INFORMATION AND COMMUNICATION TECHNOLOGY FOR INTELLIGENT AND INTEGRATED CONTROL IN BUILDINGS: CURRENT DEVELOPMENTS AND FUTURE RESEARCH

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ABSTRACT

In a near future, buildings and equipments immerged in their environment will communicate and provide information on their status ubiquitously. ICT (Information & Communication Technology) is recognised as the key for achieving such a vision. This is why the French Building Research Centre (CSTB) is currently working on an open framework for data collection and processing installed in any built environment. The research framework is called CSTBox framework. This is an internal research work aiming to develop technical and validation tools for building-related domains such as energy efficiency, ambient-assisted living and internal air quality assessment up to now. In parallel, a European R&D technology roadmap initiative called the REEB coordination action has identified all potential ICT contributions to the energy efficiency of buildings mainly via improvement in integrated design, intelligent control, user awareness and decision support to various stakeholders throughout the whole life of buildings. It has also identified energy management and trading. This paper presents a combination of the CSTBox framework and the REEB coordination action for future ICT-empowered smart buildings. The CSTBox framework offers throughout its existing components a holistic way to supervise the building by automatically analysing information coming from all connected devices, from the Internet or from energy service providers. This combination can then be used to efficiently advice the control of HVAC (heating & cooling), lighting, and hot water systems by optimizing energy production, storage and consumption devices inside the building via that same framework according to the users' needs and wishes to fulfil the REEB identified issues.

Keywords: Energy-efficient buildings, Intelligent and Integrated Control, REEB project, CSTBox framework, Data collection and storage.

1. INTRODUCTION

In the field of energy efficiency, buildings are significant consumers of energy. Although more and more buildings deploy control solutions, the latter remain often standalone and proprietary legacy systems. This especially is due to the unicity of the application (or function) for which the building equipments are developed. Consequently, the development of many new technologies should drastically change in order to deal with a reinvented built environment where energy efficiency would only be one example of the field applications amongst the following: micro-generation to management technologies for lighting including the new LED standards, HVAC (heating & cooling), security and access control, fire safety control and office appliance controls for new and retrofit applications and their integration in a holistic way.

In this new vision, ICT becomes an essential asset. The convergence of technologies and environmental regulatory drivers offers unprecedented technical and business opportunities for powerful innovations to be integrated in new and existing building stocks. The related technologies include embedded systems, standardised and interoperable communication protocols, Smart Grid and Internet applications. An acknowledged vision today considers future buildings along with their components and environment providing information on their status. This information will be interoperable via common protocols for holistic automation and control. In the energy domain, the whole building will be supervised by intelligent systems. It will be able to combine information coming from all connected devices, from the Internet and from energy service providers to control efficiently HVAC, lighting and hot water systems. It will do it along with energy production, storage and consumption devices inside the building taking into account the users' needs. ICT is recognised as a key for both empowering people with smart e-metering and new smart e-devices. Then ICT becomes fully pervasive in the future optimization of energy in the built environment where Energy-efficient smart buildings finally integrate information management for an optimal energy flow over its lifecycle. In this context CSTB has developed an open research framework called "CSTBox framework" (Control and Sensoring Telemonitoring Box) for data collection, analyse and processing to be installed in any built environment supporting networked heterogeneous sensors and allowing the assembly of various business functions with easy evolution and extension capability thanks to a concept of service-component architecture and event-driven communication.

The REEB coordination action (European strategic research roadmap to ICT enabled Energy-Efficiency (EE) in Buildings and Construction), as a European R&D technology roadmap initiative achieved in the context of an EC-funded Coordinated Action (REEB Project 2010), has identified ICT contributions to the energy efficiency of buildings. It has studied improvement (and corresponding RTD) in integrated design as well as ICT tools for:

- EE design and production management,
- Integrated and intelligent control,
- User awareness and decision support to various stakeholders throughout the whole life of buildings, energy management and trading,
- Integration technologies.

The REEB coordination action for future ICT-empowered smart buildings can benefits from the research results and experimentation capabilities provided by the CSTBox framework. The paper will present our trend of developments at CSTB in the area of ICT to support integrated and optimised control in future so-called smart buildings through the CSTBox framework as a research basis tool federating and complementing functions for built environment. Then after a short presentation of the REEB project, the paper will follow up with exhibiting the outcome of the REEB project in terms of roadmapping RTD activities in this technological field and then presents a combination of the CSTBox framework and the REEB coordination action for future ICT-empowered smart buildings. It will finally conclude in a first insight of their potential impact in the future.

2. AN OPEN FRAMEWORK FEDERATING HETEROGENOUS PROTOCOLS: CSTBOX

The CSTBox framework is an open research framework for data collection and processing, activity analysis and action performing. It is composed of a set of running software and hardware devices comprising a data management box communicating to sensors, actuators and networked data service platforms. This framework constitutes a foundation framework to two main research fields: human in building activity modelling and building lifecycle software/hardware adaptation. In this section, we will first present the related work, then the objectives of our research and give a functional description of the CSTBox framework.

2.1 Background

A sensor/actuator system is composed of a collection of network managers communicating to devices that are heterogeneous in built environments due to the various degrees of application in which they might participate. Our research deals with three main contributions: heterogeneity, modularity and context awareness and hardware system independence.

Firstly, the devices and the network managers are heterogeneous and incompatible in built environments due to their increasing number and every building is different. Sensors and actuators are not only related to monitoring and control. In fact, devices for buildings come from home automation area where multiple vendors of proprietary protocols compete with proposals for standardisation like EIB, X10, OneWire, I2C and ZigBee and various standards like UPnP, DLNA, SLP, Jini and Havi have been proposed to enable interoperability between devices. In addition, several smart services for especially home environment have been proposed, based on OSGi (Lin, et.al, 2008; Chen, et.al, 2010) and research services such as Gaia aim for the development of platforms allowing service interactions based on software agents. The CSTBox framework software system goes a step further and manages devices using different communication protocols. The retrieved information is then reduced to a set of tight building-related vocabulary. Each supported protocol can be added by implementing a driver translating the raw heterogeneous messages into classified events.

Secondly, in smart home domain, several of the existing standards also try to address specific use-cases for appliance aggregation or service aggregation (Borello, et.al, 2006, Merabti, et.al, 2008). MacGrath (2003) describes uses semantic queries that refer to ontologies for a semantic service and WISSE (Lopez, et.al, 2006) focuses on a framework that defines the interaction between mobile RFID/WSN entities and the services they receive. “Smart” entities that provide sensor data stamped with their unique ID and that can interact spontaneously and dynamically. Freustack (2006) focuses on the connection between home-based and netcentric services. Context-awareness relies on a functional decomposition to provide reusability and evolution facilities by gathering contextual information transformed into symbolic observables. Middleware models and experiments such as the Activities of Daily Living study (Surie, et.al, 2010), SOCAM (Gu, et.al, 2005) and Contextors (Rey and Coutaz, 2004) provide some mechanisms to model, collect, store and potentially process these observables. The CSTBox framework software system is based on an OSGi service-component model and CSTBox framework applications are built by assembling components at runtime. This approach enables custom-sized applications well suited for embedded hardware.

Thirdly, concerning the software/hardware techniques, existing platforms such as ProSyst (2010) are focused on open standards technology and has been most actively involved in helping to create the OSGi specifications. They offer products and services for all vertical markets that use OSGi technology, such as Mobile Devices, Smart Home, Automotive Telematics, Enterprise and Industrial Applications (SheevaPlug Guru). ZodiaNet (2010) proposes a device manager called ZiBase which connect a large range of sensors (X10, Oregon Scientific, etc.). It drives domotic appliances via HomeSeer software. Their box has no external hardware port such as USB, Serial, etc. ZiBase integrates a proprietary RF communication system at 433 and 800 MHz and keeps control of heterogeneous hardware integration by providing their own gateway. Their internal application can also be modified by uploading scripts that hide inner protocol details. CSTBox framework software is programmed in Java SE and runs at least on Linux/ASUS WL500g (32M Flash and RAM), on proprietary embedded home controllers, higher performance hardware and on MS Windows. It tries to keep external hardware connectivity by supporting standard serial interfaces.

Finally, the CSTBox framework software system is an application-independent framework that manages various devices and transforms information to a set of tight building-related vocabulary through a service-component design that enables custom-sized application on embedded systems. Nevertheless, its independence from end-user applications can only be achieved by facing to co-design challenges.

2.2 Challenges

Different to the approaches focusing on device control and interoperability, the research coming from the CSTBox framework concentrates on the openness of building services because widespread open software development is, by its very nature, a collaborative effort (Brooks, 1975). We thus take the aggregation of services one step further throughout two aspects: software and hardware openness. The definition of open systems has changed over time (Kim, et.al, 2010), but today open systems are usually considered to interoperate through open interfaces. An interface is simply a common boundary to make a connection between two software/hardware components. Once the software system is designed, they should be able to evolve to face the various potentially new ways to collect and gather information in buildings. Hardware design should be able be interfaced with vendor specific devices via standard existing connections. Derived from these identified challenges, it appears that a holistic open framework is needed to benefit from the increasing various range of achievable functions.

2.3 CSTBox framework open architecture description

The CSTBox framework is a software design with a set of hardware prerequisites that allows programmers to easily remove and replace software and hardware components to develop new applications. It is composed of an ICT theoretical research part and an engineering part in order to make as much as possible *in-situ* experimentations. The central management software system described before relies on sets of sensors. The notion of sensor is to be considered in a comprehensive way: analog or logic physical sensor, complex sub-system or wireless meta-sensor (e.g. Agilent data acquisition system or alike), or even external services (e.g. getting weather data via the Internet).

The software service-component framework benefits from the OSGi underlying deployment system and its component architecture description capability. Hence, the features can range from simple component and configuration management to multi-server repository-based deployments. It then simplifies the server operation and helps maximizing faultless services. Here is an example of the operational modules of the system:

- *Bundle management* Control your system life cycle and deployment.
- *Software repository* Profit from powerful resolving possibilities imported from Maven repository.
- *Logging* Collect and monitor all log events.

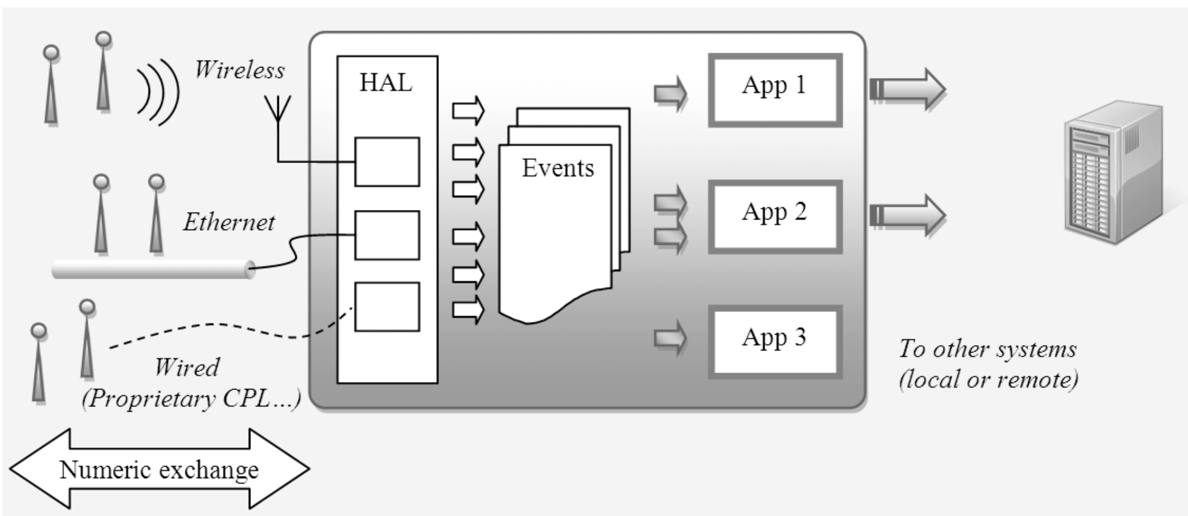

Figure 1: CSTBox framework architecture.

Two theoretical research studies aim to develop specific components for the overall CSTBox framework architecture. Firstly, advanced software component assembly techniques are studied in terms of how to automate self-evolution and auto-adaptation of the framework (Ferry, et.al, 2009). Secondly, processing data classification automatically enables a greater autonomy of the system as well as a reduced cost of its installation and configuration. We are currently working on runtime data classification and activity modelling techniques based on Zanni's (2006) work on data classification.

2.4 Results and practical experiences

Up to now, the framework has participated in several national projects, namely Energihab for energy usage monitoring and GerhomeLabs for assisted living and furnished many data and experimental results of the different components of the system. Figure 2 shows the sensors and actuators being configured before a deployment in several buildings for Energihab. Figure 3 shows the hardware being installed via network and equipped with the CSTBox framework for some experimentation in situ about the monitoring of energy consumption. We have already started experimentations in the fields of Ambient-Assisted Living, internal air quality assessment, collection of data related to inhabitants behaviours and EE in the built environment.

Figure 2 (left) and 3 (right): CSTBox framework in preparation of large scale deployment

3. THE REEB PROJECT

The CSTBox development as presented in the previous section is a typical example of research projects currently ongoing in France, and indeed throughout Europe, in the fields of ICT support to smart buildings, and with applications to various domains like energy management and energy use optimisation, or Ambient Assisted Living, just to refer to two examples only. As a need for coordinating and rationalising current and future RTD (Research & Technological Development) in Europe in the area of ICT support to energy efficiency in constructions (today considered a key challenge in Europe), the REEB Coordination Action (2010) has been launched in May 2008 (for a duration of 30 Month): it is supported by the European Commission in the context of FP7 (Framework Programme 7), and coordinated by CSTB. It has been set to develop a European-wide agreed vision and roadmap providing pathways to accelerate the adoption, take-up, development and research of emerging technologies that may radically improve building constructions and their associated services in terms of enhanced energy consumption. Hence, REEB is a generalisation in terms of R&D coverage with a focus on energy efficiency that can benefit from typical research achievements like the CSTBox framework and prototypes in which the functional application is not domain-specific.

3.1 Strategic research agenda

After feedback and validation from many stakeholders at the crossing of ICT, construction and energy, the vision and roadmap of the REEB project intend to be a key milestone in identifying, synthesising and prioritising a comprehensive set of agreed main problems, challenges and prescribed RTD. It specifies the new ICT-based solutions related to the future delivery and use of energy-efficient facilities and buildings at a European and worldwide level. Typically the elaboration of the vision (REEB Consortium #1 2009) has resulted from the crossing of inputs provided by the REEB partners and the stakeholders that have joined the International REEB Community. It brings together the ICT community and key actors of the Construction Environment and Energy business sectors. A key finding is that, while there is an emerging consensus about the key RTD issues in ICT enabled energy efficiency of buildings, the potential impact of various technologies is not sufficiently well known. Thereby it is difficult to assess the relative importance of specific technologies, applications and systems and therefore it is necessary to develop a more holistic understanding of the potential effects of ICT on the energy efficiency of buildings. Consequently, the vision in REEB consists in envisaging the high-level impacts of ICT to energy-efficient buildings ICT to evolve as follows:

- *Short term* Meet energy efficiency requirements of regulations and users.
- *Medium term* Optimise energy performance of buildings considering the whole life cycle.
- *Long term* Business models driven by energy efficient prosumer buildings at district level.

ICT contributions to energy efficiency of buildings concerns mainly the holistic design tools, automation and control systems, and decision support to stakeholders. In this field, full exploitation of the opportunities offered by

ICT requires adjustments of the processes and contractual practices of the construction sector. Therefore, the core is a recalibration of the initial focus from the construction cost to whole life performance (for instance, value to owners). To align with the industry priorities, results are then organised into five corresponding categories of research topics as depicted in Figure 2.

Finally, the REEB roadmap can then be decomposed into five sub-roadmaps and provides specific RTD challenges for each category of research topics as identified in the REEB vision to face at short, medium and long term. It also details the long-term situation and its evolution from now. Similarly, to the REEB vision, the methodology leading to the REEB strategic research agenda and its various RTD priorities for ICT supporting energy efficient buildings has been based on the integration and synthesis of inputs provided by the REEB partners and key target groups of the ICT4EEB community. This community includes the European Technology platforms, the RTD projects in the three core areas of focus and the European Commission. The baseline of the work relies on the EC policies and the visions and strategies of a number of related initiatives. The next section exhibits the Intelligent and Integrated Control (IIC) sub-roadmap, which is detailed in the REEB Consortium #2 (2010) public document.

3.2 Roadmap for Intelligent and Integrated Control (IIC)

The study of three main drivers (dynamic electricity prices, increasing energy prices and regulations) leads to the main achievements related to this IIC sub-roadmap. Firstly, the dynamic electricity prices and the local production of electricity encountered the barrier of return on investment, which has still to be proven for users. The impact is the increased demand for integrated building management system (BMS). Secondly, the increasing energy prices encounter the insufficient interoperability barrier. This provides opportunities thanks to interoperability standards. Finally, the regulations and standards for energy efficiency of buildings encounter the problem of end-user acceptance. The impact is the creation of “MS Home” (EnergyPlus for everybody). As far as the IIC field is concerned, REEB has fundamentally identified the following areas for future investigation: smart lighting, ICT for micro-generation, storage systems and predictive control), quality of service (improved diagnostics and secure communications), monitoring instrumentation (smart metering), wireless sensor networks (hardware, operating systems and network improvements) and automation and control (system concepts, intelligent HVAC (heating & cooling).

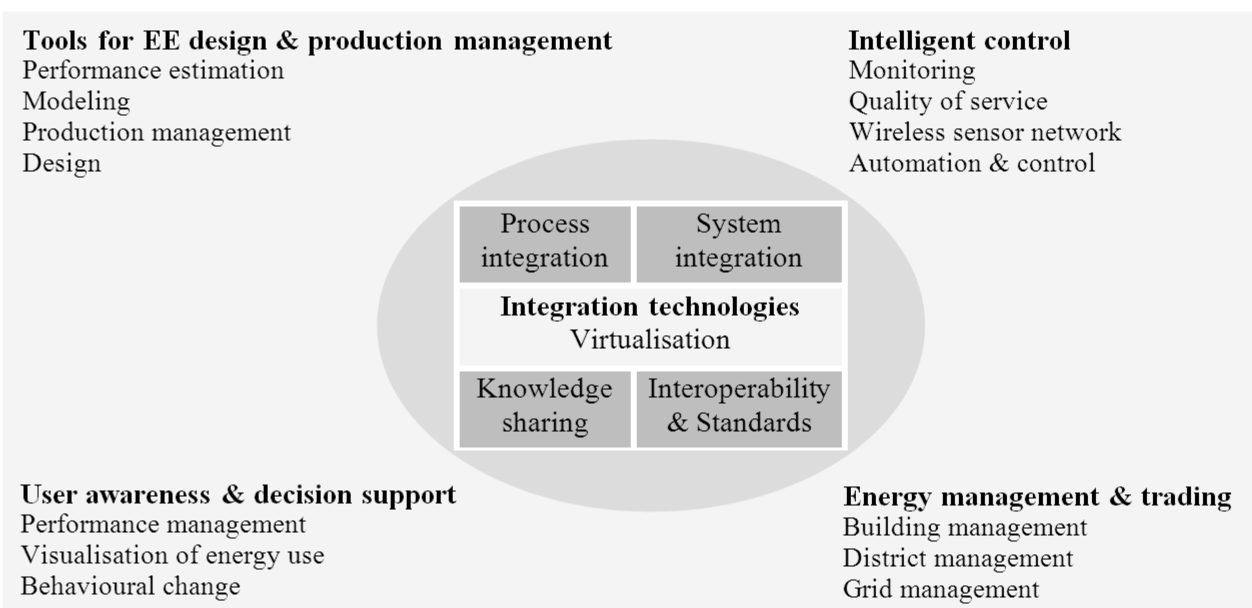

Figure 2: ICT enablers for energy efficient buildings.

In the future, buildings, their components, equipments and their environment will communicate and provide information on their status ubiquitously. This real-time available information will be interoperable via common protocols for holistic automation & control. The CSTBox framework offers throughout its activity analyser component a way to supervise the whole building by combining information from all connected devices, from the Internet or from energy service providers. This combination can then be used to efficiently advice the control of HVAC (heating & cooling), lighting, and hot water systems by optimizing energy production, storage and consumption devices inside the building via that same framework according to the users' needs and wishes.

Short term	**Medium term**	**Long term**
Quality of Service sub-roadmap		
• Enable diagnosis of EE building components (both passive ones like windows and active systems). • Develop transmission protocols that satisfy specific ICT4EEB requirements (reliability, security and privacy).	• Generalize diagnosis of EE building components by embedding sensors in components. • Develop self-diagnosis abilities of sensors. • Develop a common shared standard of ICT4EEB-oriented communication protocol.	• Develop BMS that will be fully auto-controlled and auto-monitored, discovering their own malfunctions. • Achieve WSN that will be autonomous in their energy supply.
Monitoring sub-roadmap		
• Develop new kinds of sensors when necessary and decrease costs of manufacturing. • Develop Smart Meters able to measure, record and visualize all kinds of energy consumption.	• Make Smart Meters interoperate for the build-up of Smart Meter networks at district level. • Embed more intelligence in sensors to perform a first level data analysis locally.	• Integrate tightly and securely Smart Grids and Smart Buildings through Smart Meters, allowing the Smart Grid intelligence to control directly home appliances. • Extend and distribute embedded intelligence to manage EE issues locally.
WSN sub-roadmap		
• Improve sensors in terms of reliability, sensitivity, maintenance, remote diagnosis and communication abilities. • Reduce energy consumption of WSN. • Identify possible negative side effects associated to WSN.	• Define standardized roles and services for sensors and actuators to allow plug-and-play of new devices and self-reconfiguration of sensor networks. • Allow WSN to support change of topology for network optimization. • Develop powerful embedded OS that can provide more real-time functionalities.	• Achieve completely autonomous sensors in terms of energy supply thanks to advanced energy harvesting technologies. • Integrate several functions (light, temperature, air quality) in sensors to reduce their number. • Integrate autonomous sensors in building components (windows, walls) at the beginning of the construction.
Automation & Control sub-roadmap		
• Develop holistic control strategies that integrate all building dimensions and develop a common conceptual framework for interoperability with the definition of a relevant set of services for sensors and actuators. • Take user activities and building usage into account. • Implement predictive control by considering weather forecast. • Address all BMS components for predictive maintenance.	• Design new holistic control strategies by simulation. • Integrate simulation tools in BMS to optimize control strategy in real-time.	• Introduce self-learning features in control algorithms to adapt to the user's preferences, the building age, and the possible change in the building environment. • Allow control algorithms to suggest changes in the WSN (need of new sensors, disabling of existing ones).

Table 1: Sub-roadmap classified by identified investigation areas.

A summary of the IIC sub-roadmap is provided in Table 1 classified by the identified investigation areas. Concerning the quality of service, some self-diagnosis systems already exist in the HVAC and lighting domains. Some sensors can also monitor their own functioning. Communication protocols also include error detection in the data frame and many of them (open or proprietary de facto standards) co-exist with different properties.

Concerning the monitoring, existing smart meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with Smart Grids. However, all needed sensors, with the required sensitivity and accuracy, are not available at reasonable cost for a large-scale deployment. Some Plug & Play sensors already exist, whose features can be taken automatically into account by WSN-based BMS to optimize control of the related actuators. However, existing automation and control algorithms are most often restricted to sub-systems such as heating, light, ventilation, µ-generation… and stay independent from each other and hard-coded in the devices with little possibility to update or modify them by a centralized control instance. The CSTBox framework offers a way to combine these equipments and create holistic algorithms.

The tangible development of sustainable connected buildings and homes (and groups of buildings in neighbourhoods) with intelligent integrated control, means empowering them with ICT in the context of the merging of Ubiquitous Computing and the Internet of Things: a generalised approach, as initiated with the CSTBox, and consisting in equipping buildings with sensors, actuators, micro-chips, micro- and nano-embedded systems, will allow to collect, filter, analyze and transmit data, and produce more and more information locally, to be further consolidated and managed globally according to business functions and services. The further development and implementation of meshed, self-adaptable and easy to install sensor networks (i.e. hardware and software, operating systems and protocols, advanced control systems) will lead to improved diagnostics and enhanced building performance data analysis, and therefore improve energy management systems in homes and buildings A recent political agreement reached in Europe on the proposal for a Directive of the European Parliament and the Council on the energy performance of buildings strongly recommends encouraging the installation of active control systems (based on systems similar to the CSTBox framework) that aim to save energy.

4. CONCLUSION

As we mentioned previously, ICT contributions to the energy efficiency of buildings are mainly useful to a multitude of design tools, automation and control systems, and decision support to various stakeholders throughout the whole life of buildings. Considering the operational phase of buildings, their future and their components will namely ship information via interoperable common protocols for holistic automation and control. This is an area where the CSTBox framework is a typical example of R&D development that provides solutions to the issues identified in REEB, because it is an open platform for the federation of heterogeneous protocols using a unified approach to manage information from networks of sensors and equipments. Hence, by combining information from all connected devices, from the Internet or from energy service providers, the intelligent system constitutes a first stage and will supervise the efficiency of the whole building and control HVAC, lighting, and hot water systems along with energy production, storage and consumption devices, and taking into account the users' needs and wishes. A second stage consists of being the advent of building services labelling, as a potential incentive and rule-changer in providing new evaluation approach for building performance, should it be in terms of energy consumption improvement and control, risks and costs management, providing services for in-house health and ambient-assisted Living, etc.. Eventually, another field of interest is the exploration of the synergies of intelligent buildings into the Smart Grid (i.e. the evolution from passive energy efficiency buildings to positive-energy buildings actively participating to the grid). At the same time, this would enable the identification of the drivers motivating investments and highlighting the benefits of ICT-empowered innovative building services to public and commercial property, facility managers and owners, and house tenants.

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