Integrating Building Automation Technologies with Smart Cities
An Assessment Study of past, Current and Future Interroperable Technologies

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Abstract: Future smart cities would integrate a wide range of mostly heterogeneous systems and ICT is an essential asset in the coordination of those. The smart buildings, a major smart cities research and development domain, should advance beyond the complex automation tools and the anticipated energy and comfort envelope. The universal convergence to technologies that would enable the seamless integration with the anticipated smart cities urban environment should be highlighted. Although it is a concept widely accepted for current and future developing standards, it is much less communicated across scientific fields as for example the urban development and building automation. Even worse its necessity, in the latter, is frequently challenged. This paper firstly will try to address the market and scientific criticism towards a fully web-services enabled building in a fair and transparent approach. Secondly it proposes a system as an interoperability layer able to build advanced managements schemes by integrating the assets of current automation and monitoring systems to the Internet backbone.

1 INTRODUCTION

The population growth creates immerse problems in terms of energy management and sustainability policies, rising infrastructure cost, transportation congestion, micro climate changes, natural hazards and emergency situations handling (Kelly, 2010). Besides the technical and physical challenges, there are sociological, organizational and political as well (Dawes et al., 2009). These issues triggered a global move towards an holistic approach to ensure livable conditions and continued development in the governance sphere of the current and the future cities. In this context the smart city concept was introduced as an innovative ecosystem having the potential to address the increasing problems of urban environment. It will empower the participation of city's administration, citizens, businesses and other stakeholders in the effort to transform the cities under a common strategy.

One of the main targets for the smart cities transformation is the building sector in the frame of sustainability and energy efficiency. Nowadays the building has evolved from the essential structure providing the human shelter to a very complex construction incorporating many scientific fields. However it has not advanced as much in terms of thermal and electrical energy efficiency. On the contrary, the primary energy consumption of the building sector by 2009 in United States, has increased by 48% compared to 1980 (Energy Efficiency & Renewable Energy, 2007). Considering that, building innovations become the prime objective towards the influential sustainable urban future. It is apparent that to harness this potential the building sector of smart cities should undergo fundamental transformation in terms of integrated technologies.

In the context of this potential, big market share holders, mainly in the building automation and energy, were quick to fill the gap and grasp the opportunity for enforcing their own standards. Together with the sometimes vague definitions of the smart building management, it permitted also the modest market holders and start ups to offer their own innovating solutions. This trend was more than welcome and in fact was stimulated by the authorities since it offered business opportunities for powerful innovation to be introduced. In spite of that, as more and more parties entered with their own protocols, it started to become a babel tower where hardly any integration between manufacturers' solutions was possible.

The ones commonly found in computer and em-

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Table 1: Major open Building Automation Standards.

Standard Name	Domain of functionality
BACnet	Management & Automation
LonWorks	Automation & Field
KNX	Automation & Field
ModBus	Automation
M-Bus	Field
DALI	Field

bedded networks are good candidates for meeting both public and private needs. They provide the required interoperability that would catalyze the transformation of the smart buildings. Additionally, the ICT, bulletproofed in the competitive IT market, offered the required security and authentication schemes. Despite the above and the strong academic support, not every stakeholder of the smart building industry is convinced for the need of ICT based on web services.

The Internet enabled devices are now more than ever in the spotlight of both the IT as well as the smart grid research groups. However their purpose and usability is frequently challenged by the current mature building automation standards. Literature search did not yield any satisfactory and independent research on the advantages and drawbacks of each technology camp. Instead, there is an abundance of advocates and literature for each one individually.

We strongly believe that for the future smart cities all possibilities should be taken into consideration before crossing one out. Therefore this paper attempts firstly to examine the advantages claimed by the legacy building automation standards and highlight or refute accordingly. Subsequently it brings out the unique features offered by web technologies for a feasible rapid progressing towards smart cities and suggests a platform to gradually integrate them with the automation systems currently used.

2 COUNTERARGUMENTS

This section illustrates the major claims made by the current building automation specialists and major market share holders who meet the fully web enabled building with skepticism. Table 1 highlights the current major standards prevailing in building automation and management with their major domain of functionality (Kastner et al., 2005).

2.1 IoT as a Market Trend

The skeptics were quick to consider the IoT yet another Internet bubble like the Dot Com that should not base the building and energy management upon. They state that not enough comprehensive research has been conducted on the profitability of the intelligent buildings using the IoT. On the contrary, the research work and industrial reviews which have been conducted on the longterm investment evaluation and life cycle analysis, are for the traditional building automation system (BAS) standards (Wong et al., 2005). This inhibits at the moment the interest of industrial and other large scale projects where the cost benefits are not easily estimated, thus limiting the potential to residential applications or laboratory test-benches.

It is true that the IoT are over marketed nowadays. In fact many products are named IoT when in fact are just Internet connected devices without any of the fundamentals an IoT ecosystem should have. The major concern is the lack of clear added value for the consumer in question and in fact they are usually considered as a lifestyle gadget. However this does not mean that is all of a bubble. On the contrary, the global interest lead many advocates to believe that it could take years, but it will eventually introduce the innovating concepts that would revolutionize our regards of the buildings and their energy use. Besides, as IoT for intelligent buildings gets refined in the context of smart grid's standardization, the investment assessment by research groups and firms will be quick to arrive.

Legacy building automation specialists claim in addition, that there is not a clear approach and modeling for utilizing this enormous data brought by the extensive connectivity of large number of devices. Thus concluding that IoT is becoming more of a burden that an opportunity.

This cannot be further from the truth. The research in computer science is towards the creation of extensive models for semantically representation of the data originating from the excessive number of end devices, profiling the building occupants (Dong and Andrews, 2009) and even predicting the future behavior. In market terms, this paves the way for new business models based entirely on the building's sensors data analytics. An ambitious proposal could be for example the behavioral analysis of the occupant or retrofitting recommendations in order to limit the energy loses. Another possible scenario could be the comparison between different departments of an industry and identification of their energy wasting points together with the recommended, appropriate action. Both of the above are read-only (data-mining) without any automation. Taking into account the possibility of distributed small actuators the potential scenarios increase further in scale and magnitude.

In the end the "IoT potential" will be demonstrated by the risk-taking companies that are willing to develop innovative new products and services for the public.

2.2 Interoperability Challenges

One can not expect a single manufacturer to provide continued product development indefinitely, so the only possible way to assure the market is the existence of compatible products from multiple manufacturers. The current building automation players claim that the inconsistency issues of the past has been resolved; guaranteeing the current designs sustainability. BACnet association for example claims more than 800 unique vendors use the standard with an increasing trend and most importantly the vendors are not locally isolated but global as well. The same belief is observable on the LonWorks standard group, claiming a 4000 product range and their devotion to the open standards. This abundance of vendors competing for the market share(supporting the same standard) has additionally the capacity to drive the prices down.

In fact, literature even demonstrates designs for multi-protocol devices (Granzer et al., 2008), eliminating the need of specialized gateways for interprotocol communication; thus increasing the potential product range available for each one. Research groups simultaneously built on that for delivering not only IP enabled building automation but also a glimpse of the web services; significantly questioning the IoT and WoT investment necessity in an intelligent building (Wang et al., 2004).

However the interoperability in current standards comes at an evident cost. The fact that the major automation standards are open, does not imply they are for free. For example Echelon®, who governs LonWorks standard, charges a fee for every device using their Neuron Chip. The BACnet international on the contrary does not charge a fee, unless of course you require a certification of compatibility. Same case with the KNX standard where no per device fee is required, however the only available configuration tool(ETS4) requires a license. All these initial fees for the smaller vendors can seem a costly exercise. Unfortunately this becomes even more prominent when vendors produce a base product built with proprietary protocols and change extra for the inclusion of a standard interface. According to (McMillan, 2010) this is due to the fact that many vendor use add-on translation interfaces instead of directly build-in ones.

All in all it is apparent that integration of different, and even of the same standard devices by various vendors are not always straight forward. There is high discrepancy between the interoperability that are supposed to bring and the actual one.

2.3 Building Automation Performance

Legacy automation systems advocates strongly emphasize the verified and targeted performance of their own ecosystems. Furthermore, they do have plenty of enterprise costumers which prefer the certified devices and value the deliberately slow process with which these standards evolve and get refined. Quite often as well is valued more in the B2B relations the after sales service in which legacy building automation vendors generally excel, compared to the equivalent newcomers of web enabled products.

As these systems are more mature, it is expected to have been installed and evaluated in multiple premises. Throughout the years as well many research groups used them to measure the performance of the automation and the energy management (Kim et al., 2000; Park and Hong, 2009). In addition, research groups develop expansions based exclusively on those standards. For example a prediction model based solely on BACnet generated data (Pang et al., 2012) or a BACnet based data acquisition framework (Li and Neill, 2011). Those scientific outcomes increase the impact factor and credibility of those standards to the corporate world.

Although the analysis of IoT as building automation tool falls short at the moment, this should not be deterministic for the future of the technology. As more work is conducted on their communication performance and capabilities, the more they will find their way into the demanding market of building management.

3 WEB ENABLED BUILDING MANAGEMENT

Ultimately the way to bridge efficiently the multiple stakeholders and entities in a smart city without many intermediate proxies is by utilizing the Internet backbone and the developments in the embedded electronics. Without doubt the open systems and standards found their way in the building management but the future of the market goes beyond that. As the industry matures, the target will be not only the IoT but sooner or latter the embedded web services for the building management, sometimes referred as Web of Things (WoT). Building automation specialized standards are best for applications spatially constrained in building. IoT facilitate the *communication* between the devices and across different buildings. Internet protocol however does not imply the same language of meaningful

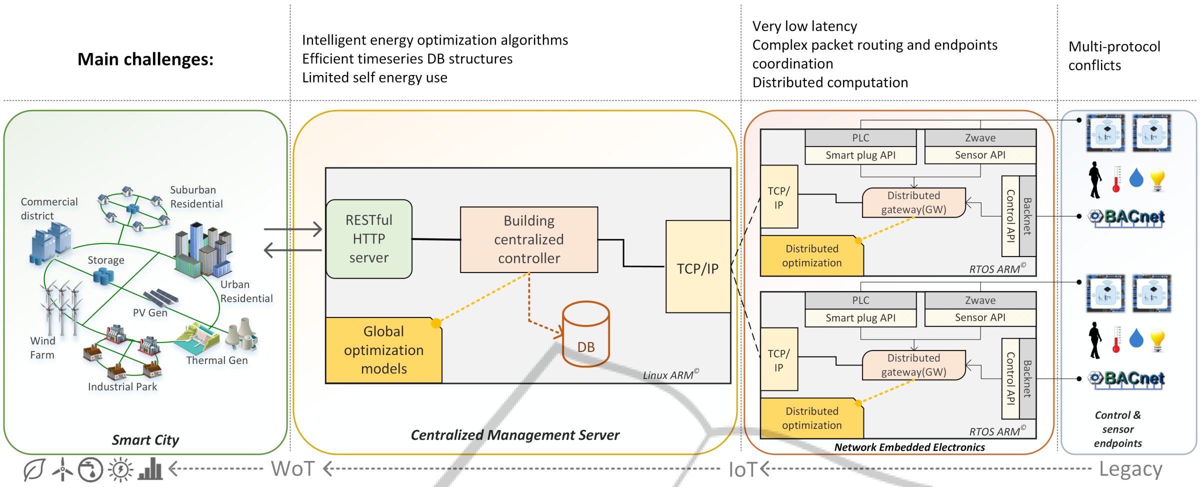

Figure 1: Implemented integration platform.

data exchange and it is where *web services* and WoT on that regard, are relevant.

The great difference between WoT and IoT is not only the existence of hundreds of micro devices with Internet connectivity, but also the semantics that extend the former (Guinard et al., 2011). In simple terms this means that no more BACnet thermostat, KNX thermostat or even IoT thermostat, there is only room temperature.

3.1 Numerous New Possibilities

A web enabled building can leverage the benefits of the abundance of end devices. Bottom up problem approach can achieve unprecedented energy efficiency thanks to high granularity in monitoring (Dawood et al., 2012) and control of individual loads. The holistic, aggregated, large scale energy management can also be an added asset.

Furthermore the ecosystem of devices and their web enabled interface libraries will enable creative application to materialize. Literature already includes scenarios where human capital get engaged in a continuous sharing, increased awareness over their energy use and carbon footprint (Manzoor et al., 2013; Diamantaki et al., 2013; Charitos et al., 2014). The web technologies are the catalyst for these where humans, their personal devices and their activities get integrated in this ecosystem with the ultimate target a greener future with higher living standards.

Web of Things builds upon the advantages of IoT and IT in general and they are not expected to face protocol incompatibility issues. Additionally the web and communication technologies used, have been field tested for many years in the IT market in terms of security, reliability and scalability. Late studies scrutinizes the IT technologies for use in the context of IoT, as for example in the domain of security. (Riahi et al., 2014; Veijalainen et al., 2012)

Apart from new civil and social opportunities and ease of adaptation, the plethora of generated data will create new business models. Those would specialize in data analytics (Leminen et al., 2012) which in turn will drive the WoT and building management market further. This development will not only revitalize the slowing augmenting building automation business, it will likewise encourage and fortify the opportunity for new enterprises to enter this competitive market.

Ultimately the demand may create a separate market with its own properties. A not so far fetched expectation can be a marketplace with applications for portable devices focusing on living quarters. Already major IT companies offer initial frameworks for smart homes. Furthermore, nobody can deny the boom to the wearable and health related applications the IoT already brought (Futuresource Consulting, 2014).

In the end, this competition and industrial development will return as socio-economic benefits to the society of the smart cities.

4 IMPLEMENTED WoT - IoT INTERGRATION PLATFORM

The future building management designers should shift from bringing new connectivity protocols, to enriching the palette of the semantic web services. Until that point, intermediate technologies should be considered in order to facilitate the transition, with immerse priority the reusability in a fully web enabled building. It would be therefore a merit if a system could combine both the legacy and the modern standard and slowly phase out the former in favor of the latter. The proposed and implemented integration architecture in Figure 1 is decomposed in 4 hierarchically distinct elements. Above the schematic, are visible the major challenges this work has faced.

The first pillar is the `Endpoint Nodes` consisting of actuators, sensors and other control devices of various manufacturers and protocols. Purpose of these are to provide the low latency interface to human activities and their impact on consumption, as well as the means of actuation inside the control and optimization loops. Besides the endpoints originating from the industry as for example are the Z-Wave nodes, this pillar also includes endpoints entirely developed in the electronics laboratory for the purpose of the building management. First technology is the distributed controlling modules which communicate through the power lines, without any additional wiring infrastructure. They are able to measure the individual power consumption as well as to offer means of actuation over the devices with the dimming and relay switching. The second custom made endpoint is an IP enabled solar energy harvesting multifunction environmental sensor.

The second pillar handles the data collection, interconnection and wrapping of the endpoints. It is consisted of a highly efficient ARM ® microprocessor unit, local flash storage, as well as the required hardware interfaces in one embedded electronics board developed in the laboratory. Low complexity consolidation and data mining algorithms are running in order to facilitate efficiently the available capacity in the form of a Round Robin Database (Oetiker, 2014). The key to address real time metering and control lies to these `Network Embedded Electronics`. The added benefit of this pillar is the transparent mapping of the multi-protocol 1^{st} pillar's addressing space to IPv6 addresses. At this point, the combination of the two lower levels is visible to the upper ones as Internet enabled devices or as commonly refereed, IoT.

The core of the system is the `Centralized Management Server`. It implements an open source, dynamic, RESTful web server. Purpose of it is to interconnect the building with the smart cities and smart grid stakeholders. It communicates with the embedded electronics in high speed LAN using secured TCP/IP links thanks to 2^{nd} pillar. It provides a custom application programming interface (API) for direct metering and actuation as well as all the tools for implementing the optimization models. It is apparent therefore that the IoT of the previous level are now becoming WoT with easily accessible functions and data analytics engine. The amount of generated data augments exponentially at this pillar due the pyramidal structure of the architecture. It is therefore a considerable challenge the storing and retrieving of them in the reasonable time required by the applications.

At the last pillar, as a proof of concept, various high level applications have been designed. The range includes custom user CO_2 profiles based on user localization and loads ownership, load type recognition, MATLAB® thermal and lighting models designed for the building behavior prediction. All of them are feasible due to the introduction of universal web services that each application can leverage. The focus therefore is swifted to the creative idea from the burden of communications and synchronization of numerous endpoints

The implementation and the benchmarking of the proposed platform is accomplished in a university building of École Polytechnique Fédérale de Lausanne and is used as a case study for the evaluation of hardware/software interconnection and performance analysis. Currently the aforementioned system is being assessed in terms of latency and bandwidth constraints, self energy use and long term reliability. After completion of those, the presented system would be a feasible intermediate solution that will not deter enterprises and consumers from investing in WoT technologies if they already are in possession of current building automation systems, ultimately keeping the best of each sector.

5 CONCLUSIONS

No future smart cities can be imagined without intelligent buildings. Legacy building automation systems served the purpose very reliably in the previous decades. It is now the time to pass the baton to the web enabled devices which have the potential to bring the deal breaking innovation that would essentially catalyze the smart cities entrance to urban life.

During the transition time, hybrid integrating platforms like the proposed, could be used to coordinate the fundamentally different systems until the universal acceptance of Internet connected devices in all the hierarchical levels of the smart cities governance. With this adaptation layer, the building stakeholders get decoupled from the underlying platform and its refining steps towards the WoT with returns in reduced investment cost and faster evolution.

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