Sensors and wireless sensor networks are being deployed around the world, measuring local and global environmental conditions. Their advanced sensing functionalities enable context-aware ubiquitous platforms, middleware and applications to proliferate.

Residences are transformed into smart homes, incorporating embedded sensors and pervasive technology. Moreover, residential smart meters, smart power outlets and smart appliances have appeared in the market, facilitating electricity metering and control of individual electrical appliances, extending homes into smart energy-aware environments. Smart metering provides energy awareness to home residents, and new generations of energy recording devices transform the energy conservation initiatives inside the smart home into a simple task.

In an idealized vision of a fully integrated smart home, all the operations of a house can be efficiently controlled by a unified smart ubiquitous application. However, we are far from realizing this scenario. A main barrier is the proliferation of incompatible standards and protocols used by various device manufacturers, which makes the smooth integration of appliances from different vendors a complex process. Having a heterogeneous ecosystem of devices, implies that even the development of simple applications requires advanced programming skills and considerable time.

In recent years, technologies like short-range wireless communications, RFID and real-time localization are becoming largely common, allowing the Internet to penetrate into the real world of physical objects. The Internet of Things allows household devices that live inside smart homes
to seamlessly communicate through the Internet while the forthcoming Web of Things ensures interoperability at the application level through standardized Web technologies and protocols.

In this thesis, we exploit these new technological possibilities to bring smart homes towards the Web, achieving high interoperability and flexibility. By employing standardized, well-known, reliable and scalable Web techniques, hardware and software heterogeneity between the embedded devices of the smart home can be addressed.

We present the development of a Web-based application framework for smart homes, supporting concurrent interaction from multiple family members. By employing intermediate request queues, associated with the physical devices of the smart home, our analysis shows that we can mask transmission failures and faults that occur in the wireless environment, thus enhancing the performance of smart home operations by means of fast retransmissions, load balancing and request priority techniques. In our analysis, we also derive formulas for estimating the response time of requests and for setting the request queue retransmission interval, an important design parameter of the system. In this way, reliability and timely responses from the devices are ensured.

We demonstrate that, by using the Web as application layer, flexible applications for smart homes can be built, on top of heterogeneous embedded devices, with little effort. In this context, Web mashups may be extended into physical mashups, by exploiting real-world services offered by physical devices and combining them using the same tools and techniques of classic Web mashups. Urban mashups may also be developed, for adapting to the high dynamics and unpredictability of a future urban environment.

We address many issues related to Web-enabling household devices, from their local discovery and service description to the uniform interaction with them. Our technical evaluation indicates that the process of Web-enabling physical devices offers satisfactory performance, mainly in terms
of response time and energy consumption, while modern Web techniques such as Web caching and event-based Web messaging can contribute in facilitating smart home operations.

The initiative of enabling smart homes to the Web unfolds novel applications. By means of these pervasive applications, it is demonstrated that Web-based smart homes have the potential to provide flexible solutions to challenges such as home automation, energy awareness and energy conservation. At first, we show how we can extend our framework into an energy-aware Web application. We explain how we can easily define energy-efficient smart rules, by following the physical mashup paradigm.

Afterwards, we demonstrate the feasibility of merging Web-based smart homes with online social networking platforms. This merging can help social groups such as families, workers and friends, to interact with their common physical environment through their favorite social networking application. Moreover, to motivate people to become more energy-aware and reduce their electrical consumption, we created a social competition between neighboring flats in large residential blocks. Our findings show that people react positively in such energy-saving initiatives. In a similar context, we introduce Social Electricity, a Facebook application allowing people to compare their domestic electricity footprint with their friends and their neighbors in a wide scale. Social Electricity has been awarded the first prize in a prestigious international competition about green ICT applications. In general, social comparisons have the potential to increase the environmental awareness of citizens, helping them to understand their consumption and save energy.

Then, we illustrate how Web-based smart homes can be seamlessly integrated to the forthcoming smart grid of electricity. We propose an architecture for enabling the interaction between smart homes and smart grid controllers, through the Web. This architecture is used in two case
studies we performed. In the first, demand response programs from electric utilities can be harnessed through the Web, to schedule electricity-related tasks in low-tariff hours of the day. In the second, a load shedding scenario is considered for maintaining frequency stability by removing intentionally small loads from energy-aware smart homes that participate in the smart grid.

Finally, we consider some issues beyond the smart home environment, which involve the generalization of the application framework for other indoor and outdoor pervasive scenarios, the global, real-time discovery of environmental services through the Web and also the advanced inference of environmental knowledge in urban environments, following the urban mashup paradigm. We briefly touch upon security both inside the smart home environment and between the home and third parties, defining some basic guidelines that need to be followed.

Our work constitutes a research towards a flexible, interoperable, energy-efficient and sustainable digital future. Smart homes have the potential to effectively contribute in this effort, using the Web as a platform.