers of the structures. Anyway, future research developments are aimed at simplifying the interfaces to facilitate non-technical users as well.

Table 2. AUREE: Attribute data for public buildings

Attribute name	Attribute description
periodo	Construction period
PPCS Zona	Zone in the city historical center
PUC Zona	Zone in the city urban plan
Bene identit.	Listed building as identity asset
edificio	Building name
uso	Intended use
Link	Web-link to the building documentation page
Link to the Model	Web-link to the BIM-WebGL interface
Classe EN.	Energy performance class of the building

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Elettr. yyyy [kWh]	Electricity consumption in year yyyy
Elettr. yyyy [euro]	Cost for electricity consumption in year yyyy
note	Annotations
Volume	Volume of the building
Sup. Utile	Usable area of the building

The documentations page (**Error! Reference source not found.**) is aimed at a not necessarily technical audience, but they must have at least an interest in increasing knowledge about the building. From an IT point of view, it is a simple page for collecting and cataloging generic multimedia documentation (text, video, pictures *etc.*) focused to the specific building, such could be: historical information, renovation projects, other useful links, and more. The documents are labeled with the building's unique code, and currently, the research work is addressed on a semantic classification framework to support the search for information when data becomes numerous.

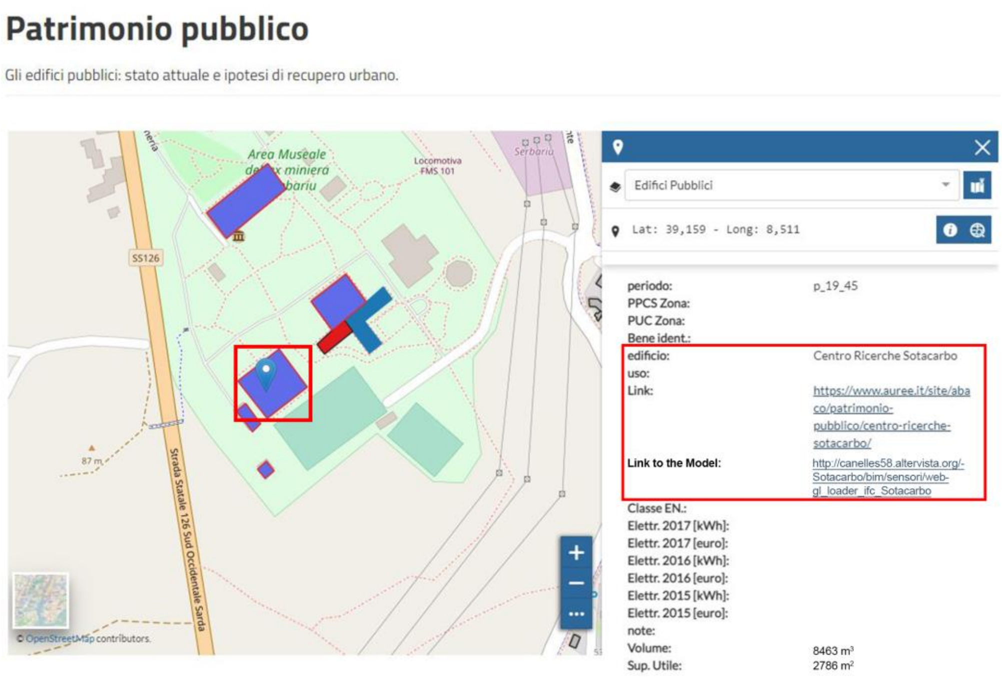

Figure 11. AUREE portal: information table of the pilot case study (*i.e.* the Sotacarbo Research Center headquarters).

The building summary sheet (**Error! Reference source not found.**) aims to collect and represent information about the energy performance and retrofit potential of the building in a synthetic way, in order to support the decision-making process of the public administration managers and promote the participation of local stakeholders. The baseline information can be obtained from some common technical documents easily available in the context of building asset management activities, such as energy diagnosis, Energy Performance Certificates (EPC), project reports, and documents for legal energy minimum requirements verifications [49]. The EPC should be easily reached for most public buildings because those with an indoor area greater than 200 square meters and buildings that renovate their systems have to make it publicly available (D.L. n. 63/2013 [50]). The summary sheet can facilitate the strategic-decision phase of the PA building energy manager by providing a framework for organizing and representing available data and a tool for comparing different retrofit scenarios. More details on this sheet will be the subject of another publication.

The other sub-sections, that constitute the levels of higher information depth described in the methodology, could be reach from the attribute section:

- the page of general documentation (**Error! Reference source not found.**);
- the building summary sheet, to support the decision-making process and participation, which will be illustrated in another contribution (**Error! Reference source not found.**);
- the WebGL 3D environment described in this work, that is the way to access the BIM information.

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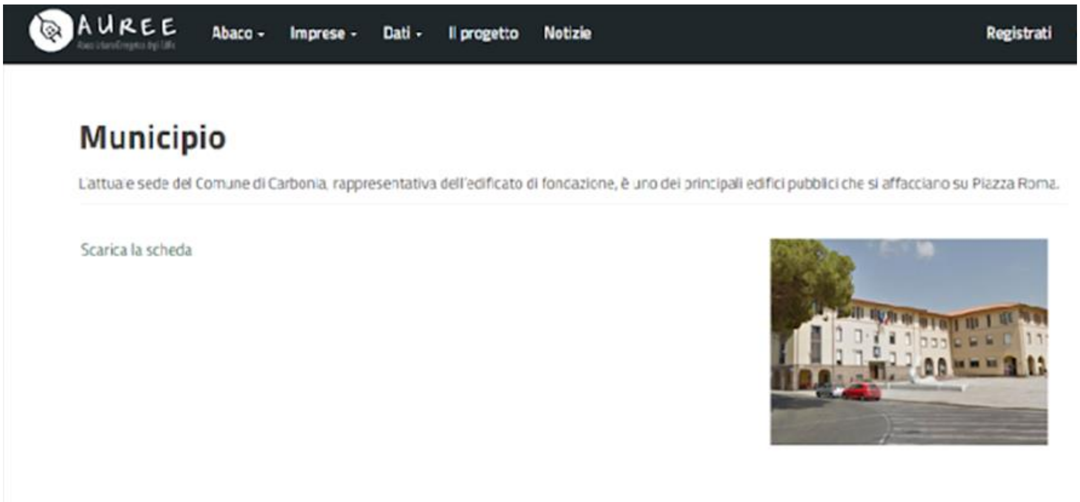

Figure 12. Documentation page.

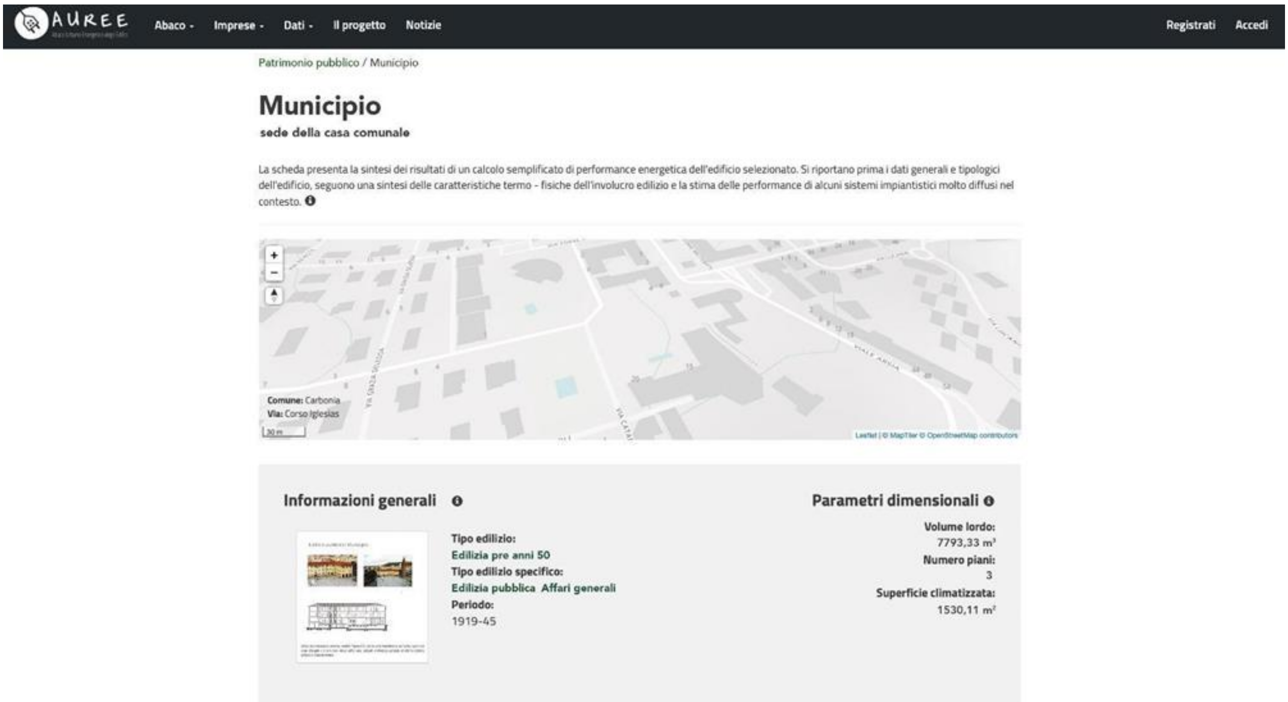

Figure 13. Sample of the building summary sheet.

BIM authoring

In accordance with the proposed methodology described in detail in previous section *§0*, the Building Information Modeling methodology is adopted to digitally represent the Sotacarbo's headquarters to properly store into specific parameters some significant information concerning the technical features of sensor devices and controller. As far as the main characteristics of the envelope and structures are concerned, it is assumed that the building is characterized by the same construction systems (described in *§0*) as the neighboring blocks.

The digital construction of the BIM model is primarily aimed at reorganizing and systematizing all information collected during the building knowledge process, by properly assigning relevant information concerning the building real components to their corresponding virtual elements in the model. To this end, the Autodesk Revit software is adopted as BIM authoring tool as it proved to be currently the most suitable to be included in the proposed workflow.

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Figure 14. Implementation of the BIM model: workflow chart.

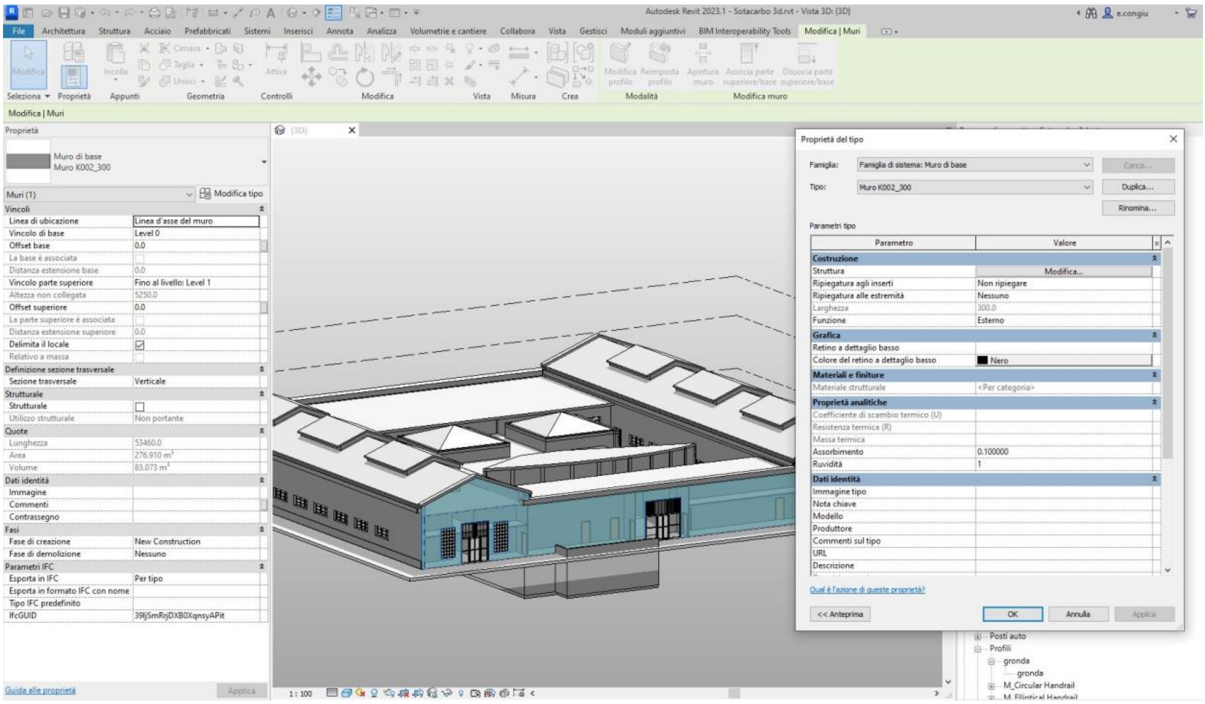

Figure 15. BIM model of the Sotacarbo's headquarters.

Starting from an accurate analysis of the information assets gathered during the building knowledge process, relevant geometric and non-geometric data that needed to be parametrically digitalized by the information modelling are selected, in accordance with the Level Of Information Need (LOIN) [35] required for the project goals. BIM models should not be considered as all-encompassing containers for all kind of information concerning building assets or projects, but rather as digital databases of graphical and alphanumeric information properly selected and structured for a specific objective. To be more precise, only general information concerning the building envelope features are included in the BIM model as it is not aimed at being subjected to energy analysis. Consistently with the main goals pursued by this work, detailed information concerning the installed IoT sensors are collected by specific parameters assigned to the building rooms, as shown in **Error! Reference source not found.**. Moreover, as room entities are not considered to be exported to the IFC-based WebGL scene, a specific set of IFC parameters including some general information concerning the installed IoT sensors is assigned to a generic parametric object, simply represented as a sphere (as shown in **Error! Reference source not found.**), designated to be exported as part of the IFC model and to be properly linked to the IoT platform for real-time data monitoring.

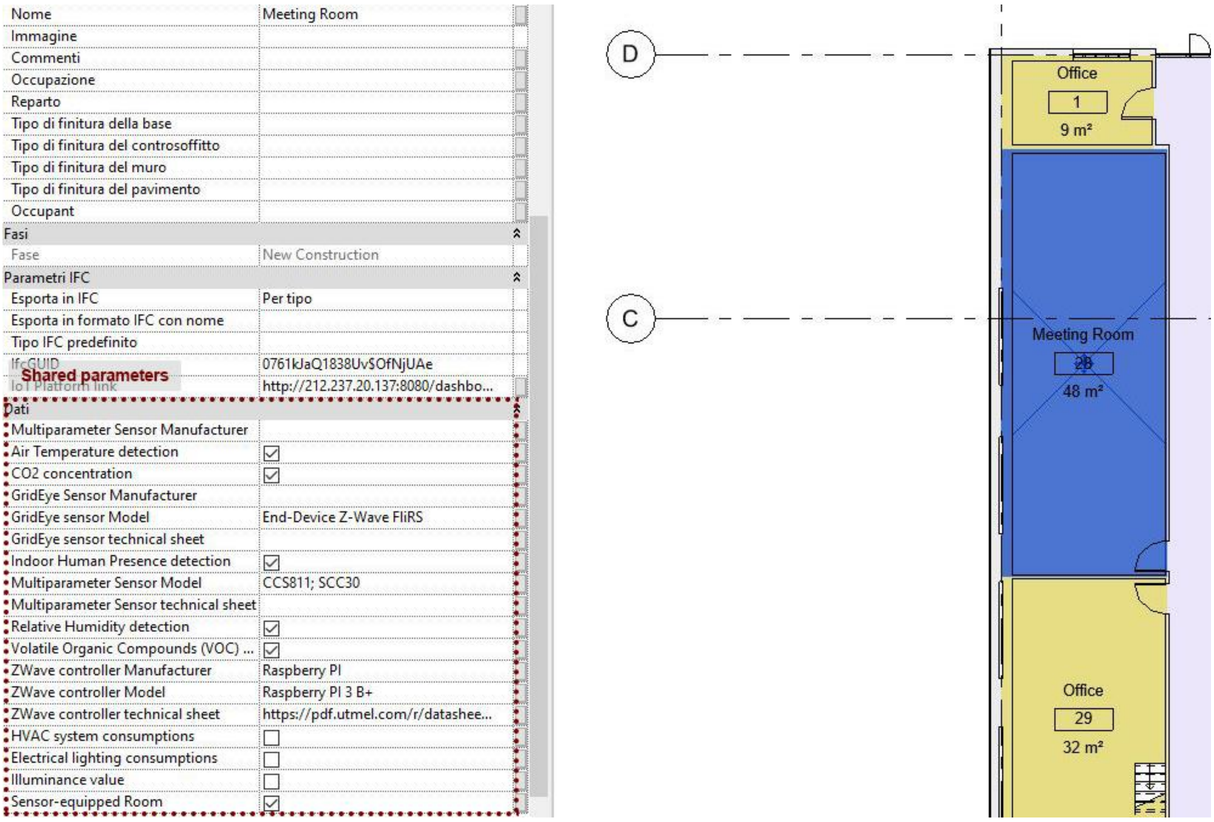

Figure 16. Instance Shared Parameters collecting information concerning IoT sensors placed in rooms.

In **Error! Reference source not found.** a visual programming code implemented by Dynamo is presented. By the presented code, executable by the Dynamo player, information tables concerning sensor-equipped rooms are automatically arranged and exported to external Excel worksheets (see the **Error! Reference source not found.**), made available via cloud by a specific web link from the web-GL scene.

The building is first decomposed into technical components (leading to the building PBS – Product Breakdown Structure), in order to properly select the information to capitalize for each of them, consistently with the required LOIN (see the **Error! Reference source not found.**).

Then, the digital construction of the Building Information Model (shown in **Error! Reference source not found.**) is carried in two stages:

1. A modeling one, where all components were geometrically modelled, based on technical drawings made available by the Sotacarbo company and on surveys data
2. A parametrization one, where all information were assigned to each building component by storing them into specific parameters.

The choice of the most suitable codification system for BIM virtual objects represents another crucial step in this work to ensure quality in communication and interoperability between all subjects involved in the process. More specifically, the code system herein adopted is created based on the UNI 8290 standard [51] but also enhanced in order to identify each single item in the model, with exact location.

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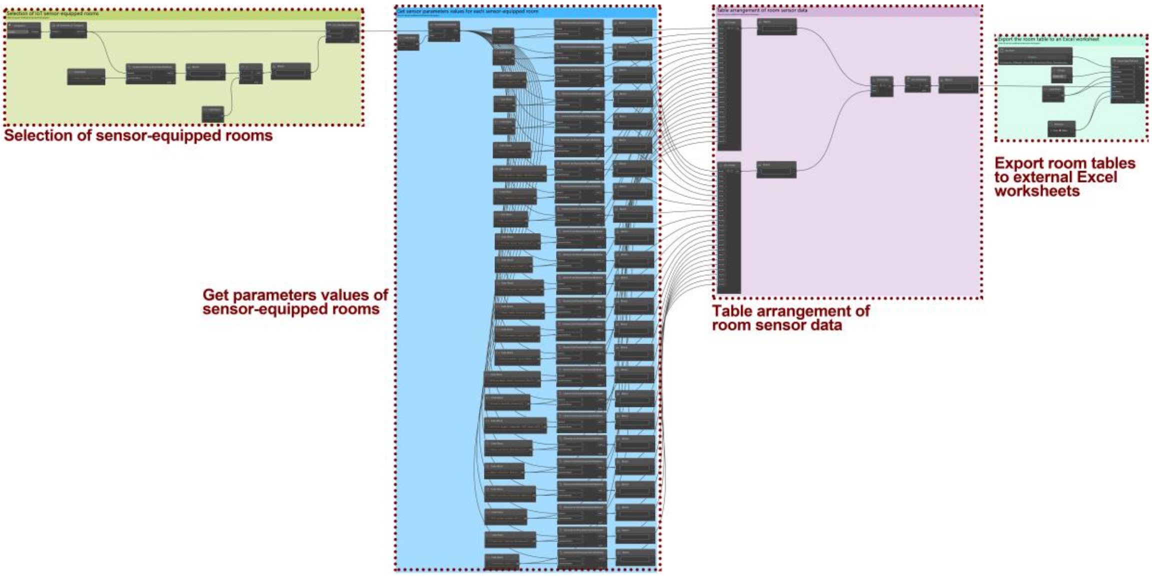

Figure 17. Dynamo visual programming code to export data tables of sensor-equipped rooms to external Excel worksheets.

	A	B
1	Numero	28
2	Nome	Meeting Room
3	Limite superiore	Level(Name=Level 0, Elevation=0)
4	Area	48,29994062
5	Volume	193,1997625
6	Sensor-equipped Room	Yes
7	Multiparameter Sensor Manufacturer	
8	Air Temperature detection	Yes
9	CO2 concentration	Yes
10	GridEye Sensor Manufacturer	
11	GridEye sensor Model	End-Device Z-Wave FliRS
12	GridEye sensor technical sheet	
13	Indoor Human Presence detection	Yes
14	Multiparameter Sensor Model	CCS811; SCC30
15	Multiparameter Sensor Model	CCS811; SCC30
16	Multiparameter Sensor technical sheet	
17	Relative Humidity detection	Yes
18	Volatile Organic Compounds (VOC) detection	Yes
19	ZWave controller Manufacturer	Raspberry PI
20	ZWave controller Model	Raspberry PI 3 B+
21	ZWave controller technical sheet	https://pdf.utmel.com/r/datasheets/digikeykitva-nhd70hdminrsxnkit-datasheets-0515.pdf
22	HVAC system consumptions	No
23	Electrical lighting consumptions	No
24	Illuminance value	No

Figure 18. Data table of the sensor-equipped room exported to an external Excel worksheet.

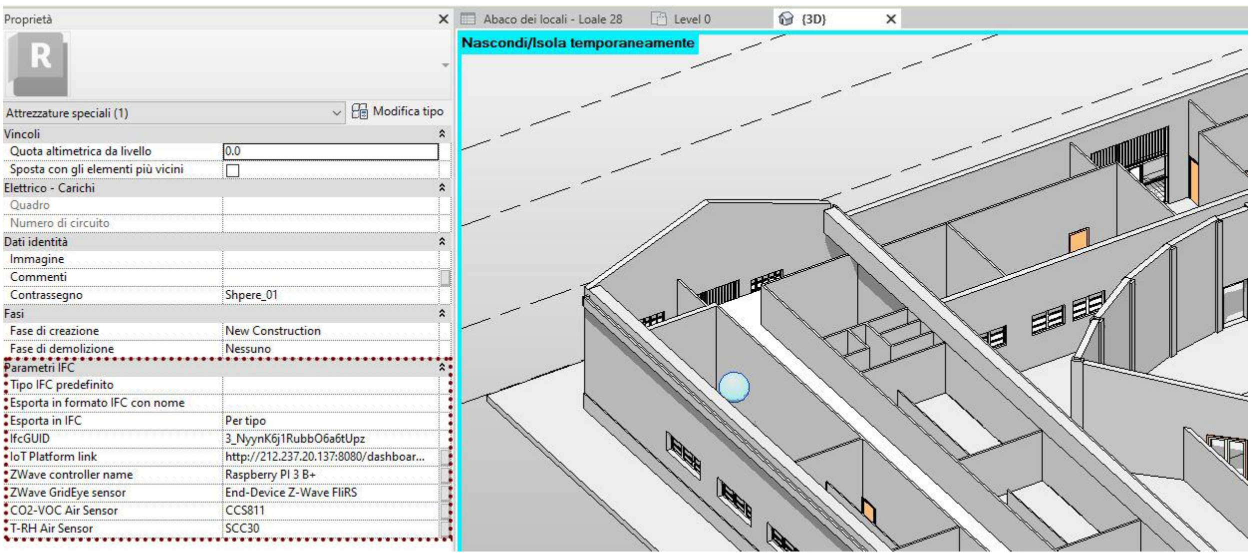

Figure 19. BIM model: parametric sphere object and related IFC parameters including IoT platform link.

WebGL graphic libray

As anticipated in the methodological section, game engines based on WebGL applications (*i.e.* Web Graphics Libraries) are adopted to make accessible the BIM model also to non-technical users and ease the display of real-time monitoring data. WebGL tools enable 3D visualization scenarios accessible via browser.

Among the WebGL graphics libraries available in open source, the "three.js" java-based library [37], developed by the MIT (Massachusetts Institute of Technology), is chosen. The choice is justified by the possibility of using the java programming language, as well as by the ability of importing BIM models via the IFC (Industry Foundation Classes) non-proprietary standard format [38].

Before exporting the BIM model to an adequate IFC format, proper display filters are applied to ease visualization and selection of the building virtual components, which are also linked to the aforementioned "Thingsboard" platform for sensors data monitoring. Programming operations through java language have been necessary to further simplify the IFC model visualization and management.

At the end of this WebGL-based process, schematically represented by the flowchart in **Error! Reference source not found.**, the web address of the "ThingsBoard" platform is allocated to a specific BIM object (highlighted as a red sphere in the **Error! Reference source not found.**).

The WebGL information model is currently available and queryable via browser, whose web address is provided by the AUREE web-GIS portal (see the **Error! Reference source not found.**). In this regard, it is worth noting that only the IFC objects linked to the "Thingsboard" IoT platform are made selectable on the "three.js" scene (see the **Error! Reference source not found.** and **Error! Reference source not found.**). As remarked in the previous section, each sensor-equipped room (even though only one room has been provided with IoT sensors so far) in the IFC model is also connected to the related information table by means of a specific web link (see the **Error! Reference source not found.**).

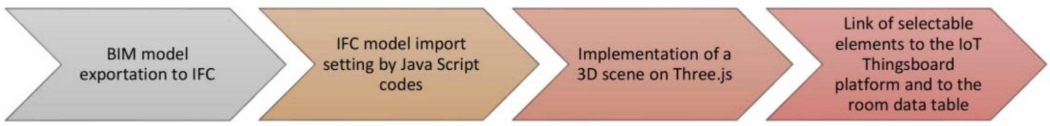

Figure 20. WebGL 3D scene implementation: workflow chart.

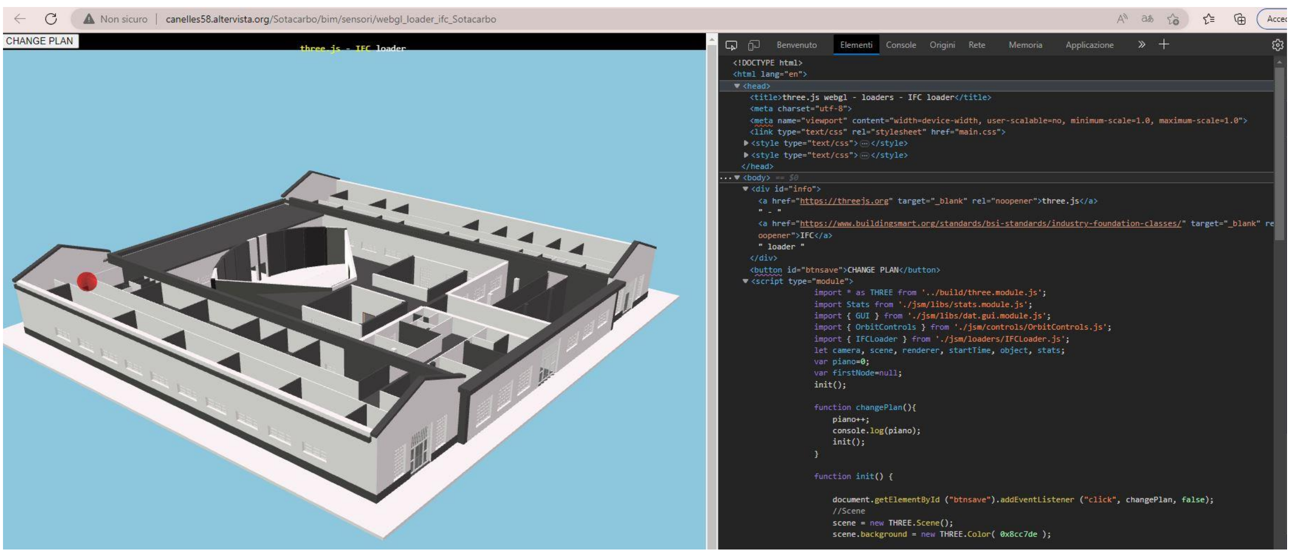

Figure 21. WebGL-based three-dimensional visualization of the Building Information Model of the Sotacarbo's headquarters on Three.js [37.]

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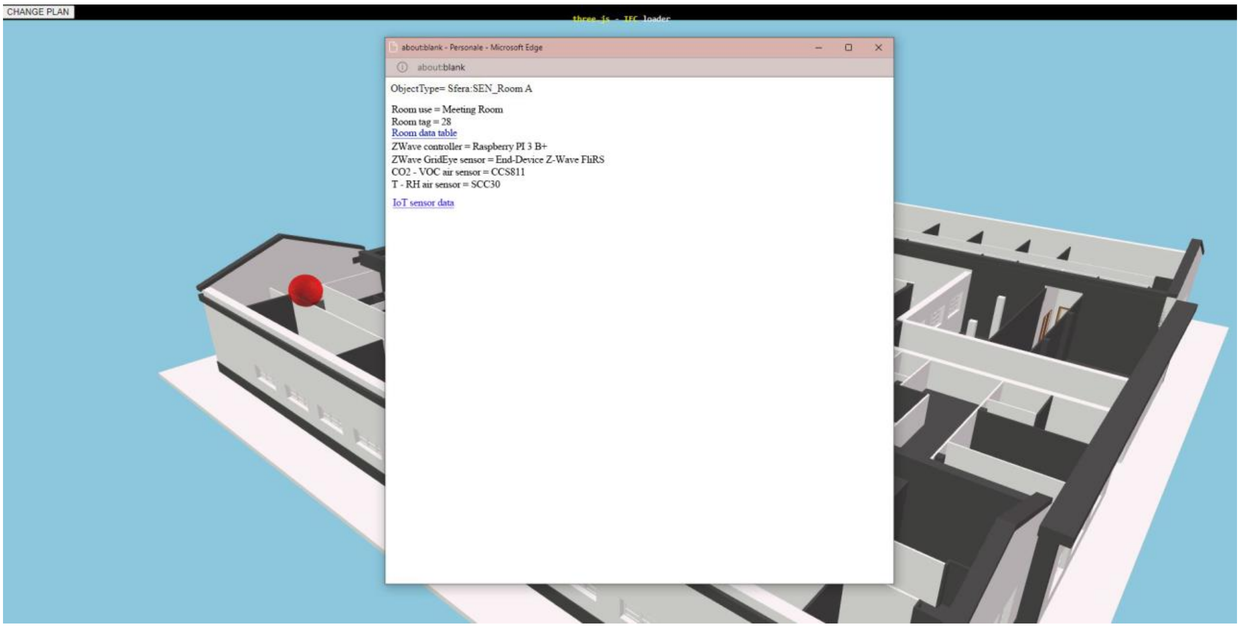

Figure 22. Three.js scene: selection of an object linked to an Excel room data table and to the Thingsboard IoT platform [39] to access sensor real-time da.ta

Real-time data monitoring: the sensor-based infrastructure

The Department of Electrical and Electronic Engineering (DIEE) of the University of Cagliari has created devices characterized by a minimal implementation and management cost (maintenance and energy consumption), suitable for environmental parameters monitoring (CO2, VOC, temperature, relative humidity) and indoor human presences detection (GridEye), constituting a network of wireless sensors managed by a gateway device. The aim is to verify the dynamic and steady-state performance of both the sensor devices and the wireless network with particular reference to the precision and repeatability of the indoor parameters measurements and the level of energy consumption of the system.

Two types of devices have been built:

1. multi-parameter sensor, capable of the carbon dioxide concentration (CO2), volatile organic compounds (VOC), air temperature and relative humidity in simultaneous measurement.
2. sensor for detecting indoor human presence.

The prototype of sensor devices is placed in communication with each other and with a gateway positioned inside the monitored environments to communicate with all the devices in the network. The sensor devices, which also act as network nodes, use mesh technology, particularly the Z-Wave protocol. At the same time, the gateway communicates with the cloud via wi-fi standard. The data acquired by the sensors are available in the cloud platform, making it possible to calculate, for example, the comfort indexes.

Operationally, the implemented sensor network is installed in the Sotacarbo Research Center in the city of Carbonia. The devices are configured to send the measurement data to the ZWave controller, which packages the data and sends them at regular intervals, set by the user when configuring the Controller/Raspberry. The management of the data acquired by the sensor devices is shown and stored by the platform "ThingsBoard" (**Error! Reference source not found.**). Each controller sends the data to the platform using the APIs made available by the same platform. The user must first create a data channel to merge the abovementioned packages. The data is then represented graphically through appropriate widgets on the "ThingsBoard" platform.

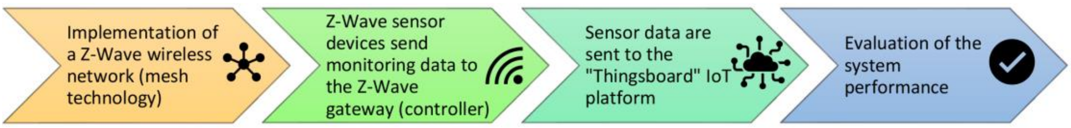

Figure 23. Implementation and test of the sensor-based infrastructure: workflow diagram.

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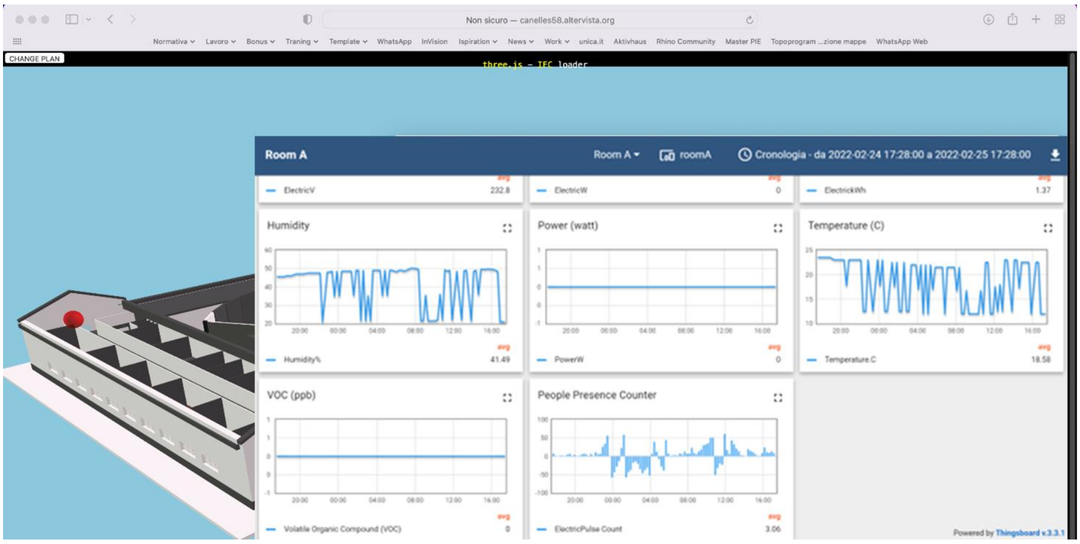

Figure 24. Access to the "Thingsboard" IoT platform: real-time data monitoring.

The network of sensors, created in the laboratory, is subjected to appropriate tests to verify their performance regarding radio frequency coverage and reliability of the data detected and power consumption.

The evaluation of the system's performance is carried out in three steps:

1. the first step consists in verifying the values read by the sensors locally, *i.e.*, at the microcontroller level, through a serial interface and the connection of the electronic card to a PC to obtain a monitoring of the values.
2. the second step concerned the aspects relating to the reception of data transmitted by the microcontrollers via the Z wave - network.
3. the third step concerns the check of the communication of the gateway with the "in-cloud" system.

From the scientific point of view, the most significant aspect concerns the reduction of power consumption of the wireless sensor and the gateway, thanks to the use of "low power" technologies and the implementation of energy harvesting technologies.

Energy harvesting technologies efficiently capture, accumulate, and manage the ambient energy and supply it in a form that can be used to empower electronic devices.

In this way, extending the energy autonomy of the wireless sensors and reducing the cost of periodic maintenance linked to battery replacement has been possible. In the near future, energy harvesting will allow for the creation of self-powered, low-cost radio sensors that do not require batteries but only a supercapacitor device for energy storage.

This would reduce the environmental impact of the sensors in terms of energy used for their operation and the disposal of particular waste, such as accumulators. As is well known, current lithium-ion technologies contain a high percentage of dangerous heavy metals that must be disposed of and recycled with high costs and environmental repercussions. In this regard, low-cost technologies for the recycling and recovering of heavy metals present in the latest generation batteries are being developed within the RecLionBat project.

In **Error! Reference source not found.** it is shown how sensors data are accessible in real-time by the link from the BIM model, made available in the WebGL scene, to the open-source platform Thingsboard. It is worth mentioning that the WebGL scene is made in turn available via a URL included in the building information sheet uploaded on the AUREE web-GIS portal, as the main overall objective of the present work is to make easily accessible, to any unqualified user, real-time information concerning public buildings usage.

Discussion

The present paper shows and discusses the last findings of the AUREE project whose latest research is focused on improving the developed UBEM-based methodology to effectively implement the portal section designated for public buildings in Carbonia (Cagliari, Italy). The main purpose of

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the AUREE Web-Geoportal is to provide a useful open tool to share knowledge about energy performance of residential and public buildings with the dual purpose of increasing end-users' awareness regarding proper energy behavior and of supporting public administrations and other decision-makers in sustainable building management.

The implementation of the public building section, which is subject of this paper and currently being developed in beta version, has started with the provision of an urban abacus of most relevant public buildings in Carbonia, classified by the related construction period and use category. As first level of knowledge, a queryable 3D map of the public building stock is provided through GeoNode and made available in the AUREE portal. From the map, through some direct links, it is possible to access the documentation pages related to the most relevant public buildings subject of this work. Documentation pages and related buildings summary sheets are intended for providing both common citizens and facility managers with some general, historical and also technical information about the building features, its system equipment, use and potential retrofit scenarios. It is worth underlining that the implementation of the AUREE section designated for public buildings required a different approach with respect to the residential buildings part (subject of previous published contributions), as the typification of the public building stock and the identification of its archetypes have been deemed needless.

Moreover, it is shown in the present work how it was also possible to deepen the knowledge level for public buildings by integrating the UBEM-based methodology with a BIM-IoT framework aimed at collecting and processing real-time data concerning buildings occupancy and indoor environmental conditions, by taking advantage of low-cost IoT sensors. This additional framework part, which is of primary relevance in this paper, introduces a building link in the map to directly access an open WebGL 3D scene designated for enabling a dynamic visualization of the building information model (BIM) and the selection of objects linked to the IoT platform, to access data from real-time monitoring. Even though this experimental part of the methodological framework has been tested only on a pilot case study (*i.e.* the Sotacarbo Headquarters), the workflow can be assumed as replicable and scalable.

The results emerged from this work demonstrate that it is possible to create an open system, which can be intuitively consulted by "non-expert" users as well, to display real-time monitoring data, such as those of sensors used to measure the energy consumption of a building, its internal environmental conditions and usage profiles. The system is fully open, works with sensors whose data are available via cloud and do not need any specific proprietary tool, except the exportation of ifc model that can be created with any BIM authoring. The present study therefore contributes to confirm the key-role that Building Information Modeling (BIM) and the latest Industry 4.0 technologies (like Internet Of Things devices, cloud computing, digital twins etc.) may have in the energy transition of the built environment, in a sustainable perspective of optimizing buildings energy consumptions in an urban scale.

From a broader perspective, the proposed tool could provide a valid open support for controlling and improving the management of rising renewable energy communities [52] made up of several buildings which, in symbiosis, organize collective and citizen-driven energy actions aimed at optimizing the production and consumption of energy from installed renewable sources locally.

Conclusions and future work

The following concluding remarks about the latest findings of the AUREE project can be made:

1. The accomplishment of the Web-GIS portal section reserved for public buildings provides both common citizens, public administrations and technical facility managers with an open Urban Building Energy Model (UBEM) by making available general, technical and also energy-related information about the most relevant public buildings in Carbonia (Cagliari, Italy);
2. The Geoportal section for public buildings supplies a valid open-source digital support to guide, through a progressive knowledge deepening, common end-users toward proper conscious "energy behaviors", as well as public administrations and decision-makers toward a sustainable facility management;
3. The experimental integration of the UBEM with an open Web Graphics Library interface, for visualizing the BIM model of a pilot case study (*i.e.* the Headquarters of the Sotacarbo Research Centre) and accessing the open IoT platform to read real-time sensors data, brings the advantages

of introducing such innovative technologies in the AEC (Architecture, Engineering and Construction) sector to light.

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Currently, the general purpose of the research is main-oriented on improving the methodological procedures implemented and the contents of the AUREE portal on residential and public building heritage topics. Relevant developments related to studies on the public building heritage concern the Indoor Air Quality (IAQ) analysis through the implementation of commercial sensors on case-study buildings and the monitoring of the IAQ variables. Measurement campaigns on the medium (weekly, seasonal) and long (annual) term will allow acquiring information both as regards the profiles of use (medium term) and the influences induced by climate change (long term). The collected data will be processed and made available to allow different end users (ordinary citizens, energy managers, facility management workers, etc.) to verify, with different detail levels, the performance of public buildings. Easier implementation is the goal of optimizing the existing procedure. The basic information models will be more detailed. The model used to represent the building and the sensors will be made networkable with models developed for the procurement of management of public buildings.

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