UNIVERSITY OF SALAMANCA

DOCTORAL THESIS

# A Multi-agent architecture for optimizing energy consumption using comfort agreements


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# Statement of Authorship

D. Alfonso González Briones, presents the thesis project entitled "A Multi-agent architecture for optimizing energy consumption using comfort agreements" to apply for the Doctorate Degree in Computer Engineering from the University of Salamanca, and states that it has been carried out under the direction of Dr. Juan Manuel Corchado Rodríguez, University Professor of the Department of Informatics and Automation of the University of Salamanca, and Dr. Sigeru Omatu, University Professor of the Department of Electronics, Information and Communication, Faculty of Engineering, Osaka Institute of Technology

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# *Abstract*

The level of global energy consumption has increased twice the amount consumed in 1980s and it is expected to continue to increase steadily. Buildings account for 25 percent of total energy consumption in the European Union. The Horizon 2020 programme is a sign of the committment of the European Union to the development of projects that promote the use of renewable energy resources through the implementation of new energy services in homes and the development of new consumer habits.

Technological advances provided us with new possibilities in the field of computing and electronics. We have developed new processing techniques, can analyze large volumes of data and develop high performance IoT sensors and devices. The concept of intelligent buildings was born thanks to these advances, which can be implemented in buildings to provide greater safety, comfort and economic savings. However, there is still room for improvement as we need approaches to be more focused on the user and adapted to the environment, achieving greater savings but not at the expense of user comfort.

This doctoral thesis defines an architecture whose objective is to optimize energy consumption while adapting to user preferences. Consumption can be optmized independently of the characteristics of the building in which it is deployed. A key aspect of the architecture is the negotiation between all the involved users. It establishes a common agreement on the comfort preferences that satisfy the majority of users while producing energy savings.

On the basis of the presented architecture, a platform has been built for collecting data from the environment, obtaining information from external sources and from the users themselves. The platform continuously analyses the collected data to convert them into information that is useful for the system and on the basis of which, decisions can be made to reduce energy consumption. In addition, the architecture integrates social computing techniques that make it possible to maintain user preferences in terms of temperature and lighting, with the problem being twofold: to optimize energy consumption and to maintain the preferences that have been set in the negotiation.

As a result, a dynamic and self-adaptive architecture is obtained, capable of achieving energy optimization in buildings while maintaining user comfort.

# *Resumen*

Desde 1980 el consumo de energía global ha crecido más del doble y se prevé que se la tendencia siga creciendo de forma continua. Del total de energía consumida en la Unión Europea, los edificios representan el 25%. La Unión Europea, a través de Horizon 2020, está apostando fuerte en el desarrollo de proyectos que impulsen una renovación energética mediante la renovación de los servicios energéticos en los hogares y el desarrollo de nuevos hábitos en los consumidores.

El desarrollo tecnológico ha producido grandes avances en el campo de la campo de la computación y la electrónica. Esto ha permitido el desarrollo de técnicas de procesamiento y análisis de grandes volúmenes de datos y el desarrollo de sensores y dispositivos IoT de altas prestaciones. Estos avances han sido incluidos en los nuevos edificios desarrollando el concepto de edificios inteligentes proveyendo de una mayor seguridad, confort o ahorro económico. Aunque todavía es posible desarrollar nuevos enfoques centrados de forma más específica al usuario y adaptada al entorno para obtener una mayor reducción económica sin reducir el confort del usuario.

La presente tesis doctoral define una arquitectura cuyo objetivo se focaliza en proporcionar una optimización energética, independiente de las características del edificio en el cual sea desplegada, mediante la negociación entre todos los usuarios implicados para el acuerdo común de las preferencias de confort que satisfagan el rango de confort de todos los usuarios a la vez que se produce la optimización energética deseada.

Sobre la arquitectura presentada, se ha construido una plataforma de captura de datos del entorno, obtención de información de fuentes externa y de los propios usuarios. La plataforma realiza continuamente análisis de los datos recopilados de forma que estos datos se conviertan en información útil para el sistema y tomar decisiones que permitan reducir el consumo energético. Además, la arquitectura integra técnicas de computación social que faculta mantener las preferencias de los usuarios en términos de temperatura e iluminación, siendo un problema es doble, optimizar el consumo energético y mantener las preferencias que se han fijado la negociación.

Como resultado, se obtiene una arquitectura dinámica y auto-adaptativa, capaz de lograr una optimización energetica en edificios manteniendo el confort de los usuarios.

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*Gracias.*

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# Acronyms

**ABN** **A**rgumentation **B**ased **N**egotiator

**AI** **A**rtificial **I**ntelligence

**ANN** **A**rtificial **N**eural **N**etwork

**AT** **A**greement **T**echnologies

**BacNet** **B**uilding **A**utomation and **C**ontrol **N**etworks

**BEMS** **B**uilding **E**nergy **E**anagement **A**ystems

**BPSO** **B**inary **P**article **S**warm **O**ptimization

**CBR** **C**ase **B**ased **R**easoning

**CC** **C**loud **C**omputing

**DALI** **D**igital **A**ddressable **L**ighting **I**nterface

**DB** **D**ata **B**ase

**DR** **D**emand **R**esponse

**DSM** **D**emand-**S**ide **M**anagement

**ECI** **E**nergy **C**onsumption **I**ndicator

**FIPA** **F**oundation for **I**ntelligent **P**hysical **A**gents

**GA** **G**enetic **A**lgorithm

**HVAC** **H**eating **V**Ventilation and **A**ir-**C**onditioning

**IoT** **I**nternet **o**f **T**hings

**JADE** **J**ava **A**gent **D**evelopment **F**ramework

**MAS** **M**ulti-**A**gent **S**ystem

**MLP** **M**ulti-**L**ayer **P**erceptron

**MTOE** **M**illion **T**onnes of **O**il **E**quivalent

**OAA** **O**pen **A**gent **A**rchitecture

**OWL** **O**ntology **W**eb **L**anguage

**PADE** **P**ython **A**gent **D**evelopment **F**ramework

| | |
|---|---|
| **PCA** | **P**rincipal **C**omponent **A**nalysis |
| **PID** | **P**roportional **I**ntegral **D**erivative |
| **PSO** | **P**article **S**warm **O**ptimization |
| **REST** | **RE**presentational **S**tate **T**ransfer |
| **WSN** | **W**ireless **S**sensor **N**etwork |

*"El que tiene fe en sí mismo no necesita que los demás crean en él"*
*Miguel de Unamuno*

# Chapter 1

## Introduction

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Chapter 1

# Introduction

## 1.1 Doctoral Thesis Introduction

This doctoral thesis comprises research in the field of energy optimisation that was conducted over four years, within the BISITE Research Group of the University of Salamanca. During this time, knowledge has been acquired progressively to achieve the hypothesis proposed by this doctoral thesis.

The hypothesis put forward in this paper is that energy consumption can be reduced in an intelligent building while maintaining the level of comfort desired by the user. Here we propose an intelligent architecture that allows to reduce consumption without having to make significant investments in the building. The architecture is based on agents which use Agreement Technologies (AT) to establish a consensus among users, guaranteeing a high level of comfort. The agreed comfort prefereneces are then negotiated in real time with the lighting system, the Heating, ventilation, and air conditioning (HVAC) system through the deployed Wireless Sensor Network (WSN).

## 1.2 Energy Consumption Problem

Since 1970 there has been an increase in the consumption of energy in a number of sectors, this increase was brought about by socio-economic growth in all countries and an increase in their population. Although the use of alternative and cleaner sources of energy has become more popular since 1970, fossil fuels still account for around 81% of the world's energy consumption. Figure 1.1 illustrates this increase in consumption and the trend of the different energy sources. From the graph, we can read that in 2008 energy consumption was double that of the early 1980s [Pasquevich, 2012].

Current global energy consumption is more than twice the amount consumed in 1980s, reaching 12,274.6 Million Tonnes of Oil Equivalent (MTOE) by 2011. Energy demand

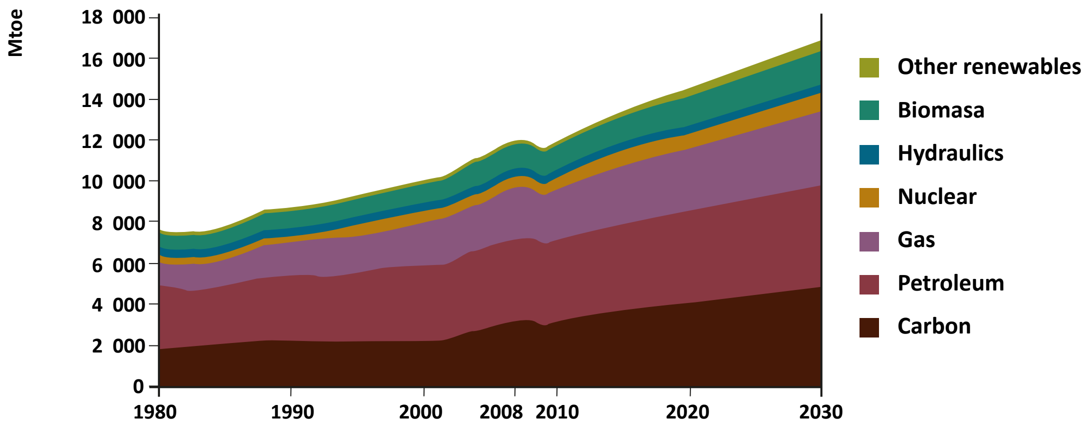
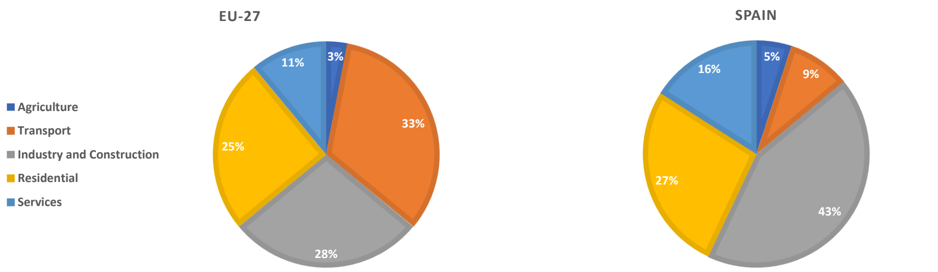



FIG. 1.1: Evolution and trend of energy consumption since 1980.

is continuing to increase steadily and it is predicted that by 2025 30% more energy will be consumed in comparison to the present year [Castillo-Cagigal et al., 2011]. This is because our needs are increasing over time. The 2030 target for reducing CO2 emissions is even more ambitious, with a share of close to 40%, these changes will modernize the EU economy and create new jobs in the energy sector.

However, the problem of high consumption levels lies not only in large industries, we also have to consider small consumers (Residential) and their energy consumption. As shown in Figure 1.2, small consumers represent 25% of energy consumption in the EU-27 and in Spain this percentage reaches 27%.




(A) Energy distribution in European Union

(B) Energy distribution in Spain

FIG. 1.2: Distribution of energy by sector in the EU-27 and Spain. Source: Prepared by the authors on the basis of data from [BP, 2014] and data published by the [IDAE, 2014]

The information presented above shows that the dependency of today's society on energy continues to grow. Even with the appearance of renewable energies, a large percentage of our energy needs is still satisfied with fossil fuels. Moreover, it can be read form the charts that the residential sector comprises more than a quarter of the total energy needs. It is important to consider these data, since the vast majority of our society thinks that

TAB. 1.1: Unit energy consumption according to the type of home in Spain, according to data from the SPAHOUSEC study.

| | **Housing in Block (TJ)** | **Single family Home (TJ)** | **Total Spain (TJ)** |
|---|---|---|---|
| Heating | 105.874 | 182.065 | 287.939 |
| Hot sanitary water | 85.328 | 30.533 | 115.861 |
| Kitchen | 26.948 | 18.702 | 45.650 |
| Cooling | 3.291 | 1.857 | 5.148 |
| Lighting | 17.300 | 8.066 | 25.366 |
| Appliances | 89.982 | 43.488 | 133.470 |
| **Total consumption** | **328.723** | **284.712** | **613.435** |

the majority of our energy is consumed by the industrial and construction sectors, and in transport [Pérez-Lombard et al., 2008]. An increase in the energy consumed by the residential sector is largely a result of the incorporation of a greater number of household appliances, technological devices, but above all by the desire to improve comfort in the home. In Table 1.1 we can examine the average unit energy consumption according to the type of housing [Davis, 2016]. It is clear that the consumption of single-family dwellings clearly exceeds that of block or flat dwellings, especially in relation to the consumption associated with heating. The total consumption of a single-family home is twice that of a block house, where four times more energy is used to heat the house.

All this makes it evident that it is necessary to implement mechanisms that will reduce energy consumption in the residential sector, focused specifically on the areas that have the greatest energy requirements: heating, appliances and lighting.

It is necessary to design an architecture that will be able to successfully deal with the different challenges encountered in the energy optimization problem. For example, the architecture must be able to make optimization decisions, this can only be done effectively if factors that affect energy consumption are analyzed.

Some simple decisions can significantly reduce the consumption of energy. For example, maintaining a constant temperature between 19°C and 21°C during the day and between 15°C and 17°C at night, can save between 10% and 40%. This is because raising or lowering the temperature by as little as one degree can boost the HVAC system's energy consumption by 7% [IDAE, 2014]. Within the field HVAC system automation, there are several commercial systems that allow for average savings of up to 30%. There are various intelligent thermostats on the market, such as Tado°, Netatmo by Starck, Momit and Honeywell [Nacer et al., 2017]. However, an intelligent heating system must be able to understand environmental contexts (state of occupancy of the dwelling, activities of the users, characteristics of the dwelling and the climate), which can be done thanks to the data emitted by the sensors (ambient temperature, $CO_2$ rate, humidity, state of occupancy, weather forecasts, etc.)) and advanced algorithms (learning algorithms, prediction algorithms), the main aim of which is to optimise energy consumption without sacrificing the inhabitants' comfort.

Once the factors involved in energy consumption are identified, it is necessary to implement mechanisms that will obtain their values. Current technology makes this possible,at software level data from external sources can be obtained in order to make predictions or have knowledge about future events and the work schedule. At hardware level the architecture obtains weather conditions through small sensors, communicates with the lighting and HVAC systems or the domotics deployed in the building. This hardware and software conjunction within a building is known as the Intelligent Building.

Thus, knowing the factors involved in energy consumption (outdoor temperature, indoor temperature, humidity, solar incidence, presence of people, etc.) allow us to develop algorithms that successfully optimize energy consumption. However, in addition to this knowledge it is necessary to consider the comfort preferences of the users and inhabitants of intelligent buildings. It is necessary to design an architecture that is dynamic and self-adaptive as each building has different architectural characteristics and the number of inhabitants or users may vary over time. Dynamic because the values of the factors that affect energy optimization vary and self-adaptive because it does not have to be configured every time the value of any of these factors changes [O'Leary et al., 1997], [Ferber, 1999]. In this respect, Multi-Agent (MAS) systems fit in perfectly with the term dynamic and self-adaptive architecture, this is because they facilitate the deployment of new agents whenever necessary [Carrascosa et al., 2008]. Agent based architectures allow to easily develop software and hardware solutions to complex problems. Therefore, the adoption of a multi-agent architecture is very appropriate in systems that must collect data from wireless sensor networks (WSN), obtain data from external sources, send orders to lighting systems or HVAC systems and be aware of user preferences [Tapia et al., 2010].

This doctoral thesis proposes a novel distributed architecture based on a multi-agent system. It is focused on optimizing energy consumption in intelligent buildings while considering the preferences of their users. For this reason, three objectives must be achieved: i) the factors that affect energy consumption in homes must be identified and the proposed solution must be adaptable to any type of building and must reduce dispensable energy consumption; ii) the architecture must implement a mechanism that will negotiation the users' preferences with the optimization decision of the architecture, so that energy can be saved while satisfying user preferences; and iii) to develop an architecture that will adapt to real environments with different architectonic characteristics.

## 1.3 Motivation and Hypothesis

Electricity has played an important role in the social and economic development of countries. With the second industrial revolution and the subsequent technological boom, economic growth was reflected in an impressive increase in the demand for electricity. Moreover, most recent history reflects a very close relationship between those variables.

Specifically, between 1990 and 2013, worldwide energy consumption increased by about 54% according to the World Bank's World Development Indicators. This increase exceeds the growth in the world population, which increased by 36% in the same period [Bank, 2016].

As our energy needs began to increase, many companies in the electricity sector started to analyze the factors that influence consumption as well as the patterns of user behavior. From these analyses they obtained knowledge on how and when electricity was consumed in each sector. One of the sectors in which most energy is being consumed is the residential sector. Public office buildings urgently require the adaption of energy saving measures. This is because the amount of energy they consume is much higher compared to other types of buildings and homes. Often, the users of public buildings are not careful about saving energy (they leave the lights switched on) because they don't have to pay the energy bill.

Public buildings are a niche in which the consumption of electricity can be reduced significantly. As a result we saw the rise of the Intelligent Buildings (IB) concept, a framework that combines the deployment of IoT sensors and devices for the collection and analysis of environmental data, providing users with greater safety, comfort and energy optimization. However, there is no global agreement on the factors influencing energy consumption. Although there is a range of proposals in this area, the majority focus exclusively on saving energy without considering the user. This means that the decisions of these systems often have a negative effect on the well-being of the users in that environment. Another aspect that should be considered is that each user has certain comfort preferences, it is therefore necessary that users reach an overall agreement to satisfy the majority in terms of temperature and lighting.

This doctoral thesis aims to cover this research gap in the current state of the art. The research line that this work follows is that of proposing an architecture that will convert buildings into IB (through domotic systems). To reduce energy consumption, we make use of the data analysis possibilities that current technology provides us with. None of the current proposals have provided a self-adaptive and dynamic architecture that would be independent of context (the environment in which the architecture is implemented), and none of them are capable of adapting to user preferences. This doctoral thesis proposes a dynamic and self-adaptive architecture for energy optimization in intelligent buildings. To this end, the architecture is designed on the basis of multi-agent systems and also includes new approaches in the field of energy optimization, negotiation and agreement technologies. The intrinsic characteristics of agents make them capable of modeling dynamic and distributed systems that adapt to the context. Agents are independent software entities that model and encapsulate subsystems which together fulfill the overall functionality of the architecture. In addition, agent-based technologies such as multi-agent systems have been widely employed and refined for use in context-independent architectures. This demonstrates that they are fully capable of dealing with the challenges posed in this work. Besides facilitating the structuring of the system, they can encapsulate functionalities based on AI techniques that can be reused in other platforms or services implemented in Intelligent Buildings, providing the possibility of applying these modular components to use cases with similar peculiarities.

The hypothesis put forward in this doctoral thesis states that *thorough the application of distributed intelligent systems that provide users with adequate guidance, it is possible to reduce energy consumption in a home or building while maintaining user comfort, this can be done regardless of the building's architectural characteristics and it is not necessary to invest large sums of money in order to achieve savings. To this end, we proposed an innovative approach which employs an agent-based intelligent architecture (MAS). To guarantee a high level of comfort, the architecture implements a consensus model through the incorporated Agreement Technologies (AT). This model is executed using a Wireless Sensor Network (WSN), establishing a negotiation in real time between the users, the HVAC system and the lighting system in intelligent buildings.*

The main objective of this doctoral thesis is to achieve a novel, dynamic and self-adaptive architecture model, that is capable of optimizing electricity consumption in Intelligent Buildings. The architecture must provide a series of methods that allow to collect data from the environment, recognize user behavior parameters and mechanisms for the establishment of agreements in which all the involved parties obtain benefits. The system benefits in terms of reduced energy consumption of the IB and users do not have to give up their comfort to obtain savings. The architecture must be implemented and validated through case studies in which the all the related aspects must be managed by the architecture.

To achieve the overall objectives, the architecture must fulfill a number of specific objectives. The specific objectives include:

- Identify the factors that affect energy consumption, direct and indirect parameters that influence their increase or decrease.
- Conduct a study of the methods and procedures used in the field of energy optimization in order to develop algorithms applicable to buildings and houses.
- Review/design the hardware elements for the collection of values related to consumption in the environment in which the architecture is deployed.
- Study the data communication mechanisms in WSNs, these mechanisms must be standard and open as the architecture must be modular and must facilitate the incorporation of new domotics in the Intelligent Building without having to develop new functionality.
- Design learning methods which will enable the architecture to learn from the behaviour of the users, this knowledge will allow to adapt past solutions achieving more efficient results.
- Review social computing methods and technologies aimed at making agreements between different actors for common benefit.
- Examine existing methods used in multi-agent systems for analysis and design and their application to the IB context.
- Design mechanisms that allow for the integration of optimization methods and negotiation methods so that they are managed autonomously by the architecture.
- Design case studies in which conditions will be simulated to verify the suitability of the architecture. Simulations will allow to identify weak aspects and refine details before implementing the architecture in a real environment.
- Design a real case study to evaluate the architecture's performance in a dynamic environment. The implementation of the architecture in a real environment will allow to test the response of the architecture to sudden and unpredicted changes.

Obtain data from the environment and make energy-saving decisions. Many proposals focus exclusively on collecting data related to factors involved in energy consumption (outdoor temperature, indoor temperature, humidity, solar incidence, presence of people, etc.). These proposals are successful in terms of energy optimisation, however their decisions do not consider the users' comfort preferences or consider them very vaguely. For this reason, this doctoral thesis presents a system designed to obtain energy savings through an agreement between users and the system. To this end, the system conducts a negotiation process between the preferences of the users in terms of comfort and the degree of optimization that the system can achieve according to those preferences. The architecture is based on a MAS whose agents learn about the social behaviour of users, obtain information from the environment through the WSN and execute negotiation processes.

Another objective of this project is to develop a visualization system that will enable the user to view their home's energy consumption. This will provide them with knowledge on data such as the periods of the day in which expenditure increases significantly or the days of the week in which consumption peaks occur. In this way, the user will achieve greater control of their energy consumption, enabling them to save, as well as contribute to energy sustainability. This system should be made available to users through a separate device.

## 1.4 Methodology

To ensure that the objectives set in this doctoral thesis are developed correctly, it is necessary to define all the activities and tasks that must be completed at each stage of the research. The Action Research Process was followed in the development of the research conducted in this doctoral thesis [Reason and Bradbury, 2001]. This methodology identifies the problem and formulates it on the basis of a hypothesis, based on concepts defined within a quantitative model of reality. Then, information is collected, organized and analyzed and the research is focused on proposing a solution to the problem. Finally, the results obtained from the research are evaluated and conclusions are drawn . In order to follow this methodology, it is necessary to define a series of activities to achieve the proposed objectives and to prove the hypothesis.

The activities that were defined at the beginning of this work are as follows:

1. **Definition of the problem**: An analysis of the environment that defines the research problem, establishing the objectives, sub-objectives and the hypothesis on which the research is based.

2. **Review of the state of the art**: Analysis of the problem and review of past solutions related to the current problem. This will allow to analyze and choose the state of the art of techniques used in the current research. The review process focuses both on techniques applied to data analysis and decision making and on techniques that allow agreements to be reached through automatic negotiation. The review of the state of the art is constant throughout the research, since it is the pillar of the research conducted in this doctoral thesis.

3. **Design of the solution and proposal of the architecture**: Proposal of different models that allow to achieve satisfactory solutions to the research problem. These models must allow to verify whether the objective have been fulfilled during the process of design and implementation of the different components that make up the architecture, both at the software and hardware level. The models are broken down into a number of components to facilitate the validation process and thus improve the research process.

4. **Design of case studies to validate the solution**: Study of the results obtained in comparison with other procedures. This determines whether the objectives and the hypothesis initially set out have been achieved. Comparison with other methodologies makes it possible to know whether the way in which the problem was initially addressed was adequate.

5. **Publication of the results obtained**: Publication of the results of the partial research carried out in order to achieve the final objective. Publication in both journals and congresses will allow us to establish a contact with researchers in the field, who will guide us along the path taken in research and help us to refine the development of the model. It is a very important process because it makes it easier to exchange ideas first-hand.

The above activities are executed iteratively throughout the research process, which is why it can be considered an iterative and incremental process, just like the methodology used in software engineering known as Unified Process.

Within this methodology, it is necessary to hold meetings with the team of the Research Group which will allow to know the state of the research. Once the initial problem has been identified, it is important to check whether the approach being taken is the right one. It may be the case that it is necessary to carry out some variation, a new technique or method may be presented that will bring us closer to the marked objective. This is intended to benefit the research from the following factors:

- Flexibility to change, ability to react to new technologies or techniques.
- Productivity, allowing flexibility in work planning provides benefits that were not marked at the problem definition stage.
- Weather forecast, the time control associated with each stage allows us to know the existence or absence of risk in planning.

In order to evaluate temporarily, if the research is carried out under the established time frame, it is necessary to establish a series of milestones. The achievement of these milestones ensures the proper progress of the work. In this sense, the following milestones have been defined:

1. **Analysis of the techniques to be used and definition of the solution**: The objective of this milestone is to learn about the techniques and procedures that allow for a reduction in energy consumption and the development of negotiation processes between users and the system. An architecture that aims to optimise energy consumption in buildings must follow a modular design that ensures that data is obtained from a variety of sources and that agreements are made. A modular design makes it easy to make changes, which are necessary in a project of this size. Once analyzed, it is necessary to define the technologies that are best suited to data capture and the establishment of agreements between the system and the users.

2. **Dynamic and self-adaptive architecture design**: This milestone aims to design a dynamic and self-adaptive architecture that combines the techniques to achieve the objectives at the software level. The architecture based on a multi-agent system must support the hardware requirements that allow data to be obtained from the context to which it must be adapted.

3. **Design of the hardware components of the architecture**: Once the architecture has been developed and the data has been simulated to validate its correct adaptation to the problem, the next step is the development of the hardware components that allow capturing data from the environment in which it is deployed. The achievement of this milestone provides us with a functional architecture.

4. **Design of real case studies that allow the validation of the architecture**: The last stage of the research concludes with the validation of the proposed architecture. Real case studies are developed, which allow us to certify the correct fulfillment of the main and secondary objectives. These case studies vary in the characteristics of the context in which they are carried out, so that the adaptability to the context of the architecture is checked, as well as the number of users of the building to complicate the problem of reaching agreement on comfort preferences while reducing energy consumption.

## 1.5 Structure of the Thesis Report

This doctoral thesis is divided into six chapters. The first chapter is the annex and a bibliography section. The structure of each of the chapters is described below.

The review of the state-of-the-art energy optimization techniques used in intelligent buildings is found in chapter ??. This chapter also studies the different techniques used in the area of computer engineering and artificial intelligence. Here, we determine which techniques should be applied to achieve the objectives set in this doctoral thesis.

The designed architecture is a vertical software solution, a set of software and hardware technologies are deployed in it, this is described in detail in chapter ??. The architecture is based on a multi-agent system that allows the deployed agents to coordinate, cooperate and communicate to achieve the final objective. The agents are grouped according to their functionality, since some will be in charge of obtaining context information, others will be in charge of developing AI techniques, and others will be in charge of communicating with the WSN for the execution of the decisions taken.

The case studies are presented in chapter ??. The first case study allows to verify the effectiveness of the architecture to obtain an energy optimization in an office building. The second case study is conducted in a home. The aim of this case study is to test the effectiveness of the architecture in establishing agreements between the users' temperature and lighting preferences as well as energy consumption.

The results obtained during the development of the two case studies described in ?? are presented in chapter ??. The conclusions derived from the work as well as the contributions made to the state of the art are presented in chapter ??. Future lines of work are also discussed, focusing on the future evolution of the designed architecture.

The annex presents the list of articles related to this work that have been presented during the student period in the doctoral program in international journals, as well as book chapters. It also lists the research projects in which the student has participated, which have to some degree influenced on the development of this doctoral thesis.

Finally, a list is presented with all the bibliographical references that have been used in this doctoral thesis and that have been referenced throughout this report.

# Appendix A

## Publications and related works

# Publications and related works

## A.1 Introduction

Below is a list of some of the most relevant publications related to this work, which have been published since the registration in the first year of doctoral studies, initially in international journals and later as book chapters. Next, the R&D projects in which we have participated are presented and finally, the intellectual properties obtained as a result of aspects of the work presented are presented.

### A.1.1 Articles in international journals.

- **González-Briones, A.**, Ramos, J., De Paz, J.F. & Corchado, J.M. (2015). Multi-agent System for Obtaining Relevant Genes in Expression Analysis between Young and Older Women with Triple Negative Breast Cancer. Journal of Integrative Bioinformatics. Vol (12), 4, 278
- **González-Briones, A.**, Ramos, J., De Paz, J.F. & Corchado, J.M. (2015). A drug identification system for intoxicated drivers based on a systematic review. ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal, 4(4), 83-101.
- **González-Briones, A.**, Chamoso, P. & Lopez-Barriuso, A. (2016). Review of the Main Security Problems with Multi-Agent Systems used in E-comerce Applications. ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal, 5(3), 55-61.
- Ramos, J., Castellanos, J.A., **González-Briones, A.**, De Paz, J.F. & Corchado, J.M. (2017). An agent-based clustering approach for gene selection in gene expression microarray. Interdisciplinary Sciences: Computational Life Sciences. **JCR 2015: 0.753, Q4**.

- **González-Briones, A.** (2017). Application of clustering and biclustering techniques to Yeast Metabolic Cycle. BPOJ: Bioinformatics & Proteomics Open Access Journal, 1(1).
- **González-Briones, A.**, Villarubia, G., De Paz, J.F. & Corchado, J.M. (2018). A multi-agent system for the classification of gender and age from images. Computer Vision and Image Understanding, 5(3), 55-61. **JCR 2015: 2.498, Q2**.
- **González-Briones, A.**, Prieto, J., De La Prieta, F., Herrera-Viedma, E. & Corchado, J.M. (2018). Energy optimization using a Case-based Reasoning strategy. Sensors, 18 (3), 865. **JCR 2016: 2.677, Q1**.
- **González-Briones, A.**, Chamoso, P., Yoe, H. & Corchado, J.M. (2018). GreenVMAS: Virtual Organization Based Platform for Heating Greenhouses Using Waste Energy from Power Plants. Sensors 2018, 18 (3), 861. **JCR 2016: 2.677, Q1**.
- Chamoso, P., **González-Briones, A.**, Rivas, A., Bueno De Mata, F. & Corchado, J.M. (2018). The use of drones in Spain: towards a platform for controlling UAVs in urban environments. Sensors 2018, 18 (5), 1416. **JCR 2016: 2.677, Q1**.

### A.1.2 Book Chapters

- **González-Briones, A.**, Ramos, J., De Paz, J.F. & Corchado, J.M. (2015). Obtaining Relevant Genes by Analysis of Expression Arrays with a Multi-agent System. 9th International Conference on Practical Applications of Computational Biology and Bioinformatics. Springer International Publishing. 137-146
- Castellanos-Garzón, J. A., Ramos, J., **González-Briones, A.** & de Paz, J. F. (2016). A Clustering-Based Method for Gene Selection to Classify Tissue Samples in Lung Cancer. In 10th International Conference on Practical Applications of Computational Biology & Bioinformatics (pp. 99-107). Springer International Publishing.
- Do Souto, L., **González-Briones, A.**, Amaral, A. J., Gama-Carvalho, M. & De Paz, J. F. (2016). Large-Scale Transcriptomic Approaches for Characterization of Post-Transcriptional Control of Gene Expression. In 10th International Conference on Practical Applications of Computational Biology & Bioinformatics(pp. 109-119). Springer International Publishing.
- **Gonzalez-Briones, A.**, Chamoso, P., López-Barriuso, A. & López-Sánchez, D. (2016, October). Revisión de los principales problemas de seguridad en sistemas

multi-agentes empleados en aplicaciones de comercio electrónico. In Hacia una justicia 2.0, Vol: 2, Chapter: 23. (pp. 315-324). Ratio Legis.

- López-Barriuso, A., De La Prieta, F., **Gonzalez-Briones, A.**, Chamoso, P. & López-Sánchez, D. (2016, October). Desarrollo de soluciones de seguridad en sistemas multi-agentes empleados en aplicaciones de comercio electrónico. In Hacia una justicia 2.0, Vol: 2, Chapter: 25. (pp. 341-351). Ratio Legis.

- López-Sánchez, D., Chamoso, P., **Gonzalez-Briones, A.** & López-Barriuso, A. (2016, October). Inteligencia artificial para la identificación biométrica basada en la queiloscopía. In Hacia una justicia 2.0, Vol: 1, Chapter: 22. (pp. 323-337). Ratio Legis.

- **Gonzalez-Briones, A.**, López-Sánchez, D., López-Barriuso, A., Chamoso, P. & De Paz, J. (2016, October). Sistema de detección de ataques DoS en tiempo real. In Hacia una justicia 2.0, Vol: 1, Chapter: 21. (pp. 313-322). Ratio Legis.

- **González-Briones, A.** (2017). Últimas tendencias en aplicación de soluciones IoT en el medio ambiente. II Congreso Derecho Ambiental Contemporáneo España/Brasil - "El acceso a la justicia para la protección del ambiente", Salamanca

- **González-Briones, A.**, Starzacheb, N. & Matos, L. (2017). A short review of the main approaches of electrical energy consumption disaggregation. Real-time demand response and intelligent direct load control – Second DREAM-GO Workshop, Salamanca

- **González-Briones, A.**, (2017). IoT para el análisis legal de información con fines medioambientales. Congreso Medioambiente y Tecnología - "Aplicación de nuevas tecnológicas a la investigación y enjuiciamiento de los procesos medioambientales", Salamanca

- Martín-Martín, P., **González-Briones, A.**, Villarrubia, G., & De Paz, J. F. (2017, June). Intelligent Transport System Through the Recognition of Elements in the Environment. In International Conference on Practical Applications of Agents and Multi-Agent Systems (pp. 470-480). Springer, Cham.

- Chamoso, P., Cordero Gutiérrez, R., **González-Briones, A.** & Rivas, A.(2017, October). Plataforma para el control de drones en entornos urbanos. In La convergencia del derecho y la tecnología. FIADI 2017. UASLP.

- **González-Briones, A.**, Rivas, A., Chamoso, P., & Cordero Gutiérrez, R. (2017, October). Revisión de los principales problemas de seguridad en sistema de

autenticación biométricos. In La convergencia del derecho y la tecnología. FIADI 2017. UASLP.

- Cordero-Gutiérrez, R., Chamoso, P., Rivas, A. & **González-Briones, A.** (2017, October) La lesión del derecho al honor en redes sociales. Detección y clasificación de usuarios. Un caso práctico. In La convergencia del derecho y la tecnología. FIADI 2017. UASLP.

- **González-Briones, A.**, Rivas, A., Chamoso, P., & Cordero Gutiérrez, R. (2017, October). Disociación de datos obtenidos a partir de Smart Meters. In La convergencia del derecho y la tecnología. FIADI 2017. UASLP.

- **González-Briones, A.** & Valdeolmillos, D. (2018). Aspectos legales y Riesgos emergentes en la utilización de Smart Contracts basados en Blockchain. 13th International Conference on Hybrid Artificial Intelligent Systems

- Valdeolmillos, D. & **González-Briones, A.** (2018). Blockchain como revolución tecnologica del sector financiero: Características y aspectos legales de las criptomonedas.VII Fórum de Expertos y Jóvenes Investigadores en Derecho y Nuevas Tecnologías

- **González-Briones, A.**, Prieto, J., Corchado, J.M. & Demazeau, Y. (2018). EnerVMAS: Virtual agent organizations to optimize energy consumption using intelligent temperature calibration. VII Fórum de Expertos y Jóvenes Investigadores en Derecho y Nuevas Tecnologías

- **González-Briones, A.**, Valdeolmillos, D., Casado-Vara, R., Chamoso, P., García-Coria, J.A., Herrera-Viedma, E. & Corchado, J.M. (2018). GarbMAS: Simulation of the application of gamification techniques to increase the amount of recycled waste through a multi-agent system. 15th International Conference on Distributed Computing and Artificial Intelligence

- Cordero Gutiérrez, R., Chamoso, P., **González-Briones, A.**, Rivas, A., Casado-Vara, R. & Corchado, J.M. (2018). Right to honour in social networks: Detection and classications of users. 13th International Conference on Soft Computing Models in Industrial and Environmental Applications

- **González-Briones, A.**, Rivas, A., Chamoso, P., Casado-Vara, R. & Corchado, J.M. (2018). CBR and Agent Based Job Oer Recommender System. 13th International Conference on Soft Computing Models in Industrial and Environmental Applications

- Casado-Vara, R., **González-Briones, A.**, Prieto, J. & Corchado, J.M. (2018). Smart contract for monitoring and control of logistics activities: Pharmaceutical utilities case study. 11th International Conference on Computational Intelligence in Security for Information Systems

- **González-Briones, A.**, Rivas, A., Chamoso, P. & Cordero Gutiérrez, R. (2018). Use of gamification techniques to encourage garbage recycling. A knowledge Smart City approach. 13th International Conference On Knowledge Management In Organisations.

- Rivas, A., Martín-Limorti, J.J., Chamoso, P., **González-Briones, A.**, De La Prieta, F. & Rodríguez, S. (2018). Human-Computer Interaction for Currency Exchange. 13th International Conference On Knowledge Management In Organisations

- Sittón, I., Hernández, E., Rodríguez, S, Santos, M.T. & **González-Briones, A.** (2018). Machine learning for predictive model on Industry 4.0 environment. 13th International Conference On Knowledge Management In Organisations

- Rivas, A., Martín-Gómez, L., Sittón, I., Chamoso, P., Martín-Limorti, J.J., Prieto, J. & **González-Briones, A.** (2018). Semantic analysis platform for Industry 4.0. 13th International Conference On Knowledge Management In Organisations

### A.1.3 Project participation

- **Project name**: HIGIA. Plataforma Inteligente para la gestión y seguimiento del personal sanitario, pacientes y activos en entornos hospitalarios.

  **Financial institution(s)**: Junta de Castilla y León(ADE).

- **Project name**: SUMA : Sistema Unificado Móvil Avanzado.

  **Financial institution(s)**: Centro de Desarrollo Tecnológico e Industrial. Ministerio de Economía y Competitividad.(Proyectos de I+D de Cooperación Nacional).

- **Project name**: GatEBike: Arquitectura basada en Computación Social para el Control Inteligente e Interacción en Bicicletas Eléctricas.

  **Financial institution(s)**: Ministerio de Economía y Competitividad y cofinanciado por el Fondo Europeo de Desarrollo Regional (FEDER)(RETOS-COLABORACIÓN 2015).

- **Project name**: EKRUCAmI: Europe-Korea Research on Ubiquitous Computing and Ambient Intelligence.

  **Financial institution(s)**: European Commission(Seventh Framework Programme for Research and Technological Development. FP7-PEOPLE-2012-IRSES. Marie Curie Action "International Research Staff Exchange Scheme").

- **Project name**: Dream-Go: Enabling Demand Response for short and real-time Efficient And Market Based smart Grid Operation - An intelligent and real-time simulation approach.

  **Financial institution(s)**: Comisión Europea (Horizon 2020. MSCA-RISE-2014: Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE)).

- **Project name**: ECOCASA: Espacios inteligentes y Computación sOcial para Cambio de comportAmiento en conSumidor finAl.

  **Financial institution(s)**: Ministerio de Economía y Competitividad (Retos Colaboración 2016).

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