ZEB PROTOTYPE CONTROLLED BY A MACHINE LEARNING SYSTEM

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ABSTRACT

This communication concerns a research project by the Interdepartmental Research Centre for Territory Construction Restoration and Environment (CITERA) of Sapienza University of Rome in collaboration with ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) based on the realization of a 1:1 scale demonstrator of a Zero Energy Building that allows continuous experimentation of new technologies for innovative photovoltaic systems, efficient storage systems and high-performance envelope materials.
In particular a measurement protocol has been developed for both the overall efficiency of the building and the individual technological components with a view to a comparative critical analysis of the integration of the individual components in the building-system complex. All the technological systems has been used in Solar Decathlon Middle East 2018 competition in Dubai.
The project concerns the development of a control and management system for photovoltaic energy production systems for the ZEB prototype, based on an intelligent self-learning system (AI) able to optimize the parameters of self-produced electricity supply based on real consumption of air conditioning equipment, electrical power supply to the equipment, access control and safety equipment.
The most immediate result concerns the integrated design of both the hardware systems for the production and use of electricity and the algorithms that continuously measure parameters such as grid load, consumption and electricity production, and which takes into account weather forecasts, energy tariffs, and learns the trend of electricity consumers through the use of artificial intelligence.

Keywords: ZEB, machine learning control

INTRODUCTION

One of the most interesting aspects of the evolution of contemporary cities is certainly connected to computational technologies integrated into buildings. Despite being a consolidated process, in recent years the binomial building/electronics is having developments that deserve a deep reflection. The building evolves by exploiting the most modern technological opportunities to be able to face the changes in society and thus continue to perform, in an increasingly “intelligent” way, to its original function of demonstrating “human needs”**.** The first step was certainly the integration of the already existing and well-tested domotic technologies in domestic environments, but the real paradigm shift is bringing artificial intelligence in its declination of *machine learning*: a real Darwinian evolutionary process in which housing units "learn" to adapt themselves to the human demands and needs, even if sometimes unexpressed. This opens up an incredibly vast field of possibilities: buildings equipped with advanced sensors and able to perceive the internal and external conditions, optimizing their energy consumption with significant savings for the individual, the community and the environment, while respecting the needs of the people living in the house, protecting residents from unauthorized intrusion, interacting with residents in an increasingly comfortable and intelligent way, ensuring the most disadvantaged categories (elderly, children and disabled) a higher standard of care. These are just some of the developments that seem to affect the intelligent building today. At the moment, the so-called artificial intelligence is only an instrument of analysis of the reality, which elaborates different scenarios exploiting the high capacities of the modern computer systems through statistical algorithms, imitating the human capacities of choice.

The design idea involving Sapienza University of Rome in collaboration with ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), comes from the experience in the Solar Decathlon Middle East 2018 where Sapienza University participated with its Team by creating a prototype of a house entirely powered by solar energy. The engineering components, technology and management systems that has been subjected to technological experimentations in both Italy and Dubai, is the "core" of the new project, which has been revisited to adapt itself to the Mediterranean climate aiming to the construction of a building classified as a Zero Energy Building, a complex building and technology system based on principles of Energy Efficiency, Home Automation and Smart System Management. This virtuous integrated domestic environment is also provided of artificial intelligence elements that adapt the environment to the user profile for whom is intended to.

DESIGN AND REALIZATION OF THE EXPERIMENTAL PROTOTYPE

The project has the general objective of dealing with the new challenges of contemporary society that require a different way of designing, constructing, managing and improving buildings. In particular, the specific objective is to create a Smart Solar House capable of ensuring maximum efficiency and effectiveness in the use of natural resources and to provide an attractive, accessible, safe, comfortable built environment, competitive in terms of costs and able to improve the quality of living.

Coming from the traditions, it is therefore introduced a new approach to Architecture which can be able to exploit all the possibilities offered by the use of renewable energy sources and highly innovative technological and construction solutions with low environmental impact. Infact the project is focused not only to the energy and environmental efficiency characteristics typical of a Zero Energy Building and a Green Building, but also to those of intelligence and flexibility through a continuous interaction with the environmental context, the built environment and users, in order to acquire data and information useful for the optimization of its operation, up to the possibility to change quickly its distribution structure and its size to meet the growing needs of the individual family, and to adapt itself to the different types of buildings existing in the city.
According to the revolutionary model of Architecture 4.0, the project intends to apply and test the most advanced tools, materials and technologies available today in the building industry in order to create a sustainable house able to meet different needs for efficiency, comfort, safety and affordability posed by the Architecture of the 21st century. Taking advantage of the enormous and still unexplored potential offered by digital modeling (BIM), mixed reality (virtual reality and augmented reality) and 3D printing, the project balances typological, construction and technological aspects, focusing on innovative design and materials, renewable sources and the latest generation Home Automation Systems (machine learning, virtual assistant, intelligent app).

Therefore the objective of the project is at the same time at a *typological level* (smart shape), relating to the shape and orientation of the building, positioning and sizing the openings and the distribution of interior spaces, in order to promote natural lighting and ventilation, the use of renewable energy and the reduction of energy needs; at a *technical-constructive level* (smart snvelope), concerning both the characteristics of the structure, in order to maximise its resilience and flexibility and reduce construction costs and times, and the thermohygrometric characteristics of the envelope in order to reduce energy requirements and maximise levels of thermal, acoustic and luminous comfort; at a *technological level* (smart systems), promoting the use of high-efficiency solutions, the integration of renewable energy sources and the use of advanced Building Automation and Internet of Things (IoT) systems in order to reduce the consumption of primary energy from non-renewable sources and maximize the levels of internal comfort; at a *socio-cultural level* (smart people) through training and directly involving users who will be able to manage energy consumption and comfort levels in the best possible way and in a conscious manner through the use of home automation systems.

The criteria underlying the design concept are those of bioclimatic architecture and sustainable design, based on a strategic approach that allows to fully exploit the climate and the context in which it is located, realizing the construction through a rational use of climatic and energy resources in order to ensure environmental well-being.
The object is the result of a study aimed at the environmental quality and the relationship/continuity between indoor and outdoor environments with particular focus on the following aspects:

Form and orientation: analysis and monitoring of climate parameters (use of ENEA climate station data); *choice of materials and components of the building envelope*: performance, comfort, standardization, regenerable materials; *internal distribution choices*: comfort, functions; *sustainability*: use of natural resources and renewable energy sources;

Standardization/pre-fabrication: development of a reproducible model for the realization of innovative components constituting the building envelope.

The components of the building/systems are designed and built with standardization criteria using technologies strongly oriented to prefabrication that allow a significant reduction in time and cost of construction, as well as energy consumption and environmental impact. Even the technological and system elements are mainly oriented to the concepts of standardization, realized with "plug and play" assembly method and integrated with management and control systems that allow to be updated and/or self-learn from the response to certain stimuli, optimizing the management of the building-system throughout the useful life of the demonstrator.

The project is a prototype of a single-family home with a net area of 47 m^2 divided into three areas: living area with open space kitchen, double bedroom and bathroom.

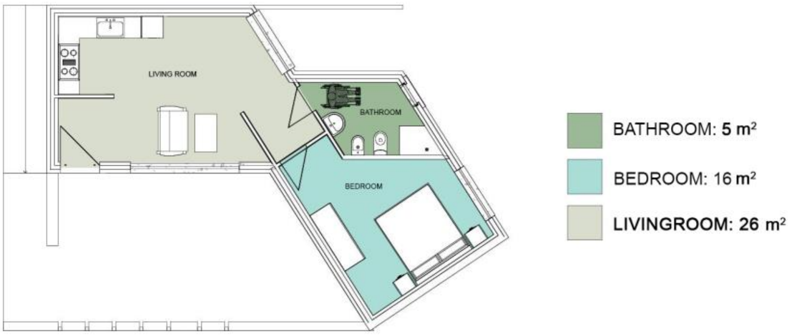

Figure 1: Solar House - Ground floor functional layout

The pitched roof is designed for the integration of a photovoltaic system (n. 32 modules) with an implemented automation system able to manage and control the entire domestic environment: envelope (opaque, transparent, shielding), ventilation, lighting, winter/summer air conditioning, hot water production, IAQ control, microclimate parameters, home automation users and security systems.
It is also planned to build a room outside the demonstrator to be used as a technical room for housing technological systems.

The construction system identified is the XLAM wood technology, which revolutionises the way of conceiving load-bearing surfaces compared to framed or trellis wood systems, introducing the panel as a new basic element for wooden construction, with which it is possible to think of load-bearing surfaces that can already be "cut out", depending on architectural requirements, complete with openings for doors, windows and stairwells, relying on a high degree of prefabrication. The XLAM panel is an engineered wood product composed of at least three layers of spruce boards, crossed and glued together.
The boards that make up the panel belong to the minimum resistance class C24 - S10 and are previously planed, classified and joined by finger joints, in order to ensure structural continuity between the lamellas that make up the individual layers.

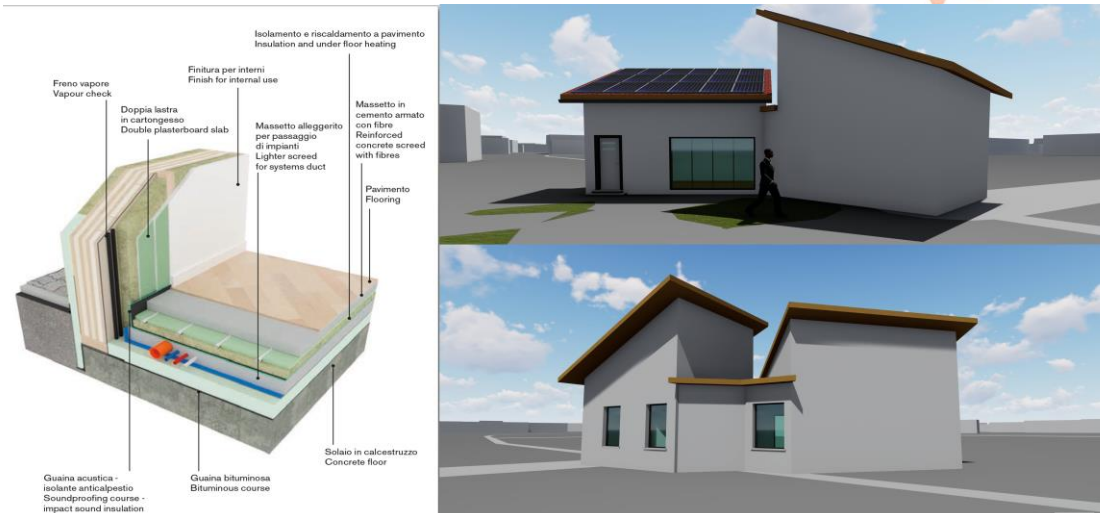

Figure 2: XlamDolomitiProduction technological section: example of wall-raft foundation stratigraphy and render views.

The structures made of XLAM have characteristics of environmental sustainability, energy saving, seismic resistance and fire resistance and are used in the construction of the load-bearing elements of the building such as walls and floors.

MEASUREMENT AND MONITORING PROTOCOL

After designing the experimental section, CITERA and ENEA have developed a Measurement and Monitoring protocol based on the requirements imposed by the Solar Dechatlon competition in terms of energy efficiency, energy management and sustainability.
As shown from the graph in the figure 4 these three criteria, were among the most important of the building presented for the competition, but unlike the communication architectural design and sustainable transportation, are likely to be further improved.

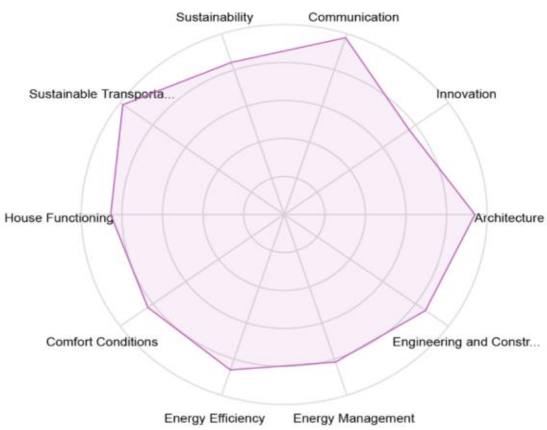

Figure 3: quality requirements

So to evaluate the house's electrical energy self-sufficiency, management and reduction of energy consumption has been realized a monitoring and measurement system, collecting data of the different electric energy flows during the house functioning period. The main parameter monitored every ten minutes are the electricity consumed for heating, cooling, ventilation and lighting, the electricity consumed by other house loads, load consumption for surface area, net electrical balance and temporary generation consumption.

Moreover the system will evaluate the functionality and efficiency of the house design, systems and components, in addition to their contribution in reducing energy consumption, demonstrating the higher level of functionality of the house structure, envelope, electricity, plumbing, HVAC, solar system, and their integration monitoring profile pattern correlation and efficiency of demand-response devices

Many sensors integrated in the bacs equipment will evaluate the capacity for providing interior comfort through the control of temperature, humidity, lighting, quality of interior air and acoustic performance.

As an example of the monitoring systems outputs in fig. 5 the net electrical balance in real time of house energy production through PV system versus overall energy consumption is shown.

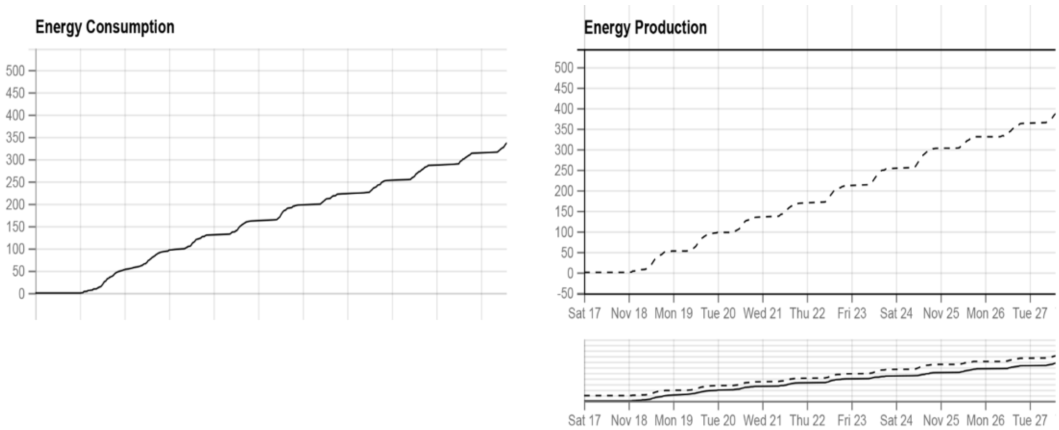

Figure 4: Overall energy consumption vs energy production through PV system

AI SYSTEMS FOR PV PRODUCTION SYSTEMS

In order to further improve the performance of energy efficiency, energy management of the demonstrator it was decided to integrate the AI and Machine Learning in the base system through the use of the so-called "neural networks", computational systems that are inspired by our nervous system. The human being, therefore, only has to monitor this learning process, correcting the program when it fails and providing positive feedback when it operates correctly. These computational learning techniques based on artificial intelligence have recently begun to take hold in the energy sector as well. In fact, the International Energy Agency (IEA) predicts that even in the energy field AI will be decisive in the years to come and will transform global energy systems in a fundamental way, making them more interconnected, reliable and sustainable. In the field of clean energy production and energy consumption in general, there are many complex problems to which AI can find solutions and there are already many projects started on the basis of this technology.

As far as the production of energy from renewable sources is concerned, it is well known that uncertainty about weather conditions is a major problem. Being heavily dependent on photovoltaic or wind power systems is risky because, in case of bad weather conditions, the supply of energy should be compensated by other sources, a very expensive and unsustainable operation. It is therefore reasonable to think of AI to deal with these problems and optimize the production, transmission and storage of energy produced by photovoltaic or wind systems scattered throughout the territory. By integrating in real time meteorological data with those from satellites, artificial intelligence systems are in fact able to identify recurring patterns, maximize efficiency and minimize the risks for the supply of electricity.

At the local level of microgrid domotics for reducing energy consumption and energy efficiency in buildings, the AI is perhaps having an even more decisive impact. IoT systems are based on a network of sensors that measure and communicate with each other via the Internet, providing a very large amount of data that is then processed and translated into efficient solutions. The domestic sector represents one of the sectors with the greatest potential as it is estimated that by 2040 there will be one billion "Smart Homes" and 11 billion smart appliances in the world, the optimization of which through artificial intelligence would allow a reduction of more than 10% of domestic energy consumption. In addition to the fact that these interconnected networks are already producing an enormous amount of data that can be used by utility companies, solutions aimed at consumers will also come shortly afterwards. Monitoring the use of household appliances, for example, can generate data that allow, with AI tools, to estimate the costs and project them on the hypothetical bill at the end of the month, helping the user to make the most sustainable choices.

In practice, the built-in artificial intelligence software, in fact, records and interprets the energy needs of the family and then actively intervenes and eliminates all unnecessary consumption. If, for example, the solar energy reserves are about to run out, then the system can automatically turn off a television set or turn down the lights at home, or even reduce the volume of the stereo or the intensity of a fan.

At the level of control and management of the photovoltaic energy production system with which the demonstrator is equipped then Artificial Intelligence (AI) techniques can be applied to three main areas: (1) Forecasting and modelling of meteorological data, (2) Basic modelling of solar cells and (3) Sizing of photovoltaic systems.

Artificial intelligence (AI) infact can monitor multiple solar PV plants and its overall status, by integrating various data such as in power generation, maintenance needs, and power generation efficiency in real time. In particular, platform enables on-demand maintenance services by tracking and forecasting various factors that are crucial to solar power generation, such as in hardware maintenance and partial component installations. Through real-time AI analysis, the system can notify users of potential power plant malfunctions, forecast power generation, and provide comprehensive database for efficient operations of solar power plants.

CONCLUSIONS AND FURTHER DEVELOPMENT

Although this project is limited to an application of AI systems to a microgrid domotics, there is no doubt that there is great potential for these technologies in the near future of other sectors at national and global level related to the world of energy. It is therefore reasonable to take a close look at the various projects and applications of the AI aimed at increasing the efficiency of renewable sources and making everyday consumption more sustainable.

The future logic in fact, to reach the 2030 objectives, is that it is not enough to have systems for the production of energy from RES installed in homes according to the logic of distributed micro-generation and local smart grid.
In order to save and correctly manage the self-produced energy, there must be a control and management system capable of learning our consumption habits and, from time to time, of programming the system according to our needs. In practice, the acquisition and management of Big data, managed by artificial intelligence, will make it possible to cross in real time consumption data, self-production data and data from the market to build the most convenient mix at that time without penalizing in any way the environmental quality of the buildings in which we live, regardless of the completion of human intervention and customizing consumption profiles based on the real needs of users of a given environment.

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