Universidade do Minho
Escola de Engenharia

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Ambient Intelligence and Affective Computing: A contribute to energetic sustainability

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Tese de Doutoramento em Informática

Trabalho efetuado sob a orientação do
Professor Cesar Analide Freitas Silva Costa Rodrigues

janeiro de 2016

STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, 29/01/2016

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Abstract

It is often the case where society is faced with sustainability problems. A fact is that the growing economy and the citizen behaviours are putting stress on resources at increasing scales. Society demands sustainable solutions for these problems. However, these solutions need to compromise restrictions enforced by either society, physics and resources. This leads to the traditional dimensions of sustainability: economic, environmental and social, which need to be addressed as a whole in order to find sustainable configurations.

Although not as old as sustainability itself, computational sustainability provides methods to specify and intervene in sustainability problems. The most used approaches to computational sustainability systems target constraint conditions, computer simulation and machine learning to solve sustainability problems. Computer science can leverage computational sustainability to acquire relevant information from environment and users, plan and predict approaches to problems and act upon physical systems.

This thesis presents an archetype platform, the People Help Energy Savings and Sustainability (PHESS), which results from experiments upon computational sustainability problems with the aid of action-research methodology. It is aimed at intelligent environments such as smart cites and ambient assisted living, and makes use of ubiquitous technologies, such as the Internet of Things (IoT) and pervasive computing. More than just measuring and reporting tool, the archetype aims to promote behavioural change and continuous improvement through techniques taken from fields such as intelligent environments, gamification and affective computing which help improve sustainability scenarios.

This archetype enabled the implementation of case studies where the platform was used to assess energy consumption to manage and monitor user environments, user comfort and urban transportation to demonstrate the adaptability of the archetype to different kinds of scenarios.

Resumo

A sociedade depara-se, muitas vezes, com problemas de sustentabilidade. É um facto que a evolução económica e os comportamentos dos cidadãos estão a colocar pressão sobre os recursos naturais numa escala cada vez maior. A sociedade exige soluções sustentáveis para estes problemas. No entanto, estas soluções devem harmonizar restrições impostas pela sociedade, a física e os recursos. Estes fatores conduzem às dimensões tradicionais da sustentabilidade: económica, ambiental e social, que precisam ser tratadas como um todo, com o intuito de encontrar configurações sustentáveis.

Embora não tão antiga quanto a própria sustentabilidade, a sustentabilidade computacional fornece métodos para especificar e intervir nos problemas de sustentabilidade. As abordagens mais usadas para sistemas computacionais de sustentabilidade abordam restrição de condições, simulação por computador e aprendizagem máquina para resolver problemas de sustentabilidade. A ciência da computação pode melhorar o desempenho da sustentabilidade computacional através da criação de informação relevante a partir do ambiente e seus utilizadores, planear e prever abordagens para os problemas e agir sobre sistemas físicos.

Esta tese de doutoramento apresenta um arquétipo, o Pessoas Ajudam na Economia de Energia e na Sustentabilidade (PHESS People Help Energy Savings and Sustainability), que é o resultado de experiências sobre problemas de sustentabilidade computacional com o auxílio da metodologia de *action-research*. É destinada a ambientes inteligentes, como por exemplo cidades inteligentes e ambientes de vida assistida e faz uso de tecnologias ubíquas, tais como a Internet das Coisas (IoT - Internet of Things) e computação pervasiva. Mais do que apenas medir e elaborar relatórios, o arquétipo tem como objetivo promover a mudança de comportamentos e a melhoria contínua através de técnicas de ramos como ambientes inteligentes, *gamification* e computação afetiva que ajudam a melhorar cenários de sustentabilidade.

Este arquétipo possibilitou a implementação de diversos casos de estudo onde a plataforma foi usada para gerir e monitorizar ambientes e utilizadores, o conforto dos utilizadores e transportes urbanos, para demonstrar a capacidade de adaptação do arquétipo a diferentes cenários reais.

Contents

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Acronyms

AC	Affective Computing.
AI	Artificial Intelligence.
AmI	Ambient Intelligence.
BFP	Big-Five Personality.
DM	Data Mining.
E4	Energetic Efficiency and Renewable Energies.
EUP	Energy Using-Products.
FFM	Five Factor Model.
GPS	Global Positioning System.
HVAC	Heating, Ventilating, and Air Conditioning.
IA	Intelligent Applications.
ICCES	Innovation and Creativity for Complex Engineering Systems.
ICT	Information and Communications Technology.
IE	Intelligent Environments.
IoT	Internet of Things.
IT	Information Technology.
MAS	Multi-Agent Systems.
MDP	Markov Decision Problem.
ML	Machine Learning.
MLP	Multi-Layer Perceptron.
NEO	Neuroticism, Extraversion and Openness.

PHESS	People Help Energy Savings and Sustainability.
PMV	predicted mean vote.
TPB	Theory of planned behaviour.
UPnP	Universal Plug and Play.

Chapter 1

From Sustainability to Computer Science

1.1 Introduction

Sustainability concerns the study of actions performed in the present that are still possible in the future. In reality, this means that a careful and realistic planning of resource use must be employed as society develops itself. Perhaps, one of the main aspects of sustainability deals with our dependence on energy sources, but clearly the same could be said about pollution, waste management and economic performance.

In 2006, the European Union Council launched a directive enforcing the necessity, for its members, to become more energy efficient and the Portuguese government implemented it in 2008, by the Ministry Council Resolution no. 80/2008, approving the National Action Plan for Energy Efficiency $PNAEE$ [1].

The field of computer science is traditionally used to study, simulate and predict the effects of behaviours and different contexts. The ability to produce complex calculi rapidly, rather than doing them manually, has produced an advantage for the sustainability problem solving. Moreover, the autonomous capability of intelligent systems may be used to further analyse and interact autonomously with the environment itself.

Taking the case of energy sustainability, the main challenge with the development of these projects is to move energy efficient assessment systems from pointing unsustainable practices to enabling them to define and guarantee energy efficiency and energetic sustainability thus solving an identified open-problem [5]. The aim of these initiatives, both at European and country levels, was to convince countries and their people that the systems to be implemented would help achieve energy efficiency and energetic sustainability and that the behaviour of people and governing country policies was important to this objective.

Over the last 25 years, energy consumption has increased each year, as illustrated in 1.1 [2], a statement that is also corroborated by the research conducted by Herring. Initial results from energy efficiency policies state that small changes in habits can save up to 10%

[1] More information can be found at: `http://www.adene.pt/ADENE_en/Canais/PNAEE/Enquadramento.htm`.

[2] The data was obtained from: http://www.pordata.pt/. It is statistical database developed by the Foundation Francisco Manuel dos Santos Foundation, created in 2009. The main objective is the collection, compilation, systematization and dissemination of data on multiple areas of society, for Portugal and its municipalities, and for the European countries.

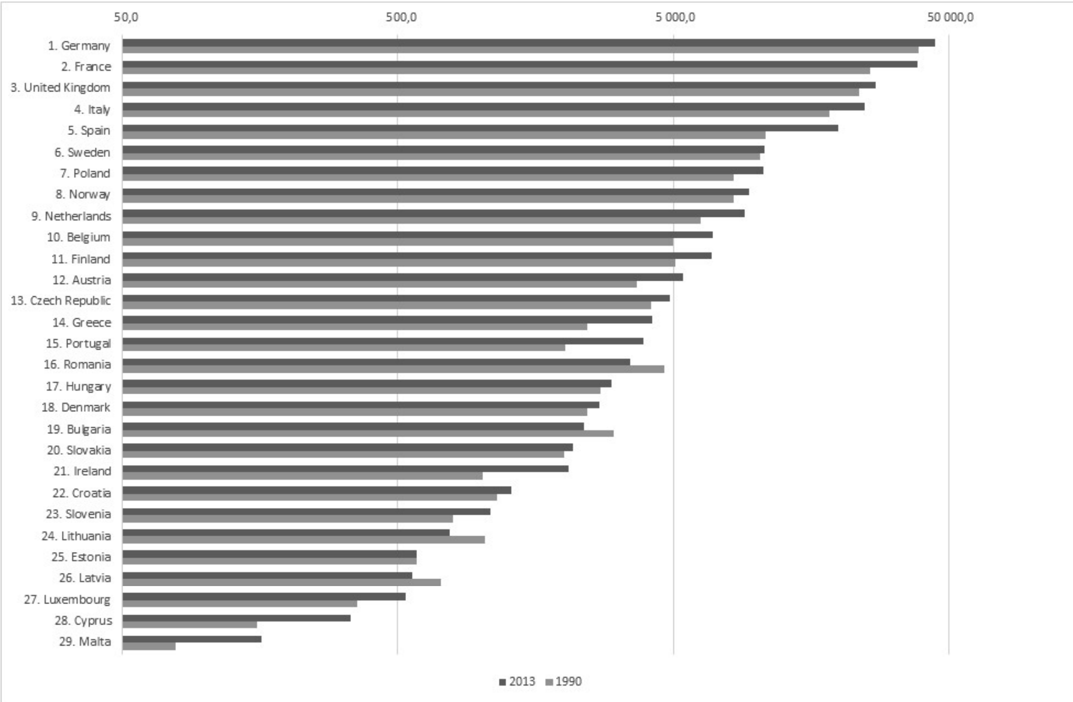

Figure 1.1: European energy consumption

in home energy consumption [3]. When users can visualize total and individual consumption on all appliances, they develop efficient behaviours and are more likely to accept energy efficiency recommendations lowering their energy bills [4].

People and the act of helping people, must be always a goal to achieve by whom intends to commit itself for and by the society. By helping people and making people intervene in the society, in the context and with the purpose of contributing to the energy sustainability of their world, informatics, computer science and computing systems are the right means to achieve this objective. Energy sustainability is concerned with creating the necessary conditions to the sustainable use of energy. On the other hand, informatics is the science that deals with the automatic treatment of information, related with the use of computing devices such as computers, sensors and actuators.

Actually, the energy sustainability issue is gaining importance and stirring society. There is the perception and the desire, in the society and in people, to discuss these matters. However, it is noticed a deficit of ability to act by the people, due to a certain resistance to drive changes or to some lack of knowledge about what to do. The help to people can be done endowing the environment with mechanisms and providing people with the tools of information about the environment, advising them about what to do, what actions to take, enabling people to interfere and intercede in the environment, always with a strong emphasis on the overall sustainability.

Related challenges include the use of context aware learning models, as well as suggestion and reasoning techniques to ensure sustainability. Furthermore, stimuli creation to adopt energy efficient and energy sustainable habits within environments and the arguing for the support of these concepts is also a point of concern in sustainability projects. As such, the intention is to explore techniques from social network platforms to access and dictate whether or not such knowledge can derive behaviours that enhance and promote these ideas and also the use of intelligent systems.

Each action should make a difference with respect to some energy saving criteria. To achieve this goal a number of key objectives are proposed to be completed inside an intelligent environment. For starters, notification tools, about the environment or about user actions on the environment, with the aim of alerting to good or bad practices, to healthy or baneful consequences. More traditionally, monitoring systems about the environment, collecting information that characterizes all the dimensions (variables) of the environment in which it is possible to intervene or from where it is viable to obtain knowledge and mechanisms to act on the environment, adapting it to the needs of a systems energy sustainability. With learning methods and algorithms the aim of gathering and perceiving behaviour patterns, both from people and from systems is also a benefit. Finally, suggestion models, based on the simulation of real scenarios or environments, adaptable and customizable to any context or milieu that are able to guide user change their behaviours presenting them with viable alternatives

In informatics and computer science, the proliferation and mass influence of computing systems, sensorization and actuators, and the actual level of knowledge, allows the development of tools able to provide people with adequate mechanisms to act on the surroundings, decisively contributing to the energy sustainability of the environment. Thus, the focus of research in sustainability is more than developing new procedures or algorithms to solve problems, putting those innovations on the hand of the user, with a clear purpose: those innovative tools should be guided to assist people in the context of sustainability. The crowning objective is, always, to build tools that will be useful to people, in order to contribute to the sustainable use of energy resources.

1.1.1 Sustainability

Sustainability is an eclectic topic applied to a wide range of issues. From financial reports to environmental studies and social issues, sustainability is generally used to measure the ability to continue developing the same action both in the present and in the future. It is concerned with the foreseeable ability of maintaining and endure present states in the future. Unsustainable actions or states can be found in situations where present actions will lead to a future state in which such actions can no longer be performed due to insurmountable restrictions. For instance, if we consider that crude is a finite resource, overuse can create a situation where in the future it will be impossible to obtain it for our daily tasks.

Restrictions are natural invariants present in our environments such as the amount of energy produced over periods of time, the amount of clean air or even the amount of available sunlight. The existence of these higher restrictions, for instance, can lead to unsustainable states and they are often dealt with by constraint restriction problems which are common when preserving sustainability. Such methodology may be found on global warming, CO_2 emissions, energy consumption, financial support and population control. Current innovative technologies are being sought in order to ease such problems. They range from technologies that help optimise the impact of human actions to the enforcement of simple modifications, not significant for users, with great impact on sustainability.

From a computer science perspective, a new expression called computational sustainability, has been developed to gather efforts towards assessing and most importantly guaranteeing sustainability. This expression covers a range of subtopics within computer science such as, but not limited to, artificial intelligence, assisted living, machine learning and context recommendations.

As a multi-disciplinary concept, sustainability is defined across different fields such as economy, environment and sociology. Although they are interconnected, there are different approaches to them. Computational approaches to measure, evaluate and maintain sustainable states need to take human behaviour into consideration where it is the most influential. Such is the case with energy efficiency problems where the demand for energy is solely created by human interaction, routines and demands. Ideally, a computational platform to support and promote a sustainable environment, should take the decisions as unobtrusively as possible so it does not cause discomfort to its users. Consequently, several psychological studies were developed [5], [6] and a common conclusion indicates that users of environments are not always conscious about their own behaviour and, as a consequence, its implications [7]. This unawareness by users dictates problems for sustainability, therefore, to overcome these barriers, it is suggested the engagement of multiple users in a competitive environment of positive behaviours so that participants feel the need to strengthen their knowledge of sustainable actions. In fact, such awareness from users is also object of related studies in the field of psychology where sustainable behaviour is also studied. The psychology field of sustainable behaviour, despite focusing on measurement and understanding of the causes of unsustainable behaviour, also tries to guide and supply clues to behaviour change. The research conducted by Manning, shows some aspects that are necessary to consider promoting and instilling sustainable behaviours [8]. It is necessary to keep in mind that, regarding sustainability and human behaviour, when the situation or event changes, the behaviour also changes and there are hardly unique solutions but rather an unknown set of possible actions, planning or configurations. Fewer barriers to the implementation and acceptance of the proposed solution are also desirable as they will lead to less attrition to change.

In regard to energy efficiency, a sub-field of sustainability, it is directly related with human behaviour and human comfort. No policy, guideline or recommendation is followed if not understood and accepted by users. The most sustainable action towards lighting appliances would be to have them turned off all the time, but, due to the routines and comfort of users, that is not possible as the same users would rather be in a room where they can turn the lighting appliances on at will and follow sustainable principles. Efficiency does not mean always to reduce consumption but rather consume the necessary amount of energy to perform the task at hand.

1.1.1.1 Sustainability Definitions

Sustainability is a subject of concern for the assurance of the steadiness, viability and use of a system. Different approaches to measure and assess sustainability were proposed in the literature, with some focusing on an economic perception, while others emphasize on environment or social perspectives [9]. A common accepted definition for sustainability concerns an equilibrium from social, economic and environmental factors. When some of these features cannot be met, the system is not considered sustainable, but it may be pondered viable, bearable or equitable [9], [10], as shown in figure 1.2, according to [11].

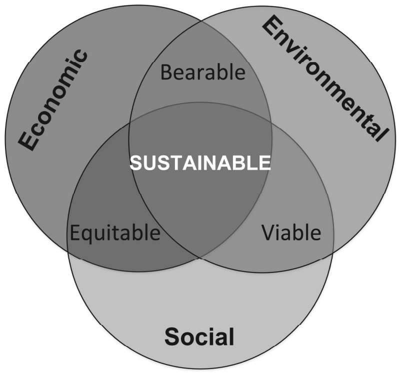

Figure 1.2: Representation of sustainability dimensions

There are, however, some deviations to this definition of sustainability as some authors include a fourth dimension generally related to political or institutional concepts that govern actions.

Sustainable development, is also another concept related with sustainability. It reflects the quality of the development and its sustainability.

There are factors which govern the update of a system. For instance, considering the economic dimension of sustainability, it may not be feasible to improve other sustainability dimensions through the acquisition of new machines even when, in the long term they become sustainable. If the rhythm of change does not allow for the generation of a positive return then an economic unbalance is created.

The definitions presented are already embedded in most of the research community and, thus, widely accepted. Due to this, research in the field of sustainability is focused on systems, assessment and assurance. In the field of computer science, sustainability is often presented as a resource constraint optimisation problem and, thus, solutions encompass system designs to handle resources better, produce better resource planning and techniques for sustainability sensorization and actuation. In the field of energy efficiency, sustainability has duelled to maintain acceptable environments and energy consumption, while keeping in mind the needs of environments, environment users and the necessity of task scheduling in environments.

1.1.1.2 Sustainability Assessment and Indicators

The sustainability of a system may be pointed out by a set of indicators, as suggested by many authors, allowing the definition and monitoring of indicators. The ability to measure and assess sustainability is important to make it addressable as a mathematical problem. For instance, it is necessary to measure contributions that have an impact on the overall sustainability and take into account considerations about sustainability standings in order to put in place optimizations and cognitive processes that improve it. One common method of doing so is through indicators. Although the measurement and definition of indicators may change from implementation to implementation, it is perceived as one of the most popular methods. Indicator assessments are often used to measure parcels on some dimension of the sustainability problem, and they cover sustainability by aggregating a group of indicators that cover all sustainable dimensions and may or may not overlap themselves. Indicators that span across multiple sustainability dimensions are also possible, but they are harder to define.

According to the main dimensions of sustainability, indicator count tends to become more skewed near the category closely related to the area for which each indicator assessment methodology is applied. In the financial sector, economic dimensions are more important as their indicators are used to monitor whether or not a certain resource or asset as reached a critical point. For instance, in the case of the degree of debt for loan purposes or budget control, indicators monitor whether or not a certain level has been exceeded.

The design of indicators may be implemented using different philosophical strategies, as documented in the literature. As an initial analysis, indicator design can be measured from bottom-up or top-down approaches depending on how the problem is tackled initially. From that point on, the relative perception of the important factors towards the sustainability concept plays its role. Across the literature, multiple definitions can be found for different approaches to monitor and develop such indicators. It is, of course, of great importance to clearly understand the strategy employed as it has significant importance when translating these indicators into computational systems. As an example, if the focus is on studying environments, indicators should be oriented from a top-down approach in which the detail of the indicator portraits our level of detail for such environment. On the other hand, if our focus is geared towards elements of environments, then a bottom up approach would be best as it would provide detailed information for the element at study which may be generalised to an environment but with lack of generality. When considering models and simulation environments these aspects play a vital role to adequate the error of experiments to the expectations.

Other strategy to develop indicators is to monitor positive and negative influences in a system so it can re-adjust itself in order to maintain a sustainable scenario. Considering the energy spent in the acclimatization of a home environment, an indicator can measure when too much energy is being spent over what is necessary for user comfort. It is also possible to assess when the energy spent is deemed satisfactory for other sustainability problems such as budget control or pollution.

It is possible to find indicator proposals specialized towards the energy efficiency problem in the research community. For example, the approach followed in [2] uses four different indicator categories under a slightly different definition of sustainability. The authors definition adds the resource dimension to the traditional social, economic and environmental. The specific resource indicators add information about the physical structure that produces energy in terms of the quantity of resources used versus the quantity of energy produced. Likewise, environment indicators relate the quantity of waste produced with the quantity of energy produced. The remaining indicators introduce different relationships against the energy produced. As such, in their research, a total of 14 different indicators were found to be closely related to the energy efficiency parameters. The full list is presented in table 1.1.

Of course, the number of indicators differs from field of application or even from project to project. Taking into consideration the indicator definitions from Alwaer et. al.[12] and the assessment of sustainable intelligent buildings, the list is slightly different from the the example in 1.1. As it can be seen in table 1.2, the three dimensions of sustainability are present but the fourth is modified to encompass what is called the technological indicators group which refers to intelligent and technological development in such environments.

Table 1.1: Afgan et. al., sustainable development indicators [2]

Sustainability Dimension	Indicators
Environmental	Carbon dioxide, Nitrogen oxide, Sulphur dioxide.
Economic	Capital, Diversity and vitality, Efficiency economic, Community economic.
Social	New jobs.
Resource	Fuel, Carbon steel, Copper, Aluminium.

As it can be seen, the lack of standardized indicator implementations leads to different implementations, albeit very similar in most situations. There is also room for improvement in the case of sustainable indicators. It has also been discussed that most indicators, while useful at pointing out unsustainable practices, do not allow to accurately define and guarantee sustainability [13]. The definition of a sustainable indicator is sometimes difficult and it may differ from environments to environments. In more specialized contexts like intelligent buildings, there are commitments to build Key Performance Indicators (KPIs) to monitor sustainability, and act as sustainable indicators from information gathered by a panel of experts [12].

Table 1.2: Alwaer et. al., sustainable development indicators

Sustainability Dimension	Indicators
Environmental	Energy and Natural Resources, Water and Water Conservation, Material, Durability and Waste, Land use and Site Selection, Transport and Accessibility, Greenhouse Gas Emission.
Econonomic	Flexibility and Adaptability, Economic performance, Building Manageability, Whole life value.
Social	Functionality, Well Being, Architectural Considerations.
Technological	Intelligence and Controllability, Communications and Mobility.

In order to shape systems to address sustainability, different models may be designed and developed according to their typology. Todorov and Marinov [10] proposed model cataloguing according to time (static/dynamic), place reproductions (general/local) and scale (general/specific) models. Using the three proposed classes of models it is possible to build sustainable metrics that assess and evaluate sustainability on its key indicators and on its key modelling strategies. The approach adopted in Todorov and Marinov's work uses a theoretical proof approach to computing, which deals with dynamic time, general and local places inside a framework. The measurement of sustainability is a hard problem as it needs to concern the different dimensions of sustainability. In this matter, proposals have been discussed in the research community, and a current popular approach in policy making circles uses indicators. These indicators are denominated sustainable development indicators. They are regarded as an important tools to policy making and report of social, economic and environment *status quo* [9].

However, there are common problems with this practice, enumerated in the literature, as stated by research conducted by Afgan et al., [2]. The definition of global sustainable indicators, as a means to compare environments, is difficult since environments have different characteristics. Selection and formal definition of indicators is, also, a matter of concern as it has to be agreed by all participants and must have a series of properties, in which the indicators express their relevance. Some authors approach this problem characterizing these properties as dimensions, where some indicators are more important in some dimensions than in others, while monitoring the same object. One other problem is the definition of units and meta-data. If not defined accordingly, it may be impossible to compare indicators of the same type. Measuring data makes it possible to obtain an indicator which might have a range of optimal values and a range of non-optimal values.

The process of building indicators for sustainability can be quite complex as it is considered critical to evaluate performance of attributes under their scope. As such, the development of the process to build better indicators have been proposed in the literature. In [1], authors present a methodological approach to build indicators consisting of 6 steps illustrated in figure 1.3.

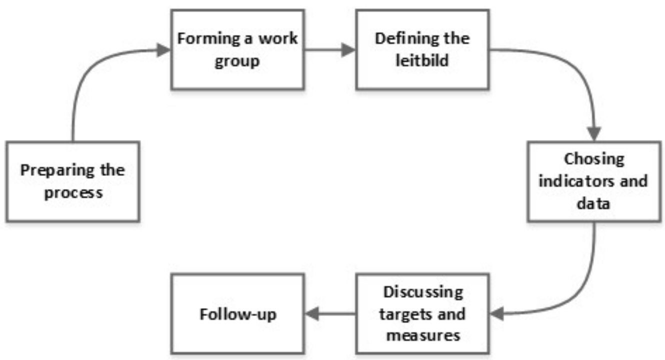

Figure 1.3: Methodology for indicator design according to [1]

The procedure, in figure 1.3, produces a document containing a set of indicators grouped by category inside the definition of sustainability. It is possible to have inter-leakage of indicators across multiple dimensions of sustainability which may result in multi-criteria indicators. One relevant aspect is the fact that the definition of sustainability presented considers the institutional category, as well as the standard social, economic and environmental categories. Though this approach follows a methodological procedure, it lacks some characteristic to assure the correct scientific soundness and it also lacks the definition of boundaries towards the values of these indicators. In this case, the researchers argue that such problems should be addressed locally by each team during the methodological procedure.

In [14], it is presented a discussion between the involvement of communities in the sustainable process and top-down and bottom-up approaches. While more general, top-down approaches often involve different specialists that decide indicators based on scientific knowledge rather than the specific needs and concerns of communities. Communities often miss the motivation to participate in such process due to the complex scientific effort. Even though, the researchers argue that a bottom-up approach results in more complex processes to select sustainability indicators, despite having better accuracy towards the region of interests. Therefore, the list and type of indicators varied from region to region, adapting to the specificity of each region. These results were support by three case studies in different regions with different backgrounds in which the latter was true.

Nevertheless, it is argued that some of the most popular indicators used today are not scientifically meaningful as it is difficult to comply with the requirements for the definition of these indicators [15]. In order to make them scientifically sound, sustainable development indicators must cover the definition of sustainability and its equilibrium, be significant and meaningful, be able to be measured over large periods of time and developed through process oriented procedures in order to achieve standardization. However, in terms of data analysis, more restrictive requirements, such as the ability to adequately normalize and aggregate data, are debated. Moreover, it should be present that different components of the same indicator should be analysed and weighted according to their importance.

The assertions made do have valid and logical truths to the use of sustainability assessment through indicators and their application have been extensively documented in the assessment of the sustainable development and sustainability. Nonetheless, the capture of the sustainability definition essence through indicators is, itself, an hazardous procedure. Its equilibrium should be reflected in the values of the specific indicators under different conditions and be able to relate to other indicators in the same order of comparison. The approach followed by these researchers also argues about normalization and weighting of indicators with mathematical procedures for normalization and expert analysis towards both normalization and weighting. It is also noted that even with such procedures, the process is considered subjective and prior decision towards normalization have to be assumed and used.

In [16], the role of the academic community is discussed in regards to the implementation of protocols towards the definition of sustainable indicators in an attempt to make sound and scientifically correct indicators concerning the problem at hand, with transference of knowledge from research institutions to the sustainable indicators definition team.

Finally, the presence of indicators to assess sustainability is a common practice. However, it does not give any information on how to guarantee or plan sustainability. In fact, indicators only inform about the current status of a system. In order to address this last issue, mechanisms and planning strategies are necessary to intervene where necessary to preserve the *status quo* of sustainability standings.

1.1.2 Research Hypothesis

This doctoral thesis is aimed at providing an Intelligent Environment for Assisted Living, with the purpose of helping its users with sustainability solutions and suggestions, contributing to a better living experience, both in terms of comfort and economy. With this purpose in mind, this research project will address several issues in the areas of Computational Sustainability, Artificial Intelligence, Ambient Sensing, Affective Computing, Energy Efficiency and Social Sciences, among others.

The research hypothesis developed in order to conduct this research project states that *it is possible to intervene in the sustainability of an ecosystem developing intelligent systems supported by ambient intelligence, machine learning, context awareness, social behaviour, by means of computing devices.*

Thus, it can be stated as a broad objective the development of an assisted living ecosystem, led by computational sustainability concerns, based on a multi-agent platform. The platform should act autonomously, assuming some of the properties of multi-agent systems, using machine learning algorithms to learn frequent habits from users, and taking actions based on user preferences, needs and wills. Ambient sensorization addresses the issues of providing an environment with sensing capabilities and sensor fusion techniques to gather data and produce knowledge. Such an environment will allow the development and furnish learning processes with data gathered from the users and its surroundings.

Suggestive models, with the ability to indicate sustainable behaviours, shall be developed to address issues related to context aware and social behaviour. These models will go beyond the act of measuring sustainability scenarios such as efficiency on energy usage. They will make predictions based on patterns of users, suggest user behaviour changes, and make adequate changes on the environment autonomously.

Affective computing is intended to take into consideration emotional aspects in the decision making process, taking the state of mind of user into account. Models to evaluate moods and emotions of users will also be developed and integrated in the multi-agent platform.

As a result, there are objectives related to the research hypothesis and the work plan detailed aimed to validate and justify this research program. These are presented here in form of research questions.

Research Question 1 Multi-agent systems are able to gather, monitor and process data from heterogeneous sources and produce sustainability assessments.

The elaboration of different workflows to manage each flow of data in motoring and data fusion process can be a complex task. The publish-subscribe model approach to this task is suitable for this problem to which the use of software agents to automate the process is a natural path. Moreover, aggregating agents with specialized tasks allows the processing of data from its acquisition to the classification of information. This research question shall be answered by multi-agent systems that produce a consistent design specification to achieve this objective.

Research Question 2 Indicator assessment can produce accurate evaluations in the field of computational sustainability allowing, at the same time, the comparison between ecosystems.

Indicator specification can identify software agents responsible for monitoring resources in a computational sustainability platform. The coverage of an indicator is determined by the objectives of each specific case study. However, indicators are able to express the performance of users and environments. This research question can be demonstrated by example scenarios and specification of user and environment assessment techniques.

Research Question 3 Affective computing may add a social response from users to take into consideration in a sustainability assessment.

Affective computing can foster the social dimension, interpreting user reactions. Furthermore, from its assessment, new indicators, regarding, user and environment shall be used in the field of computational sustainability. This adds interpretive assessments from user and environment attributes. Validation of results must come from experimentations, and adjacent fields, such as psychology and sociology.

Research Question 4 Behaviour modifications can be promoted by user awareness, user suggestions and gamification elements that drive both cooperation and competition between users.

Means to create the necessity of change can be provided by examples or suggestions, making users identify the benefit of behavioural changes. For such, raising user awareness through the implementation of ranking reports through indicators and milestones are a typical approach. Further development on suggestion systems based on contextual information shall provide extra motivation, as well as, the use of gamification elements where communities interact in a competing environment, either collaborating or challenging users. These strategies must create paths for the continuous improvement of users and environments and resist time constraints.

The answers to these research questions aim to demonstrate and provide theory and design specifications in order to prove the validity of the research hypothesis. Our research hypothesis is demonstrated using action-research which deals with continuous experimentation until evidence supports the design of our generic platform to support computational sustainability, for which the case of energy, user comfort and driving analysis shall be used as testing sustainability scenarios.

1.1.3 Strategy and Research Methods

The adoption of an investigation methodology is important when conducting research. It helps the researcher stay on track and provides a number of steps to organise and ease the research. Perhaps, the most used investigation methodologies are based on hypothesis testing which devote time to design an hypothesis which to be used as object of study and guide the research activity. After its definition, experiments are designed to validate the hypothesis and results are analysed and compared against expected results. From experimental testing, the hypothesis may be validated, proven inconclusive or denied. The analysis of experiment results may also create new research directions based on which the initial hypothesis is reformulated and the process re-initiated.

Although hypothesis testing, the entitled scientific method, is popular, there are other methodologies that can be used, which rely on different assumptions and work-flows. One of such is the action-research methodology. In this methodology, experimentation is more valued. Thus, at the heart of this methodology is the design an implementation of experiments about the phenomena object of study. The experiments are analysed and only then conclusions in the form of hypothesis are formulated. When compared to the scientific method the focus on experiments rewards this methodology more hands on the problem and less theoretical. Among its strengths is the adequacy to exploratory research which often is characterized with lack of knowledge about phenomena which might invalidate the formulation of a good initial research hypothesis.

Due to the objectives proposed in this doctoral project, action-research was used to research the use of computational methods and their integration in current Ambient Intelligence (AmI) and Intelligent Applications (IA). The experiments are based on the construction of testing environments to which computational methods are added. Their interaction should generate behavioural modification and the overall system behaviour should also change. Research hypothesis are based on the results of these experiments and they will be used to fine tune further experiments with more refined criteria.

From the initial experiments, it is intended to observe results and provide detailed analysis on the verified data captured by each experiment. If a base is found then, it is explored in different experiment set-ups and case studies. This is intended to explore the resilience of the solutions found under different perspectives and their broad application or restrictions on their use.

Research methods used during the research activities are explained in sections 1.1.3.1, 1.1.3.2 and 1.1.3.3 with indications to what research approaches and methods are the most appropriate to justify the desired results during research activities.

The aim with this doctoral plan is to provide empirical research in order to demonstrate principles of sustainability in intelligent environments through the monitoring, sensing and actuating of an intelligent environment. Empirical research tests the feasibility and validity of a solution and hypothesis with a set of experiments conducted in laboratories, field experiment or simulation environments. For the purpose of the research to be conducted interest will be given to computer simulation and laboratory experiments to prove sustainable theories in an environment governed by ambient intelligence theories. The research program is intended to provide quantitative based research methods to prove the hypothesis that of principles of sustainability could be enforced on human behaviour and in the environment through the use of ambient intelligence technology.

During the execution of the research plan, it is planed to use more than one research method. This is also recommended as there is no single research method without flaws and weakness. Different researchers have debated this problem and concluded that every research method is flawed due to the three horned dilemma, from generality, context and precision of a research a single research method can only maximize at most two of these three topics. In order to reduce the effects of such dilemma different research methods and research strategies are planned.

1.1.3.1 Proof of Concept

Due to the novelty of the research area and the proof of concept research method will probably be the most used in order to demonstrate the application of the principles of sustainability to ambient intelligence. The main purpose of proof of concept research is to prove the feasibility and practicability of innovative concepts through prototypes or demonstrations of functionality. Ambient Intelligence and Intelligent Environments are still an emergent technologies brought up by advances in the 90's such as the appearance of the concept of ubiquitous environment by Weiser [17]. Different researchers have been applying such technology and concept to an even broader range of applications and that has been done through the use of proof of concept research where initial models and algorithms are used to demonstrate the application of such concepts. The activities intended to pursue during my research plan follow up on this idea and will try to expand ambient intelligence and intelligent environment design to account for the principle of energy efficiency and sustainability in its broader meaning which includes concern from economical, social and environmental points. My objective is that it is possible to provide an ambient intelligence platform design so sustainable indicators are monitored and proactive measures are calculated and executed in the environment through automation, user persuasion and direct suggestions to users so sustainable factors are enforced upon the system.

1.1.3.2 Computer Simulation

Computer simulation is also another research method to be used during the research plan. The purpose is to simulate an intelligent environment where ambient intelligence and principles of sustainability can be simulated. The system is supposed to be supported by laboratory experiments to validate the devices and testing environment. Then, from the data collected, a simulator will be built where the results from the experiments with devices and the environment are integrated and explored. This procedure is also intended to speed the analysis process and the testing of sustainable theories inside a real environment simulated through the developed simulator. The sustainable theories tested upon the intelligent environment involve actuators and sensors in the environment and also human behaviour modelling. The advantage is that the simulation of processes allows carrying out experiments that would otherwise be costly, time consuming and hard to do in a real environment. Of course, a simulated environment may not represent reality with 100% accuracy but it may help prove theories inside a defined margin of error resulting from the error in the simulation.

1.1.3.3 Laboratory Experiments

Other interesting research method to be used over the course of my research plan is laboratory experiments to prove separate hypothesis during the research. As a research method laboratory testing is considered a methodical procedure carried out with the goal of verifying, falsifying, or establishing the validity of a hypothesis. The experiments may vary greatly in their goal and scale, but always rely on repeatable procedures and the logical analysis of the results. In the field of computer science, ubiquitous computing and pervasive environments the experimental set up is not like other natural sciences such as physics, biology or chemist. Nevertheless, a laboratory experiment may be defined using a controlled space where human interaction is possible. Such experiments have already been carried out in research centres throughout the world an some of the researched papers even detail environments and conditions. In the design of these experiments hypotheses that suggest reasons to explain a phenomenon, or predict the results of an action are used against what is called the null hypothesis, that there is no explanation or predictive power of the phenomenon through the reasoning that is being investigated. Through the development of my research project laboratory experiments are intended to prove that the use of intelligent systems in a contextualized environment such as a room, building or space will see increases in the sustainable factors of such environments. This research methodology is intended to be used in the study of human interaction with the ambient and how it is influenced by it.

1.1.4 Research Plan

The work plan is divided into six main tasks, which were developed along the 4 years of the research program. Publications in conferences will document and share research conclusions upon the conclusion of each task. The timeline for task execution is detailed in this section, where the six tasks are scheduled over a period of four years.

Over the following text each task plan will be detailed, where a brief summary of the task is presented.

Review of the state of the art The aim of this task is to review the state of the art of the main issues, and to consolidate knowledge throughout the whole research program. This is why it was planned to activate this task in the first period of the entire 4 years program, extending it to a semester in the program's first year. One objective is to make a state of the art on a wide range of themes, which include AmI, Intelligent Environments (IE), Sustainability, Energy Efficiency and Computational sustainability among others. Current energy efficiency systems should also be reviewed to get an insight about how current technology approaches energy efficiency and sustainability. Another objective is focused on reviewing learning mechanisms, able to deal with data acquisition from devices, from people and from other means, commonly known as sensor fusion and data integration. Thus, special attention will be paid to Machine Learning (ML) algorithms, Artificial Intelligence (AI) approaches, as well as to strategies able to learn user habits from sets of data.

Experimentation and Exploration with Tools and Resources In this task, experimentation and exploration of sensors, actuators and computing devices was conducted in order to be able to make decisions on which resources should be selected, having knowledge about their ability to monitor, sense and act on an environment. Sensors used might have a stationary position or might move around the environment freely or adjacent to inhabitants.

One important goal of this task was to gather data from an inhabitant, in an intelligent environment. Such data might consider routines, normal behaviour and variance in behaviours. Considerations about data gathering from multiple users are also important, to accomplish user profiling. With multiple user routines, ML and AI, it is intended to predict user behaviour and adapt some variables of an intelligent environment such as temperature, natural light or ambient music.

Integration of energy efficient plans with profiling techniques With the data gathered along Task 2, user profiling is necessary to identify user routines and intentions. This information will then be used to predict and take proactive actions on the environment, in order to ease the life of its occupants, respecting user preferences or wills. The system should be able to relate this data and energy efficiency to assess potential optimization in energy consumption.

An important goal with the integration of energy efficiency plans is to extend the consumption estimating models with suggestions that a user might take, in the environment or, proactive actions of the environment itself using actuators.

Affective Computing and Assisted Living From emotion detection mechanisms, the system was intended to improve user satisfaction in the environment. Affective computing might be used to evaluate user reactions to proactive actions from the environment. This enables the use of reinforcement learning algorithms which naturally evolve according to user needs, wills and preferences.

Ambient Assisted Living is dedicated to assist people in their everyday lives in a pervasive manner. With this technology and the actuators present in intelligent systems the goal was to assist users in their tasks as possible without being intrusive. Also, it may enable the system to assist users maintain energy efficiency and the sustainable use of energy.

Suggestion Support System to Develop Energy Efficient Environments The objective with the suggestive system was to support decisions where knowledge is relevant to customize intelligent environments according to user profiles. The suggestive system might use information from multiple intelligent environments to develop efficient building patterns with sustainable energy use and lower consumption, or to propose intelligent environment's room re-arrangement to better accommodate each user group needs.

Using all the data gathered since the beginning of this work and the experience obtained, the intention was to, with the help of machine learning compare results from different intelligent environments clustering user types and extracting their preferences on the arrangement of their environments and also how to leverage energy efficiency for each user group by physically changing their environment.

Multi-Agent System Design, Conception and Implementation The development of the archetype will be done making use of intelligent agents and multi-agent systems computational paradigm. The system design will focus on a multi-agent architecture with intelligent agents responsible for the interaction between, users, sensors and actuators in the intelligent environment. Standards to be used can include FIPA-ACL and restful web-services for messaging communication and interaction along with platforms which implement them like the multi-agent frameworks and traditional web-servers.

It is also intended to be an open, extensible platform in which new modules and components can be added or connected to.

In terms of functionality, the multi-agent system should include the results from the work in the previous tasks, and enforce policies to assure sustainability and energy efficiency like turning off sensors where situations do not require their intervention.

1.1.5 Synthesis

The introduction section is used to create a preliminary view of the thesis. From the initial introduction to the research area there are also considerations about the research hypothesis and investigation methodology followed. The investigation activity is planned out through systematic methodologies in search of valid experimental results that corroborate the research hypothesis.

Being the research about the use of computational methods to help energy efficiency and general sustainability, layout of the work is designed according to the research methodology and research methods employed. Although considerations about each methodologies advantages and disadvantages exist and are described in the literature, the combination of different methods helps diminish these shortcomings and strengthen the quality of results.

Research methodologies that drive results from simulation experiments to proof of concept environment and field experiments are design to observe the transition from expected results to observed results and prove result consistency and adequacy.

1.1.6 Document Structure

This thesis is organized by chapters which take into account the progress achieved during the research activities. This first chapter, from which this section is part of, contains the motivations for the research activity in conjunction with the presentation of sustainability as a field of study. After fundamentals, the research objectives are presented, as well as, the strategies and methods planned for research activities. A review of the state of the art and analysis of related project encloses the first chapter.

In the chapter 2, Innovation and Research, there are some prospective experiments which were done throughout the execution of the research plan. Taking advantage of the action-research methodology, these experiments help shape the specification of a generic platform to handle projects in the field of computational sustainability. The sections of this second chapter portrait the research topics starting with sustainability assessment and computational sustainability, user awareness, gamification and communities, and context-aware well-being. The fields addressed in this thesis are related to sustainability and they are applied according to the research programme. Moreover, research from sustainability assessment to raising user awareness and accountability while keeping comfort and well-being are also reviewed and their application considered. Each experiment phase is accompanied with scientific evidence validated by peers, in conference papers with, at least, three reviewers.

One of the results of the research plan is the specification of a computational sustainability archetype platform as it is presented in chapter 3 Design and Implementation. Taking cues from the experiments detailed in chapter 2, an archetype platform is detailed in a modular structure. Due to its application to the research field of computational sustainability and intelligent environments, there is focus on sensorization strategies, modelling attributes and data-fusion. The ability to further extend its coverage through extensions is also a benefit of the archetype defined. Examples of use for the platform are based on sample use cases, documented in scientific journals and conferences which are also presented.

Chapter 4, Conclusions, is the last one and provides an analysis of the main results obtained during the doctoral programme, the considerations about the research hypothesis and further directions of research. It is accompanied by a list of publications in journals, conferences and other scientific events which help support the results achieved from research activities. Related activities not directly dependent on the research programme during the doctoral programme are also demonstrated.

1.2 Review of the State of the Art

1.2.1 Computational Sustainability

Computational Sustainability is a relatively recent term, first used by Carla Gomes[3], to describe computational systems that work for the benefit of sustainability. Admittedly, the work on sustainable systems using computer science is as old as the science itself, though the use of the new term makes people rationalize computational systems as resources to help solve complex problems.

Under this perspective, problems can be subdivided by the application of computer science to deal with those problems.

Computational simulation is used to model complex environments with complex interactions using mathematical rules combined with strict or statistical interpretations. Not only does simulation help preview the state and behaviour of systems it can also be used to test solutions. Other application is to enable a cost effective research on topics generally too costly for feasible studies.

Constraint optimisation is another kind of problems that is directly related with sustainability being that sustainable systems mostly deal with restrictions and their satisfaction in a efficient manner. These problems are often used to meet certain sustainable criteria in the most efficient way possible. Their design is often implemented and treated as heuristic problems. Of course the complexity that these problems can achieve leads to time intensive computational resources being used. The algorithms also responds differently according to the size of the problem and their complexity which, in certain cases, can render finding an optimal solution almost impossible

[3]Carla Gomes is a a Professor of Computer Science at Cornell University, a Fellow of the Association for the Advancement of Artificial Intelligence (AAAI) and the director of the newly established Institute for Computational Sustainability at Cornell University

within an useful time-frame. Therefore, research as also been conducted in meta-heuristics algorithms that are able to find an adequate solution without the certainty of it being the optimal one. Further research on the field has also targeted the exploration of hybrid heuristics and soft computing algorithms to improve solutions. In these cases, the most common approach is to find an adequate solution to the problem and iterate over it to try to find a more efficient one during a specified time-frame.

Machine learning and Data-Mining , have also been used in the context of computational research to address complex non-deterministic problems. These try to predict the state of the system with models based on past evidence, past trend and past knowledge. Their use is limited to the application of the models but they are considered powerful tools to uncover traits and trends often hard to spot. One application with popular use is the application of these algorithms in big data collected by a number of sensors that can latter be used for analysis either online or offline. The ability to understand and predict the state of the system enables early detection of non-sustainable scenarios and to take preventive actions which are often more cost effective than remediation efforts.

Bringing together the fields of computational sustainability and ambient intelligence requires a multi-disciplinary effort. Restrictions on the models created and simplification of the sustainable parameters might also be frequent due to complexity and nature of the problems. Taking lessons from model theory, the more general the project is the more complex it will be to create, and even with large computational resources it may become untreatable. This is where the craftsmanship of computer science and model simplification can be used to reduce complexity without compromising the end result in a significant manner.

Another closely related topic is smart cities, which can be perceived to some respect as a group of ambient intelligence environments or a rather large one. In fact most ambient intelligent approaches are applications for medium to small environments whereas smart city demands procedures that work on a large scale that accommodate large metropolitan areas. Research trends have also motivated researchers to move from ambient intelligence to smart cities both by political initiative and findings opportunities. In the European Union, under the Horizon 2020 programme [4] , the research focus was clearly changed to smart cities [18]. This means that the application of computational sustainability under this paradigm necessity general models with broad coverage that yield meaningful results to assess sustainable parameters. These parameters can be inspired by both previous work or the design of new and relevant approaches. The United Nations and the Millennium goals initiative[5] has conducted studies that resume some sustainability indicators for air quality, social standings, economic perspectives, traffic control, gas emission among others. The cheer number of indicators defined is well above 200 individual contributions that require the analysis of complex and often hard to retrieve data. Computational infrastructure and resources such as sensor networks and data fusion help automate these tasks but the harder the complexity the more carefulness is needed designing those systems.

[4]Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness

[5]The eight Millennium Development Goals in clue environmental sustainability and global partnership for developement. More information can be found at: `http://www.un.org/millenniumgoals/`

In order to implement energy saving measures, different authors proposed different strategies, from active action and control of the environment to more proactive measures, such as the planning of the materials and physical structure of the environment itself. Some strategies are enumerated in the following text.

1.2.1.1 Behavioural Change

The consciousness of user can lead to behavioural change. In this regard and applied to energy efficiency, studies support the idea that user are more responsible when information regarding energy use is available and demonstrates their accountability [4].

In fact, Herring studies [3], state that over the last years consumption of electricity has increased steadily despite the fact that energy efficiency policies are being adopted. This reckons that, energy efficiency is allowing people to use energy for more services and devices unaware of the impact on final consumption rates.

In order to address this problem, automatic systems are being proposed in the literature control environment attributes and, as a consequence, modify user behaviour to act according to energy efficiency policies that actually reduce overall consumptions. In [19], a rule based system is proposed to this end, where rules control an environment attributes such as temperature through middleware which results in a stated 4% daily savings. This example is not a unique case, in fact, in [20] a survey of rule based system was conducted supporting the strategy to control user routines through intelligent systems that reduce the occurrence of suboptimal behaviours.

1.2.1.2 Environment Configuration

The physical structure of buildings is also important for energy efficiency measures. In fact, energy consumption inside commercial and non-commercial buildings is said to be between 20% and 40% of the total energy consumption. Among the services inside such buildings, heating, ventilation, and air conditioning (HVAC) account for about 50% of energy consumption in the US, [21] followed by lighting, about 22% and appliances, about 13%. Although the percentages may differ from this order of service consumptions is preserved for countries like US, UK and Spain [22]. The significantly energy consumption of these services is an important motivation to address building efficiency inside intelligent environments. In order to tackle the HVAC energy consumption problem, there are purposes for intelligent thermostats that use information about current building occupancy and user preferences to perform energy efficient decisions to control HVAC systems. This type of thermostat is purposed by Nest [21], with the use of a device that performs ambient sensing and records users interaction with it.

1.2.1.3 Industrial Community

Industrial environments are also object of energy saving measures, in Heilala et al. [23] an industrial AmI platform is proposed for the optimization of energy consumption. In this example two devices are used to gather and concentrate data about the environment. Afterwards, the data is sent to the AmI platform developed so it can be processed. The AmI environment will be responsible for assessing the energy efficiency through an Energy Using-Products (EUP) directive [6] and the European Standard EN 16001:2009 [7] to help establish process and system for energy efficiency. The main technique used by the AmI platform is case based reasoning, comparing the data gathered and processed in the AmI with EUP values to assess and diagnose possible inappropriate energy consumptions.

1.2.1.4 Automatic Systems

An automatic system approach to energy efficient systems is proposed in [24]. Authors propose an intelligent decision support model for the identification of the need for intervention and further evaluation of energy saving measures in a typical existing building. They propose an innovative model where the assessment of intervention needs, upon an intelligent building, is done through data collected from a BEMS system and a list of external parameters important to take into consideration evaluated by a panel of experts. To evaluate intervention needs, like costs and interest rates, the list of intervention proposals is combined with a decision support unit. The decision unit is responsible for combining the experience gathered from the BEMS system with the possible actions in the proposals list resulting in a set of possible cost-effective actions that can be taken in the system. The demonstrated concept shows that it is possible to have an intelligent model to perform energy management on a building, combining aspects like ambient climate conditions, investment rates, fuel, carbon prices and also past experience.

1.2.1.5 Gamification and Information Diffusion

There are already many studies in regard to gamification, where people use it to change the behaviour of the systems in order to make them more efficient. Still, there is a common trait among them, they are oriented to efficient actions of a system and not efficient actions of the user [25]. Changing the former is determining what should be its behaviour, while changing the latter means changing their habits, the behaviours acquired. In order to tackle this problem, two main concepts will be put in practice: Gamification and Information Diffusion.

In [26], gamification is applied in education where the authors try to take the elements from the games, that lead to engagement, and apply them in school, to students to keep them motivated.

Another example uses a framework that allows users to share their daily actions and tips, review and explore other people's actions, and compete with them for the top rank by playing games and puzzles [27]. On another example authors developed a service-oriented and event-oriented architecture framework where all participants communicate via events over a message broker. This system is composed by a set of game rules that define game elements like immediate feedback, rank/levels, time pressure, team building, virtual goods and points. There is also an analytical component that may be used to analyse user behaviour

[6]The European Union has implemented an ambitious energy program (EuP) to address the security of its energy supply, as well as energy-related health and environmental issues.

[7]The I.S. EN 16001:2009 Energy Management Systems Standard was developed to ensure that energy management becomes integrated into organisational business structures, so that organisations save energy, save costs and improve energy and business performance.

in order to improve game rules and optimize long-term engagement [28]. Through these examples, the application of gamification can raise the levels of loyalty of the users and keep them engaged in our objective by making it more enjoyable.

With respect to information diffusion, studies have proven [29] [30] [31] is that social networks have the potential to share information at a high rate. Besides this point, they can also influence other peers to participate by sharing content. The use of social networks, also mentioned above, has the goal of enhancing the engagement of the users to higher levels by bringing the results to public (respecting user's authorizations) and making each user responsible for his actions at the eyes of the respective.

1.2.2 User-Awareness and User Profiling

User-awareness and user profiling are areas of interest for the promotion and assurance of sustainability. An ubiquitous approach to this problem requires the intervention on user routines and environment configuration without requiring constant user attention to the final objective using services and devices spread around the environment. Gamification was studied in this research plan to implement indirect behavioural change in end users. Science studies support this idea and are presented below, as well as, the means to achieve such result.

Behaviour modification can have significant impact on the performance of an intelligent system. However, it is necessary to monitor through means of profiling such as statistics and machine learning. Optionally, affective computing, due to the interest of this research plan, can offer insights towards the reception of change trough user affective response, which in turn may also be an object of profiling.

This section introduces the use of such strategies.

1.2.2.1 Gamification

Playing games is an entertaining and motivational activity. The research field of gamification tries to incorporate these elements into real world problems and systems. Nevertheless, these applications do not want to make a game out of every system but rather add simple game elements such as points, levels and achievements to engage and motivate users.

Other possibilities enabled by the use of game related elements is to compare and differentiate users based on the performance of their game elements. This can then be used to fuel competition between users which, in turn, makes them more involved in the particularities of the system.

To be successful any gamification initiative must take into consideration the real world elements and attributes that compose their initial system. It is important to focus on the most impactful areas and to take closer look at game dynamics. Static implementations are the most evident, where points are rewarded based on activity and experience in the same manner through the system and time. More complex approaches have dynamic point systems that react to user engagement. This is akin to customer retention and customer recover practices in the world of retail and marketing where special promotions are employed to bring back users and maintain them engaged in the system. Due to its particularities, gamification is a viable option to manage communities of users.

Gamification itself is a new term coined by Nick Pelling around 2002 who first presented the case for the so called serious games applied to computer science. The truth is that concepts key to the development of gamification have already been used in the prior to this date, most notably by marketers and business with the use of loyalty programs and reward programs. Nevertheless, the path towards the definition of gamification in computer science was pioneered by the development of multi-user games such as MUD1 created in the university of Essex by Roy Trubshaw which was the first Internet multi-player online role-playing in 1978.

Deepening the analysis to the definition from Deterding, gamification can be put closer to games and further from playfulness; as stated in game studies, the difference between game and play is strongly related to the differences between the Caillois' concepts of paidia and ludus as two extremes of the play activities' dimension [32]. In these studies, paidia, associated with playing, is characterised by free-form and expressive behaviours while ludus, associated with gaming, is identified by a structured set of rules followed by the players and the existence of a competition between these players towards a clear goal. The classic definitions of game studies also follow this thought and declares that games are defined by an explicit system of rules and the struggle of players towards a discrete goal or outcome [33].

On the other hand, we are addressed to the elements present in games. Here, it is worth noting how the concept of gamification differs from the concept of "serious games". While the former confines itself to the integration of some elements of games, the latter means the construction of games with a very high degree of maturity and build with non-recreational purposes. However, the line that separates a game from an application with game elements is, most of the time, poorly defined, so, for this reason, the following considerations will be taken: an application as well as the social elements of a game must be taken into consideration and applications' elements must be designed with the objective of providing gameful experiences instead of being gameful by nature.

After this, only remains the need to define which elements belong to the set of games' elements. There is great uncertainty about the composition of this set because there are many kinds of games and, even between digital and non-digital games; furthermore, the way the elements of games can be perceived are dependent on the user role. Everything considered, Deterding defines as elements of games the ones that are characteristic to games, which means the elements that can be found in most games but not necessarily in all of them, the elements that are rapidly associated with games and that play an important role in the game-play, like, for example, points, rewards, virtual currency, leader-boards and badges.

Another fundamental point in the definition followed is the design since applications that apply gamification are not the only ones where elements of games saw their purpose altered. In different fields of Information Technology (IT), video game designs are used with different purposes so, for the sake of an existing clarity, both conceptual and terminological, it is helpful to reserve the term "Gamification" for the description of game design and not game-based technologies or practices.

Through the literature reviewed, it was found that such game design elements can be classified at different levels of abstraction and, according to Deterding, all those levels should be included in definition and can be ordered from the more concrete to the more abstract as depicted in 1.3.

Table 1.3: Levels of game design e lements, according to Deterding

Level	Description	Example
Game interface design patterns	Common and successful interaction design components and design solutions for a known problem in a context, including prototypical implementations	Badges, leader-boards, levels
Game design patterns and mechanics	Commonly recurring parts of the design of a game that concerns game-play	Time constraints, limited resources, turns
Game design principles and heuristics	Evaluative guidelines to approach a design problem or analyse a given solution	
Game modes	Conceptual models of the components of games or game experience	Challenges and Mechanics, Dynamics, Aesthetics
Game design methods	Game design-specific practices and processes	Play-testing, play-centric design

Looking at the examples provided for each level of this table, we can see how all the projects analysed had implemented leader-boards, mostly a consequence of all projects using points as a reward, and levels, also called as status, and used with the purpose of distinguishing different kind of users.

At the second level, we find elements that are not used very often like time constraint as seen at UbiAsk [34] where you earned points by answering question, a kind of turns, and the fastest the answer, the better.

At the third level, we have the type of play and clear goals, elements that are also seen in a variety of projects, although due to the fact that Enterprise Gamification [28] is intended to be generic, there is no clear goal as it depends on what context the framework is applied.

Finally, the fourth and fifth level are too abstract to be defined as elements of Gamification, also the validity of these examples regarding any application is dependent on the type of user. Once analysed the table, it is possible to see how this model for the division of elements puts interface design patterns at a different level of abstraction when compared to game design patterns or game mechanics. Even though they are related to the concept of pattern languages, contrary to interface design patterns, game mechanics and game design patterns do not refer to any kind of implementation and this can be verified by the fact that both can be implemented with various and different interface elements.

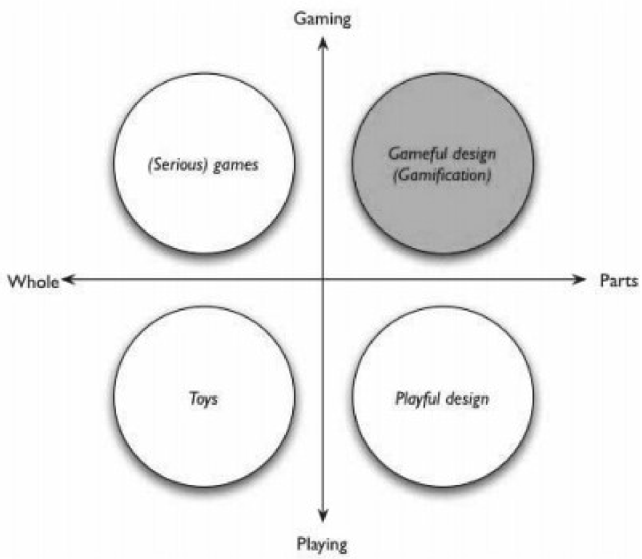

Figure 1.4: Gamification between the dimensions

Last but not least, comes the explanation about non-game contexts. As the "serious games", gamification also makes use of elements of games for other objectives than the ones we would expect from a game, assuming that games are still developed with the main goal of entertaining its users. Thus, a good user experience and engagement are the primary purposes on which gamification is used, even more when considered that gameful experiences are, most probably, a design goal. By taking this into consideration, it is possible to start looking to gamification as a concept to be applied only to specific usage contexts, purposes or scenarios, something that should be avoided since this limitation does not bring any obvious advantage.

When Gamification refers to the use of design elements, it is putting those terms against the implementation of a specific technology or the development of a full-fledged game, and when it mentions the non-game contexts, it means a wide approach to any type of context without taking into consideration any specific usage purpose. This definition puts Gamification against various concepts discussed here and it can be categorised in a two dimension universe [35]. First, the dimension with the opposites playing/gaming that represent the nature of a given concept regarding the type of behaviour that the users exhibit; in this case, and according to its definition, Gamification belongs to the "gaming" quadrant whereas, regarding the second dimension represented by the extremes whole/parts, it is set in the "parts" quadrant since the purpose is to take advantage of some elements characteristic to games and not to develop full-fledged games. Through the cross of both dimensions, "parts" and "gaming" 1.4, it is possible to distinguish Gamification from other concepts that emerge in this context, such as "serious games" or playfulness.

Since this is such a recent and increasingly discussed concept, one can find many examples of applications that implement game design elements in non-game contexts.

Another considerably recent and important concept that will be part of this discussion is information diffusion. This concept relates how the information is disseminated through the peers and if this dissemination occurs as influence of external peers.

Even though the studies about information diffusion on social networks are new, the study about different types of information diffusion is not. In 1962, Everett Rogers [36] advanced with the theory that there are four main elements that are directly tied to the spread of an idea: the innovation, communication channels, time and a social system. Each element plays a role in the information diffusion where the innovation refers to the idea, practice or object to be adopted, communication channels are the ways through where one message travels from one person to another, time is the length of time required to pass by the process of deciding about the innovation and the social system is “defined as a set of interrelated units that are engaged in joint problem solving to accomplish a common goal”. Along the years, new social systems have emerged while others became obsolete. The most common social systems nowadays are blogs [37], social networks and social media like newspapers, advertisements and magazines; since all these social systems became much more effective thanks to the use of the Internet, their role in the information diffusion also became more impactful.

With the increasing number of social networks and the increasing success of these, as it can be seen by the growing number of users of Facebook or Twitter, it is important that the interactions in these social systems can be replicated in our application as a way of increasing the level of engagement of its users and stimulate a strong feeling of community. Once examined the literature, some studies were found [30] [38] proving that social networks have a great potential to spread information at an elevated rate as well as allowing people to influence their peers. However, this strong ability to influence brings downsides like the power of this influence being strongly tied to the different types of users or the sharing of incorrect information that may mislead other users. Taking into account that we seek to address a problem that affects everyone, it becomes important that we maximise the information diffusion and make the users themselves play an active role in this diffusion.

1.2.2.2 Affective Computing

As the name says, affective computing deals with emotions, moods and personalities of users in computational systems. It might be perceived as an attempt to humanize computational system or to try to capture user emotions through computational means.

This field has characterizations for emotions, moods and personalities which are said by psychologists people as three different things although highly connected. Emotion is predominantly a reactive reaction to some event and thus generally short lived. Mood is a more stable state of mind influenced by emotions. Personality is part of user configuration and it tells us about its predisposition to event reaction and actions. It is stated that personalities have high influence on the manner people invoke reactions to deal with events so assessing one’s personality is essential to predict their emotional response.

The term Affective Computing (AC) was introduced by [39]. It is a computational area that tries to replicate the psychological mechanism of human behaviour in order to include them in computer systems for interaction between these systems and man become closer knowing that the studies of psychology and neuroscience shows:

- A person reacts differently to certain emotions expressed by another person, when they come into contact;

- The emotional system affects the cognitive system;
- This emotional core is directly associated with the process of decision-making of the human nature.

Embedding this affective system in artificial systems aims to increase the level of user interaction with the increase of his level of comfort and to reduce the non-determinism of decision making in a virtual agent, giving it another layer of intelligence. [40] [41]. In AC despite some critics who argue that certain emotions like anger or passion in a human-human relationship tend to be more harmful than beneficial and therefore not worth including these features in a logical system as computers, there is a rule underlying this field. “It has never been about making machines that would look more emotional; instead, it has been about making machines that would be more effective.” (Picard [40]) Inside this category of systems there are some techniques for simulation emotions, personalities and behaviours - emotions models such as the OCC Model [42], [43] and the PAD space oriented to emotional mood [44], [45] are very common among computational researchers and they clarify the psychological process with a set of computable parameters.

Experimenting the use of affection in computational systems requires the representation of human emotion, mood and personality. It is believed that by taking emotion into account, decision can be made in a more natural fashion. This should ease adoption of suggestions and optimize the rate of accepted suggestions. In computational sustainability, there is also the realm which deals with the interventionists in the environment. Such is the case with the human factor. Although optimization can streamline actions and mitigation problems, there is also the process only reached by human hand. Those can be influenced by suggestions, awareness and regulation, but, nevertheless they remain outside the computational scope.

Acquisition of emotion, mood or personalties is an inferred process. It means that an amount of testing parameters are monitored on the subject either directly by questionnaires or monitoring action-reaction events. Either one gives clues that can be used to estimate and percept the current state of affective attributes.

In the following sections, a discussion about capturing user behaviour related to affective computing shall be detailed. To this end, considerations of the application of emotion and mood systems are also debated from a computational approach.

User behaviour To help people to act upon a sustainable form, a computational system needs to give them suggestions to improve their relation with the world’s objects, resources and electrical devices. In order to predict actions, the psychology field tries create methods to perceive the person’s past actions and to get clues of what will be his future actions. In order to formulate methods to achieve this objective Ajzen presents a model called Theory of planned behaviour (TPB) [46]. This model considers that behaviour is formulated by weighing three forms of individual beliefs such as control, behavioural, and normative beliefs, that regulate the intention to perform certain actions. The final stage of the model is activated by how strong is the intention to perform the action and it is calculated summing the weights of all beliefs. To understand the flow of information it is necessary to determine these three forms of beliefs processed by three initial states:

- Perceived behaviour control – this state determines if it is an unintentional behaviour or not, if so, the person does not have time to formulate an intention, and the behaviour is thrown; otherwise the intention is formed with the help of other states, i.e., this state treats the control beliefs;

- Subjective norm – dataset of moral and immoral statements, normative beliefs , and cultural boundaries;

- Attitude toward the behaviour – perceived if the target behaviour worth the effort, for example, a person believes that the behaviour he will trigger will have a bad consequence for him, so he won't launch this behaviour.

To undermine the weights of these beliefs, Ajzen proposes the usage of questionnaires to self report [47] and to obtain wanted data from questions is defined a set of parameters. To evaluate the intention to perform the formed action, the answers are summed to measure the strength of beliefs. This theory presents a model to perceive if a person or a population set will repeat a behaviour.

This model is used in works that investigate and incite sustainable behaviours, for example, TPB was used to analyse laws imposed by Chinese government to reduce consumptions of water. These rules affect directly the people habits and behaviour. So the goal of this work was to predict the intention of habitants to change their toilets into dual-flush toilets and, in conclusion the use of TPB by itself cannot predict a precise value of intention [48]. Another study which used this model to predict green behaviour on recycling issues reported by Tonglet et al. the model by itself does not respond precisely to determine the goal [49]. In both works, the TPB has been changed to meet the needs of the objectives, moreover provides a starting point to understand how behaviour can be anticipated thereby helping governments, associations and groups to take policies that are appropriate to people's perspectives without their having disruptive attitudes that may gradually and almost naturally change their behaviour.

Applications for this research field include the creation of an emotional system that reacts with users based on a specific personality and emotions or to perceive emotions of user's based on their personality detection and interaction with the environment. This short characterization can, of course, span into a large sub field of applications in areas such as robotics, ambient intelligence and assisted living. It helps systems become more natural and less mechanical which may ease people response and interaction with computer systems.

Emotion and Mood There is no consensual definition of the concept of emotion, but in common sense they are seen as mental scenarios of humans triggered by certain events or situations in the real world, i.e., an emotional state of a person can be turned on by him, by others, by object aspects and by event consequences [50]. A computational approach for assigning emotional states for different events is achieved by the model created by Orthony, Clore and Collins in their work "The Cognitive Structure of Emotion", this model generally called the OCC Model it is like a decision tree, the leaves are emotional states, they are activated depending on the event that is split on consequences, action/interaction of agents and aspect of objects then it is determined the origin of it [43] with this model it is possible to represent twenty two different emotions. The model developed by Steunebrink et al. that it is a formalized and extended version of OCC and operates the same way as a decision tree since the original model suffers from logical ambiguities [42]. With this approach, it is possible to represent thirty three different emotions, because certain variables used on the original model became emotions in this extended one, for example positive or negative which may be considered proto-emotions or primitive emotions.

The OCC model helps choose an emotion according to the nature of the external event, but emotions are seen as states, for example a sequence of events can cause an emotion transition to another state. A method to simulate emotional change and its update was presented by Guojiang et al. this approach is based on the statistical model of Hidden Markov Model (HMM). In this work, it is assumed that emotional states are not isolated and that these states interfere with others and receive interference from others. This model has the capacity do model emotions and also model personalities.The experiments in this work prove that this model can reflect the changes of emotion in human beings and provide an different approach to existing models [51].

Newtonian Emotion System (NES) are other alternative in this field of emotion simulation based on psychological theories such as Plutchik's wheel of emotions [52] and Appraisal theory from Lazarus' [53] work mixed with Newtonian physics. First is defined the Newtonian Emotion Space, a set of concepts that enable emotional state do interact with other emotional with the world and itself influence. This set of concepts is similar to Newtonian physics, such position of emotion on the Plutchick wheel, distance as the Euclidean distance between emotion states, velocity that returns the magnitude and direction of an emotional change per unit of time, acceleration that returns a magnitude and direction of emotional velocity change per unit of time, mass represents the tendency to emotion's velocity continue constant, a external stimuli can force this mass and force is the external stimuli influence. Emotion space has a center and emotional state have the tendency to gravitate around this center. All agents have different predisposition to a kind of emotive behaviour therefore a different emotion space center. The gravitational force causes the emotional state decay to center after a certain period of time [54].

The methods HMM and NES are similar in fact they define a set of emotion and they move from state to state, and calculate the impact of external stimuli and decay of the intensity of the emotion per unit of time. To deduce what emotion they can pick through the external event OCC model can perform this choice.

Mood Simulation Mood or temperament is a medium term emotion, its effect takes longer than emotions. The model brought by Mehrabian the Pleasure Arousal Dominance Space (PAD) [44] and a computational approach was made in the framework ALMA by Gebhard [45].

The PAD-vector is a three dimensional vector, and defines the average number of emotional states related to real events, where each vector value is given in the form - (p, a, d) takes values in the interval $[-1, 1]$. To initialize it is necessary to take into account values from the personality obtained from FFM. This equation calculates the values for the independent variables P,A, and D.

The variables (o, c, e, a, n) take values from the interval $[-1, 1]$, and are evaluated according to a personality declaration. These equations return positive or negative values for each variable P, A, D. With that it is possible to define eight different moods [29]. The mood can change or be intensified by emotional experiences this creates two phases pull and push respectively. This model can infer emotion too, in fact every (p, a, d) value refers to different emotional states. For example, if a person has personality with predisposition to pleasant emotions usually has an exuberant mood so his center is located around – $(+P, +A, +D)$, will be easier to have emotions like joy–$(+0.4, +0.2, +0.1)$, and harder to have emotions like distress–$(-0.4, -0.2, -0.5)$, this last emotion is because it will change the mood state so the leap of emotion is greater (push phase). So a current emotion has a certain intensity and it will be returning to its center again in a certain period of time, because it does not last forever – short term emotion [45]. This is done with decay functions, similarly to the HMM and NES models.

1.2.3 Methods for Information Acquisition

As part of the methods of information acquisition, there are several methods and techniques useful in the field of computer science. The approach given is to try to gather information about user habits and common behaviours that influence resource consumptions, influence ecosystems and affect the personal being of people.

1.2.3.1 Ambient Intelligence and Multi-Agent Systems

Ambient Intelligence (AmI) was introduced by Mark Weiser in 1991 [17], a multi-disciplinary paradigm which promotes the development of intelligent systems, assisting users in terms of productivity, care, education and creativity [55]. AmI contexts can be found in works like [56], where a home environment with sensor information acts in benefit of its users in a pervasive way and, also, in reports by the European Union describing different scenarios for AmI [57].

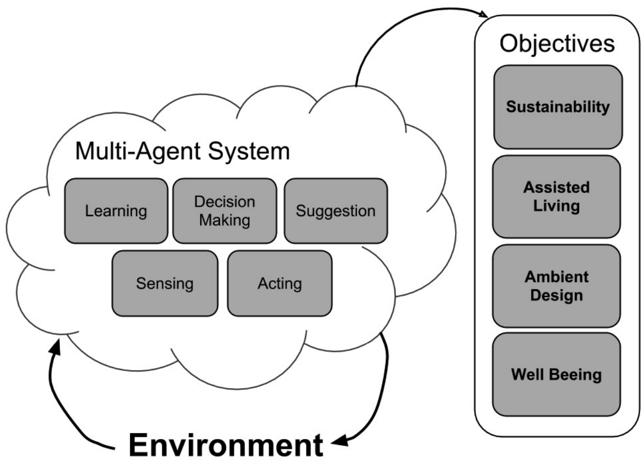

Figure 1.5: Ambient intelligence objectives

Intelligent Agents and Multi-Agent Systems are common definitions used inside AmI.

Multi-Agent Systems are well defined by Woodridge and Jennings [58] and implementation of such systems in domains related to this project can be found in affective computing modeling emotions [59], decision making [60] and learning inhabitants routines [61]. Current ambient intelligence implementations are used to perform experiments on ambient intelligence theory. As examples of such ambients, the iDorm ambient can be enumerated. This environment contains an inhabited environment at the University of Essex. The environment contains space for activities like sleeping, working, and entertaining. The sensors can sense temperature, occupancy (for example user sitting at a desk, user lying in bed), humidity, and light levels. The effectors can open and close doors, and adjust heaters and blinds. Other environment for ambient intelligence can be found in HomeLab [62]. It is composed of an house filled with hidden cameras, microphones to monitor users and a remote power control system able to operate switches and control lighting. This lab is used by researchers to assess social responses to different color schemes in lighting and monitor its users. Yet another ambient intelligence environment can be found in the MavPad project which uses a smart apartment created within the project [63]. This project consists of a living/dining room, a kitchen, a bathroom, and a bedroom, all fitted with different types of sensors to gather information from objects, users and contexts. One common aspect of the addressed AmI environments is that they are applied to home or dorm environments where the user spends more time. However approaches for industrial AmI are also found. AmI can be applied to manufacturing process controlling energy efficiency based on metrics such as EUP [23]. In this case the AmI system is responsible for obtaining data from sensors and to calculate energy efficiency measures with EUP formulas and a case base reasoning to purpose optimizations. Current ambient intelligence environments have been documented to have applications such as Smart Offices, Smart Classrooms, Cities, Museums and Tourism [64], [65]. It is also argued that intelligent energy saving system fall into the definition of intelligent systems as well as other definition presented in this paper such as computational sustainability projects.

1.2.3.2 Sensor Networks

The use of sensor networks has become widespread by the increasing popularity of trends such as biometrics, ambient intelligence and smart cities. These examples require high flows of data from sensorization objects to develop their work. The organization of sensors into networks is thus a natural option when working with these subjects. Of course it is still possible to work over these matters with ad-hoc connections but the an efficient management needs organization, addressability and maintainability.

Different sensor network classification systems exist and they may vary by type of internal organization, functionality and operation. A classical overview about sensors displays sensors as organized in plain networks, ring networks, hierarchical and federative configurations. Of course, this is only in relation to the addressability and the path to each sensor and the transport of data. Other configurations such as the one used to deal with vehicular networks use other denomination such as delay-tolerant networks, vehicular sensing and vehicular networks itself. These classifications are related to the traffic and mobile sensor grid commonly used within smart cities and means of transport.

In terms of reach, there are local networks, body networks and wide networks. These are related to the area and reach of the network of sensors. Therefore, it is possible to use different classifications for the same sensor network depending on the classification scheme used.

Arguably, more important than this, is the adequacy of a sensor network configuration to the problems it aims to solve or the problem for which it is designed. With this perspective in mind it might not be uncommon to use hybrid configurations that are connected between each-other. Problems addressed by research areas such as computer sustainability with intricate multi-disciplinary dependencies demand specific responses which might be better implemented using specialized networks and then implement communication channels between those.

1.2.3.3 Sensorization

One important task for any ambient intelligence environment is sensorization. It is used to gather data about an environment so information and knowledge about the environment can be calculated and used to plan actions and measures to implement on the environment. In the literature some proposals for sensor architectures for ambient intelligence were already proposed. An example of such can be found in Rui et al. [66], where it is proposed a conceptual system model for ambient intelligence. This model consists of a physical structure and a multi-agent system architecture. The architecture is demonstrated upon an ambient intelligence model concept where the system provides information from the fridge about existing food through RFID tags on the food and suggests meals on a PDA terminal. Tests conducted showed the proposed system provided good results in the service discovery mechanism, the design of the AmI adaptor, high interoperability and systems flexibility and efficiency. Other approaches to build sensor architectures for ambient intelligence include Universal Plug and Play (UPnP) devices. Wang et al. [67] developed a hierarchical AmI platform which consists of four layers, the ubiquitous environment, middleware, Multi-Agent Systems (MAS) and application layer. Additionally, a ubiquitous set-up box is also detailed and conceptualized with a design to support the type of sensors in the proposed UPnP system in a realistic environment. Furthermore 3 different user interfaces are developed and compared in the system, one simple convectional interface, a PDA interface and a virtual reality interface. The validation of the proposed system in order to examine the feasibility and practicality of the proposed AmI platform is demonstrated over a series of tests as the control response time that is the period of time between sending out a control command and displaying a corresponding acknowledgement on the user interface and hence providing a good indication of the real time performance. The process of sending a control action and getting an acknowledgement back needs to go through each layer of the communication stacks of the proposed AmI platform which is also validated with this test. In an environment one may find sensors and actuators. Sensors monitor the setting and gather data for reasoning processes [61]. Actuators act upon the environment and accomplish doings such as controlling the temperature, lighting or other appliances. The types of sensors used in the environment may be divided into categories to better explain their purpose. In terms of sensorization, one may have:

- Sensors that monitor the environment;
- Sensors that monitor the user and its activities.

This classification may be presented in a different form, taking into account the role of the sensor in the environment [68], [69]:

- Sensors installed on objects like appliances, furniture or light switches, providing information about their use;
- Context sensors provide information about the environment, such as temperature, luminosity or humidity;
- Motion sensors provide information about the user's location in the environment $i.e., GlobalPositioning$

1.2.3.4 Activity Tracking

In order to become user aware, an AmI system would benefit from tracking of human activities. This enables the system to propose more contextualized answers to each user. Different methodologies and procedures exist to keep track of human activities and to make predictions based on previous knowledge and current information gathered in these environments. Some of the most common approaches with machine learning techniques involve the use of neural networks, classification techniques, fuzzy logic, sequence discovery, instance based learning and reinforced learning. Nevertheless, human activity tracking algorithms have to acquire data about the user and the environment, reason about such data and present the information in some comprehensible form. One problem with tracking human activities is that there is no way to define the behaviour of humans with 100% accuracy. Moreover, it is often the case where user patterns change over time which results in the need to constantly adapt learned patterns to add newly discovered ones and drop discontinued patterns [61].

An approach to this problem using fuzzy logic algorithms is proposed by Hagras et al [70] who present an algorithm to learn the user's behaviours and preferences in a non-intrusive manner for controlling the intelligent environment. This approach differs from other authors due to the manner how the learning of user behavioural patterns is made. It uses the user's particular rules and interval type-2 Membership Functions (MFs) where these rules and MFs can then be adapted online incrementally in a lifelong learning mode to suit the changing environmental conditions and user preferences. Membership functions and user rules are inferred from an incremental adaptive online fuzzy inference system (IAOFIS) built from previous work of the author.

Sequence discovery approach is at the heart of learning algorithms in Aztiria et al. [69], which demonstrates a system that can learn user behavioural patterns and take proactive measures accordingly is proposed. The theory developed consists of a pattern of user behaviour system which is composed by three modules, the representation of patterns, the learning patterns and the interacting system. These three modules are then predicted to be capable of interacting with the user in natural language, learn patterns of user's behaviour and represent the contents of each discovered pattern in a simple if-then-when rule. Other approaches to this problem aim to combine different techniques into a learning algorithm. Studies show that this technique can result in better performances. In Wang et al. [67] a benchmark analysis of some algorithms was conducted. In this particular case the algorithm AOFIS is compared to three other adaptive algorithms ANFIS (Adaptive Network-based Fuzzy Inference System), GP (Genetic Programming) and Multi-Layer Perceptron (MLP). The results showed that all approaches show improvement rates between 40% and 58%. Furthermore, the results also show that the proposed AmI platform achieves up to 58% reduction in control errors by incorporating two algorithms in a multi-agent scenario to handle different tasks. Human activity tracking algorithms demonstrate great potential for intelligent environments in order to adapt to specific user preferences or environment specific objectives taking in consideration the habits of its users. In this work, these algorithms aim to help create specific energy profiles for each user so then proactive measures can be taken without disrupting normal user behaviour.

1.2.3.5 Machine Learning

ML techniques or methods concede the modelling and learning of preferences and habits in different contexts. These methods also sanction the acquiring of past and current trends and predict future results. From information assembled from different environments, ML techniques may derive models of behaviour and interaction based on specialized backgrounds (e.g., users, environment, social interaction or consumption). ML and Data Mining (DM) techniques may also be used to obtain information about user's habits in AmI settings, from data gathered by sensors in the environment, namely using practices borough from Sequence Discovery [61], Fuzzy Logic [70], Genetic Programming, Multi-Layer Perceptron or combinations of these techniques [67] or Evolutionary Intelligence [71]. ML may also be used to rule discovery in order to monitor and manage the consumption of resources, such as energy utilization inside intelligent environments [72], [73].

1.2.3.6 Context-Aware Computing

Context-aware systems are a component of a ubiquitous computing or pervasive computing environment. These systems consider information about user location and the resources available. User context operations can be performed on a per-thread basis. Indeed, when working with multiple locations, for instance, while servicing requests via a thread pool, one must explicitly set the location at the beginning of each new thread or request in order to provide the right location context to each request, i.e., one hopes to make informed and personalized decisions based on contextual factors that may lead to different results in terms of the same situation, once placed in different contexts [74]. Evidence of these context-aware systems can be found in e-Commerce, Information Retrieval, Ubiquitous and Mobile Systems and Data Mining. In these examples context awareness is used to personalize systems and applications to the present user context [75]. Despite the interest in context-aware computing, context definition for applications and systems is still challenging in some situations. A context may be assembled and made explicit by the user, implicitly from data in the environment or from DM and ML tools. Some studies propose the use of ontologies to assess and reason about user settings or contexts in a particular environment [76]. Concepts from context-aware computing are important in order to personalize the sustainable equilibrium for each specific environment and each set or group of users. If it is true that the environment should regard sustainable option so does its user base which makes user base which makes it important to include both contexts into reasoning processes.

Table 1.4: Relevant attributes to driving analysis according to previous studies

Attribute	[80]	[78]	[81]
Wheel rotation	+	+	-
Motor RPM	+	+	-
Pedals Monitoring	+	+	-
Street type	+	+	+
Fuel Consumption	+	+	+
Velocity	+	+	+
Acceleration	+	+	+
Standard deviation of acceleration	+	+	+
Trip duration	+	+	+
Hour of day	+	+	+

1.2.3.7 Driving Pattern Detection

Usually, driving pattern is defined and associated to the speed profile of the driver, but it can be expanded to other variables, such as gear changing, on the acceleration [77]. In 1978, Kuhler and Karstens [78] introduced a set of ten driving pattern parameters. Later, in 1996, André [79] reviewed some of the most common parameters such as action duration, speed, acceleration, idle periods and number of stops per kilometre. In other studies [80], [77] other parameters were used to collect data from ordinary drivers in real traffic situations, such as wheel rotation, engine speed, ambient temperature, decelerations and fuel use. In these studies, GPS data was also monitored, where each driving pattern was attributed to street type, street function, street width, traffic flow and codes for location in the city. It was concluded that the street type had the most influence on the driving pattern. The analysis of the 62 primary calculated parameters, resulted in 16 independent driving pattern factors, each describing a certain dimension of the driving pattern. When investigating the effect of the independent driving pattern factors on exhaust emissions and on fuel consumption, it was found that only 9 factors had a significant effect.

Table 1.4 provides the main attributes identified. These studies share most of the identified attributes to analyse and classify driving patterns. With the exception of attributes such as motor rotations per minute and pedals monitoring that are obtained directly from the physical vehicles, driving analysis with mobile and non-mobile sensors take interest in the same subgroup of attributes.

1.2.4 Summary

The presentation of concepts such as computational sustainability, user-awareness and methods for information acquisition is intended to give a broader perspective on how technologies can be integrated to the benefit of sustainability projects. From the motivation for computational sustainability, it is discussed the mean to address the problems through a computer science approach.

Furthermore, in order to take action, cues are taken from related projects and research to reach user-awareness and user-profiling. These are essential to characterize user and how to improve their behavioural or ranking trough profiling systems.

Concepts such as gamification and affective computing are a part of the research plan for this thesis, and as such they are analysed according to their definition and their usefulness to address computational sustainability.

Finally, as for any computer science project, methods of acquisition of data and information are essential. The analysis is done from the top-down with increasing detail to focus the reader to the relevance of data, and how it is achieved in the by computer science theory. It should be admitted that the list of acquisition methods is not absolute, but rather a subset, closely related with the work developed. There is also further explanations on methods of acquisition that was relegated to the sections where they are relevant in this thesis, thus easing the reading of this document.

1.3 Related Work and Projects

Related project are described in this section according to two categories of application. These categories are chosen by the nature of the projects enclosed, either focused in planning and reasoning aspects inside manageable environments or focused on user communities and large environments. Nevertheless, the aim of these project is related with energy optimisation and achieving sustainable parameters, thus they can be classified inside the computational sustainability field.

1.3.1 Planning and Reasoning

In this section, attention was devoted to plan and reasoning projects that use computational means to achieve sustainability and energy efficiency. A total of four examples are detailed.

Transformative Energy-saving Schedule-Leveraging Agent (TESLA) Reducing energy consumption is an important goal for sustainability. Thus, conserving energy in commercial buildings is important as they are responsible for significant energy consumption. This energy consumption is significantly affected by a large number of meetings or events in those buildings. Energy-oriented scheduling can assist in reducing such energy consumption. Although conventional scheduling techniques compute the optimal schedule for many meetings or events while satisfying their given requirements (i.e., computing a valid schedule), they have not typically considered energy consumption explicitly [82].

To that end, it is presented TESLA (Transformative Energy-saving Schedule-Leveraging Agent), an agent for optimizing energy use in commercial buildings. TESLA goal is to save energy, continuously running an autonomous agents. TESLA's key insight is that adding flexibility to meeting schedules can lead to significant energy savings. Users in a commercial building continuously submit meeting requests to TESLA while indicating their flexible meeting preferences. TESLA schedules these meetings in the most energy efficient manner while ensuring user comfort [82].

This work particularly provides four key contributions. First, it provides online scheduling algorithms, which are at the heart of TESLA, to solve a two-stage stochastic mixed integer linear program (SMILP). This SMILP considers the flexibility of people's preferences for energy-efficient scheduling of incrementally/ dynamically arriving meetings and events. Second, TESLA also includes an algorithm to effectively identify key meetings that could lead to significant energy savings by adjusting their flexibility. Third, this work provides an extensive analysis of the energy saving results achieved by TESLA. Lastly, surveys of real users are provided indicating that TESLA's savings can be realized in practice by effectively leading people to change their schedule flexibility. To validate our work, we used a public domain simulation testbed, which is described below, fitted it with details of our testbed building, and compared the simulation results against real-world energy usage data. Our results show that, in a validated simulation using our testbed building, TESLA is projected to save about 94,000 kWh of energy $roughly\$18K$ annually. Thus, TESLA can potentially offer energy saving benefits to all commercial buildings where meetings affect energy usage.

Sustainable multiAgent system for optimizing Various objectives including Energy and Satisfaction (SAVES) Recent developments in Multi-Agent systems are opening up the possibility of deploying Multi-Agent teams to achieve complex goals in such energy domains that inherently have uncertain and dynamic environments with limited resources. To model and optimize buildings' energy consumption, building agents, facility managers and human occupants are demanding robust, intelligent and adaptable ambient planning techniques. To realize both tangible benefits such as energy and operation savings, value property, reduction in occupant complaints as well as the intangible benefits such as occupant comfort and satisfaction, designers must develop energy adaptive capabilities within the building environmental control systems.

This project focuses on a novel application to be deployed at Ralph & Goldy Lewis Hall (RGL) at the University of Southern California as a practical research testbed to optimize multiple competing objectives:

- amount of energy used in buildings;
- occupant comfort level;
- practical usage considerations.

This work provides three key contributions. First, it is considered uncertainty while reasoning about coordination in a distributed manner. In particular, they use a novel algorithm for generating optimal Markov Decision Problem (MDP) policies that explicitly consider multiple criteria optimization (energy and personal comfort) as well as uncertainty over occupant preferences when negotiating energy reduction. Second, human behaviours and their occupancy preferences are incorporated into planning and modelled as part of the system. As as result, their system is capable of generating an optimal plan not only for building usage but also for occupants. Third, the influence of various control strategies for multi-agent teams is evaluated on an existing university building as the practical research testbed with actual energy consumption data in the validated simulation testbed. Since the simulation environment is based on actual data, this result can be easily deployed into the real-world. For future work, we consider opportunities for direct occupant participation and incentivization via hand-held devices and deploy our system to the real-world [83].

They also design and conduct a validation experiment on a group of human occupants in commercial buildings via a set of agents in their system: room and proxy agents. There is a dedicated room agent per office and conference room, in charge of reducing energy consumption in that room. It can access sensors to retrieve room information and energy use and impact the operation of actuators. A proxy agent is on an individual occupant's hand-held device and it has the corresponding occupant's models. Proxy agents communicate on behalf of an occupant to the room agent based on their adjustable autonomy - when to interrupt a user and when to act autonomously. Room agents may directly communicate with occupants without proxy agents, and different room agents coordinate among themselves as well as with proxy agents.

Energy Saving Incentivization - THINC Large number of meetings or events significantly impacts such expenditures. Using algorithms and optimization techniques, known as THINC, energy minimization is possible by scheduling meetings back to back; reducing reheating or re-cooling costs. In order to gain a greater global maximization of savings participants were asked to specify a single time slot and location for their meeting to be held in a campus library which schedules over 300 meetings per day. When indicating a time slot you may offer a wider window around your preferred time slot and location by being flexible; offering different times and locations.

Assume that you are looking to schedule a meeting using a meeting reservation system, where you can specify a single option in terms of time and the location for the meeting. When scheduling this meeting you may offer a wider window around the previous preferred slot by being flexible; offering different times and locations. This will allow energy savings as an energy efficient algorithm generates a schedule; reducing re-cooling costs of vacant rooms.

Shapley allocation divides the combined energy savings of the group amongst its participants. Encouraging participants through monetary compensation may yield towards future offerings of flexibility. Shapley value is taken for each participant and is an average over all possible scenarios or combinations of the groups flexibility related to the scheduling effect of a single participant. This effect is the difference of going from a state of no flexibility to their offered flexibility related to the current state of the system. Thus the value is the individual's contributions to the whole as it relates to the contribution of all other participant in the system.

Although the shapely value is algorithmically fair in dividing cooperative gains an individual participant's perception of fairness need to be evaluated. It is of utmost importance from a policy and behavioural perspective that people believe that they have been treated fairly as it may be determinant for them to participate again. By finding ways to positively promote energy saving behaviour by offering flexibility better schedules and greater achievement of energy savings are possible [84].

Sensor9k The use of testbeds to demonstrate technology is often a strategy within the scientific community. In this project, Sensor9k, is one of such testbeds to test sensor and actuator networks in AmI environments. The focus of the project is energy efficiency and global sustainability through the control of sensors in sensor networks and action upon the environment with the help of actuators [85].

This project entails a sensor platform able to maintain sensors and offer services that model actions against sensor values. For instance, through logical inference, it is possible to use sensor data to predict people in enclosed rooms.

The architecture of this testbed, uses a physical abstraction layer that communicates with the AmI platform to process data from the available sensors. In this version, the platform has modules to estimate user presence, manage energy consumptions and create user profiles.

An acting layer, makes use of fuzzy rules to control consumption of energy in the environment autonomous switching appliance on and off based on the interpretation of the environment and users.

As any AmI project, ubiquity is promoted in order to ease user support and trust in the system.

1.3.2 User Behaviour Analysis in Large Environments

This section encloses project applied to large areas with the aim to promote the use of computational sustainability applied to the concept of Smart Cities and Internet of Things (IoT). The difference lies, in the size of the sensing environment and the possibility to have more heterogeneous sources of data and services. In this section two examples are presented.

Smart Santander A comprehensive approach was taken in the Smart-Santander project. SmartSantander proposes a city-scale experimental research facility for services in a smart city. It is large, open and flexible to enable horizontal and vertical federation with other experimental facilities and stimulates development of new applications by users of various types including experimental advanced research on IoT platforms [86].

The prototype was designed, among other aspects, to use delay tolerant information to update information on communication nodes. This design allows to share information across the city with one of the interests for smart-cities being urban networks and traffic flow. The connection of a node for residential and comercial areas are also covered, also contributing to the services available in the platform.

Though an important example for the use of information technologies, it can be improved both on coverage to account to user voluntary input through personal devices and compound services. The project targets user-awaress by discolouring open data to the users but fails to have a strategy to drive change if needed be.

It relies on external use of its services to address the management of attributes such as traffic control or energy efficiency. Nevertheless, it implements a large testbed with the necessary services so that applications can be designed to achieve such goals. It is also an objective of this project to demonstrate some of these application by building sample platforms to fuel the use of their sensorial testbed.

City Sense CitySense has the goal of supporting the development and evaluation of wireless systems that span over an entire city. CitySense is under development and consists of Linux-based embedded PCs outfitted with dual 802.11a/b/g radios and various sensors, mounted on buildings and street lights across the city of Cambridge.

The goal of CitySense is explicitly not to provide public Internet access, but rather to serve as a new kind of experimental apparatus for urban-scale distributed systems and networking research efforts. It has the potential to support a host of new research and application developments [87].

As seen in the SmartSantander project, Citysense offers primarelly a sensor network over large IoT environment applied to a city. Based on a publish subscribe model it makes information available to applications that may solve societal problems.

There is the opportunity to create application based on the information present in the nodes of these environment being them person or based on local environments.

1.3.3 Summary

Computational sustainability projects are not designed by nature, rather they apply to projects that serve the objective of promoting sustainability parameters in some field of application. In intelligent environments, computational sustainability may control energy expenditure, optimize efficiency, control cost, monitor behaviour or planning actions such as urban transport.

The review of related work and projects was divided into areas of application. From environment planning to large environments such as smart cities and urban areas. Although common technologies are shared between some projects, strategies and means of execution differ. An understandable argument is that these project can be diverse in data and objective, although sources of data, processing needs and availability of information are mostly common.

The links between these data and information is often surpassed with technology developed to ease independent shortcomings but the integration of concepts such as user-awareness, notifications, gamification and predictions is harder due to missing links and common infrastructure. A continuous development process to promote these, is an opportunity to gather different approaches for problems of computational sustainability, by targeting not only parameters but also environment configurations and user behaviours in a common format. Therefore, to improve solutions not only innovative ideas should be approached, but also, known mechanisms from literature. A focused effort should be better than a singular approach and thus the opportunity to streamline such projects.

Large projects seems to be lacking in a communal approach to solve societal problems such as sustainability problems. Rather, they support primarily the availability of sensor nodes spread over the environments leaving implementation to smaller approaches. This fact evidences the need for research on community management and data processing for large environments which seems harder to implement.

Chapter 2

Innovation and Research

2.1 Sustainable Indicators

The expression energetic sustainability appeared in the USA after the oil crisis between 1973 and 1978. It was applied to the personal habits and industrial change. The energetic model present in most countries needed to be revised to assure less dependency and vulnerability to oil producing countries. Even more, it was necessary to plan the energetic offer in order to make it more sustainable [88].

The sustainable exploration of resources is important to assure the development of societies and satisfy the needs of present and future generations. Energetic sustainability can be perceived as a responsible use of energy that does not impair the future availability of the same amount of energy for future generations.

As energetic sustainability is a sub-domain from sustainability itself, researchers across the scientific community have proposed methods to characterize and define energetic sustainability based on the general concept of sustainability. It is broadly accepted that three base dimensions are used as to steer sustainable analysis: social, environmental and economic [9], [10], [11]. One popular method to assess sustainability is to define indicators across these domains to characterize the general behaviour towards sustainability from an environment. This way, to create impact on energetic sustainability, these indicators have to be compromised and connected to energy efficiency and energetic sustainability. This means that an indicator based approach shall use all the dimensions for sustainability to define indicators relevant to energetic sustainability.

A fourth dimension to sustainable characterization can be found in policy and technology. Though not broadly accepted, it has been mentioned in the research community [89]. In this dimension it is hypothesised the power of decision and the governance inside environments. This translates to the technological support to make and monitor sustainable decisions, monitor policy enforcement and allow autonomous processes. In the case of energetic sustainability authors denominate this dimension as Energy Technology.

In the case of Portugal, the Portuguese government has in place an instrument of energetic policy, the Energetic Efficiency and Renewable Energies (E4) programme, which is a group of policies to promote a coherent and integrated approach to energy supply [90], [91]. This programme states global objectives for renewable energy production, energy efficiency, control harmful gas emissions, waste management and taxes schemes to promote sustainable development. The nature of these programmes are adapted to use indicators to control the execution of plans. Although, the nomenclature is not always coherent, most of these policies deal with sustainability parameters adapted to the focus of current national and international policies.

Government plans are mostly generic in nature, and directly motivated to take use of fields such as computer science to monitor and control executions. Rather, it is computer science that adapts its system to display and control these indicators where possible. Therefore, there are missed opportunities for indicator definitions, motivation strategies and raising user awareness. Although, only taking initial steps, smart city design is slowly introducing Information and Communications Technology (ICT) to the management of cities. These further the development of computer science as a vessel for continuous monitoring, planing and control of sustainable indicators.

Definitions such as comfort, efficiency and security are often assessed from a range of interlaced indicators combined to express these concepts. Naturally, different definitions lead to different assessments, therefore it is more common to compare indicator values from different implementation than their sum values in what regard such concepts.

The research conducted in this doctoral programme aims to explore and motivate the adoption of fields such as ambient intelligence, intelligent environments and ubiquitous systems to explore new possibilities for sustainability assessment and indicator definitions. Aside from new indicator research, there is the opportunity to monitor and control indicators in real time, use complex indicators taking input from several data-sources using sensor fusion techniques and contextual indicators adapted to time and situations. Different case studies are used to demonstrate the capabilities of real monitoring systems for household environments and office environments.

In the following sections, a set of experiments on sustainability assessment are presented through scientific papers published in the scientific community in the context of this doctoral programme. From experiments with sustainable indicators to address sustainability assessment to concern with the impact of sensor networks, different experiments were compiled to address efficient environment and user sensorization to produce reports based on sustainable indicator managed by autonomous systems.

2.1.1 Sensorization and Intelligent Systems in Energetic Sustainable Environments

Scope of the 6th International Symposium on Intelligent Distributed Computing

Intelligent computing covers a hybrid palette of methods and techniques derived from classical artificial intelligence, computational intelligence, multi-agent systems to distributed computing studies systems that contain loosely-coupled components running on different networked computers and that communicate and coordinate their actions by message transfer. The emergent field of intelligent distributed computing is expected to pose special challenges of adaptation and fruitful combination of results of both areas with a great impact on the development of new generation intelligent distributed information systems. The aim of this symposium is to bring together researchers involved in intelligent distributed computing to allow cross-fertilization and synergy of ideas and to enable advancement of researches in the field.

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Sensorization and Intelligent Systems in Energetic Sustainable Environments

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Abstract Sustainability is an important topic of discussion in our world. However, measuring sustainability and assessing behaviors is not always easy. Indeed, and in order to fulfill this goal, in this work it will be proposed a multi-agent based architecture to measure and assess sustainable indicators taken from a given environment. These evaluations will be based on past and present behaviors of the users and the particularities of the setting, leading to the evaluation of workable indicators such as gas emissions, energetic consumption and the users fitting with respect to the milieu. Special attention is given to user interaction and user attributes to calculate sustainable indicators for each type of structure, i.e., the aim of this scheme is to promote sustainability awareness and sustainable actions through the use of sustainable markers calculated in terms of the information gathered from the environment.

1 Introduction

Ambient Intelligence (AmI) is still considered an emergent technology that may be embedded into environments, making them both sensitive and responsive. In this sense AmI may be used to achieve several objectives inside such environments, e.g., in sustainability assessment, enforcement and suggestion [5]. In fact, there is an increasing source of concern as more researchers make use of computational resources to find sustainable equilibriums. Sustainable models developed in the literature are also focus of research and improvement, although they may differ on their approach. Some of these models use economical metrics in order to assess sustainability, while others follow social and environmental perspectives in a more accurate form [11]. The work presented uses a multi-agent system to obtain information about an environment so that deliberative and reactive decisions concerning

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sustainability can be made. Indeed, multi-agent system architectures that foresee these problems, may be found in [9]. Performance tests showed good results for the service discovery in terms of flexibility and interoperability. Decisions are created using reasoning processes upon the data gathered either with machine learning or context-aware computing, so that specialized intelligent decisions may be made for each user present in an AmI setting. With respect to this area of research, Machine Learning inside AmI environments have already been used for feats such as human activity tracking [3]. Current sustainability assessment considers different indicators and sub-models created and used by specialized people. Our work aims to make it simple to assess and determine sustainability indicators in an intelligent environment through the use of multi-agent architecture and environment sensing. It has been demonstrated by previous research that when people are aware of the consequences of their actions in detail, and they are set with an objective, they tend to act in the best manner to attain it, as it was the case with eletrical consumption [4]. It is expected that the use of architectures like the one proposed in this paper causes the same effect on sustainable measures and user behaviour as it was demonstrated for electric consumption and user behaviour.

2 Previous Study

In this section there are presented studies related to the research being conducted. As such each category will be presented and a general descritpion will be made.

Sustainability is a subject of concern for the assurance of the steadiness, viability and use of a system. Currently different approaches to measure and assess sustainability were proposed in the literature, with some focusing on an economical perception, while others emphasize on environment or social perspectives [11]. Sustainability indicators have been useful at pointing out unsustainable practices, however, they are not as good to define and guarantee sustainability [7]. A common accepted definition for the notion of sustainability concerns an equilibrium from social, economical and environmental factors. When some of these features cannot be met, the system is not considered sustainable, but it may be pondered viable, bearable or equitable [11]. In contexts like intelligent buildings, there are commitments to build Key Performance Indicators (KPIs) to monitor sustainability, and act as sustainability indicators from information gathered by a panel of experts [2].

Machine Learning (ML) techniques or methods concede the modeling and learning of preferences and habits in different contexts. These methods also sanction the acquiring of past and current trends and predict future results. From information assembled from different environments, ML techniques may derive models of behaviour and interaction based on specialized backgrounds (e.g., users, environment, social interaction or consumption). ML and Data Mining (DM) techniques may also be used to obtain information about user's habits in AmI settings, from data gathered by sensors in the environment, namely using practices such as Sequence Discovery

[3], Fuzzy Logic [6], Genetic Programming, Multi-Layer Perceptron, Evolutionary Intelligence [8] or combinations of these techniques [12].

Context-Aware Computing is a component of a ubiquitous computing computing environment. One hopes to make personalized decisions based on contextual factors that may lead to different results to the same situation, once placed in different contexts [10]. Evidence of these context-aware systems can be found in e-Commerce, Information Retrieval and Ubiquitous Systems. In these examples context awareness is used to personalize systems and applications to the present user context [1]. Despite the interest in context-aware computing, context definition for applications and systems is still challenging in some situations.

3 Multi-Agent System for Sustainable Environments

This case study presented encompasses an intelligent environment and its user interactions in order to obtain information about its current sustainable condition. The source of such interest may be economical challenges or a conscious mind about the future sustainability of his environment, as described in [4]. The user is supposed to do daily routines such as cooking, sleeping or watching television. Nevertheless, the system records each action on the part of the user interactions, and uses such information to reason about existing sustainability indicators and metrics of control concerning the environment i. e., resource utilization, CO_2 emissions and of its own attendance on each internal premise in the environment for example.

The objective is to use different model representations, for example, environmental vairiables, ambiental variables, interactions and appliance consumptions. These models may receive input from different sensors distributed in the environment or mathematical formulae. There may also be the case where a different intrepretation of the values of a primary model or group of models may derive new ones, i.e., electric costs and carbon emission from electric consumption. Therefore, the user is aware of his impact on his environment.

System Architecture as proposed is a multi-agent system which encompasses a set of agents accountable for the assessment of current sustainability indicators in the environment. These agents communicate with the environment in order to retrieve data about it and use intelligent models to assess it based on sustainability indicators. Indeed, the proposed architecture uses 4 (four) different types of agents, namely:

- Sensing - an agent connected to sensors that is responsible to gather data about the environment, such as user presence or energetic consumption;
- Modeling - an agent responsible to model a representation of the essential aspects of a system which presents knowledge and relies on both mathematical and physical formulas as well as data from the sensing agents;
- Reasoning - an agent that reasons about perspectives, setting a method that fulfills the formal requirements for a theory of context, and offers an explanatory account of contextual reasoning in terms of information flow;

- Actuator - an agent that acts on the environment and monitors the execution of those acts to reassure a correct behaviour on the system.

With this setup the environment has all the necessary agents to gather data, transform and process it into agent's knowledge models.

Sustainability Indicators available in Table 1 are in the form of the three key sustainability categories: economical metrics that include the running costs associated to the environment continuance versus the available income in the same period; social metrics that relate the presence and the possible interaction among the users that populated the environment; and environmental that assesses the the amount of carbon emissions that are generated. The values from the proposed indicator are interpreted as unsustainable if the value is below 1 or sustainable otherwise.

Table 1 Sustainability indicators

Economical	Environmental	Social
$\frac{EnergeticCosts}{IncomeAvailable}$	$\frac{EmissionTreated}{TotalEmission}$	$\frac{TimeInside}{TimeOutside}$

The overall sustainability of the environment is calculated by 1, which denotes a compromise among the three main categories of sustainability indicators.

$$S_{index} = \alpha \times I_{economic} + \beta \times I_{environmental} + \gamma \times I_{social} \quad (1)$$

The equation presented in 1 has three qualifiers, one for each sustainability indicator. The values of such indicators are between 0 and 1 where their addition totals 1. All indicators are calculated either locally or for the entire setting which sums the assessment of all premisses. This way, if the environment is considered sustainable, the user may still assess changes in premises with low supportable standards.

4 Tests and Results

In order to set up initial scenarios both a simulation and a real environment were studied. On both environments it is possible to record consumptions, presence and emissions. User notification is made through a dedicated interface that displays environment configuration, its sensors, and the levels of consumptions and emissions.

For the simulated environment, a model of a traditional home with a bedroom, a living room, a bathroom, a kitchen and a hall was conceived. The actions simulated included user movement and the swapping of the state of the appliances (on or off). Electrical consumption, user presence and carbon emissions were modelled from simulated sensor values for a period of 3 days and a total of 201 actions simulated representing a user presence of about 58% in the environment each day.

The Intelligent Systems Laboratory (ISLAB) at University of Minho was selected as the real environment. ISLAB is made of one room available to researchers where they can gather and work together. This room was modeled containing a set of appliances such as computers and lights. In this room it was also installed sensors which recorded user presence, luminance and temperature for the period of 5 days where 2 of those were holidays. The sensing and modeling agents were used to obtain model representation of user occupancy, lightning and temperature on the ISLAB.

Table 2 Results from simulation

ISLAB Environment			
Room	Carbon emission (g)	Energetic Consumption (kW)	Presence (%)
ISLAB	7078.46	21.80	11
Home Environment			
Room	Carbon emission (g)	Energetic Consumption (kW)	Presence (%)
Bedroom	5.51	0.02	55
Kitchen	3537.32	9.95	9
Living Room	994.43	2.80	32
Bathroom	3.47	0.01	1
Hall	13.87	0.04	3

Results from both simulations are presented in Table 2 according to the formulas presented in Table 1 and data simulated and obtained from sensors. In order to estimate an economic indicator, the user is supposed to have 1,5 euros per day for daily energy consumption. From these results it is possible to calculate the sustainable indexes defined in 1 which are 3.19, 0.67 and 1.38, in the home setup, and 1.92, 0.67 and 0.14, in the ISLAB setup, for the economic, environmental and social indexes. It is also demonstrated, in the home environment, that it is economically viable, however, there is a penalization on the environmental indicator. This points out that the environment under study does not treat effciently emissions derived from its services. It is a potential source of improvement.

On the ISLAB results it is possible to demonstrate that if there is a budget of 1 euro for electricity on a daily basis then, sustainability indicators show that there is a penality not only in the environmental indicator but also in the presence indicator due to the limited time the room is occupied and its eletrical consumption. Changing the environment generates different simulation results, so simulation can be used to assess the impact of desired changes in the environment in terms of sustainability.

5 Conclusion

The proposed work features the perception of a multi-agent system able to handle sustainable monitoring and assessment in an intelligent environment. Furthermore, the use of formal models, was found to be a bright way to test and assess its sustainable actions and behaviours. It was found that it is possible to derive conclusions from the use of such systems in order to improve its efficiency and sustainability indicators. This is achieved with user awareness about his current situation, indicating which of his actions are more sustainable. As future work there is the need to further validate the model using real sensors in real world settings and design new metrics for sustainability indicators. The multi-agent system needs to be extended with the ability to monitor different environments in parallel, and explore connections and influences among them, such as a home and an office in the same environment. A recommender system may help in the improvement of the sustainability indicators.

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2.1.2 Information Fusion for Context Awareness in Intelligent Environments

Scope of the 8th International Conference on Hybrid Artificial Intelligent Systems

Hybrid Intelligent Systems are becoming popular due to their capabilities of handling many real world complex problems, involving imprecision, uncertainity, vagueness and high-dimensionality. They provide us with the opportunity to use both, our knowledge, and raw data to solve problem in more complex problems in a more interesting and promising way. This multidisciplinary research field is in continuous expansion in the artificial intelligence research community.

This conference provides an interesting opportunity to present and discuss the latest theoretical advances and real world applications in this multi-disciplinary research field.

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Information Fusion for Context Awareness in Intelligent Environments

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Abstract. The development of intelligent environments requires handling of data perceived from users, received from environments and gathered from objects. Such data is often used to implement machine learning tasks in order to predict actions or to anticipate needs and wills, as well as to provide additional context in applications. Thus, it is often needed to perform operations upon collected data, such as pre-processing, information fusion of sensor data, and manage models from machine learning. These machine learning models may have impact on the performance of platforms and systems used to obtain intelligent environments. In this paper, it is addressed the issue of the development of middleware for intelligent systems, using techniques from information fusion and machine learning that provide context awareness and reduce the impact of information acquisition on both storage and energy efficiency. This discussion is presented in the context of PHESS, a project to ensure energetic sustainability, based on intelligent agents and multi-agent systems, where these techniques are applied.

Keywords: Information Fusion, Machine Learning, Intelligent Environments, Context Awareness

1 Introduction

Ubiquitous spaces are a common research field nowadays, mostly due to the increase in sensors installed on environments and the technological opportunity it presents. This, coupled with the recent surge of ubiquitous devices and applications, has led to the opportunity to create budget-friendly intelligent environments with different objectives, ranging from energy efficiency, sustainability and user comfort [1], [2], acquiring user context, assisted living and automate tasks [3], [4]. Such environments are able to monitor users, objects and the environment itself, generating rich sets of data, upon which may be used to make decisions and perform optimizations.

In a wide range of practical applications, information is obtained not only from processing data acquired through sensors in a ubiquitous environment, but also from information and knowledge shared across environments, such as mathematical models, profiling and machine learning models. Contexts can be created by fusing data from sensors and other sources of information. Such concept is designated as information fusion and is used for tasks that involve gathering information from different sources, using it to improve its quality, accuracy or derive new information [5]. An example of this approach can be found in the Sensor 9K testbed [6] where data about humidity, temperature, air velocity, among others, is used to derive human thermal sensation. Such sets of data, information and knowledge can be used as context to help identify profile and optimize solutions and may be accessed directly through sensor data, middleware or context servers [7].

Considering a system designed to save energy, from a sustainable perspective [8], it entails a delicate equilibrium due to the fact that any effort made in order to gather knowledge incurs in energy expenditure and, thus, this expenditure needs to be significantly lower than the saving obtained with the information gathered. In terms of research methodology, this is usually called the observer dilemma, where the observation, by itself, introduces changes to the actual state of the system. In energetic terms, observing energy consumption and computing energy saving measures increases consumption, thus changing the problem in the process, creating an overhead that needs to be mitigated by the end solution.

Hybrid structures and planning are often means to reduce the impact of certain solution upon the global objective. One strategy to tackle this problem is to use shared data between different systems to their benefit. However, this solution needs to generalize assumptions about environments and thus reduce optimization opportunities in specialized environments. Some approaches use only user awareness by using monitoring sensors that transmit current data about consumption and aggregation systems. Other hybrid approaches use both generalizations with some contextual specializations in order to introduce some context to the solutions represented.

With information fusion, context awareness and machine learning models, it is proposed a set of strategies aiming to reduce energy and storage expenditure, reduce side effects from this workflow while maintaining accuracy and context-aware capabilities. Such strategies were used in the PHESS project, currently being developed with the aim to bring energy efficiency, comfort and sustainability to intelligent environments.

1.1 Information Fusion

Information fusion compromises the use of heterogeneous and homogenous data and information sources. There is some confusion with the terminology as some authors use the terms sensor fusion, data fusion and information fusion with the same meaning [8]. Nevertheless, it is commonly accepted that sensor fusion is a subdomain of information and data fusion as it only considers the use of data from sensors. With these theories it is possible to maintain and update information, enrich data creating new content, improving quality and providing more accurate contexts. Information fusion might also be used in order to enrich with additional contexts machine learning models describing environments, behaviors and actions inside intelligent systems. It offers basic steps for data pre-processing in machine learning activities, but they are also used to build data models and extract information [5]. Data by itself is limited in the type of knowledge and information that can be extracted from such environments. Analyzing data from different sources poses the opportunity to increase the quality of the measurements, although it may also increase some uncertainty as well [9]. Multi-sensor management and sensor fusion are terms applied when the source of data are sensors and it is defined by Xiong and Svensson [10] as a process that manages and coordinates the use of a number of sensors in a dynamic uncertain environment with the aim to improve data fusion. Sensor fusion tasks have to take in consideration a number of factors such as data imperfection and outliers, conflicting data, data modality, data correlation, data alignment, data association, processing framework, operational timing, static versus dynamic phenomena and data dimensionality [11]. In order to tackle data imperfection a number of filters and inferences were developed such as Bayesian inference, probabilistic grids, Kalman filters and Monte Carlo methods.

1.2 Machine Learning

Machine learning techniques allow the modeling and learning of preferences and habits in different contexts. These techniques also allow the learning of past and current trends and predict future results. Among the contexts where the use of machine learning provides an opportunity to enhance systems, there is the concept of sustainability. With information from one or several environments, machine learning theory can derive models of behavior and interaction based on specialized contexts.
Machine learning and data mining techniques can also be used to obtain information about user's habits in intelligent environments. In this aspect, there are re-search examples demonstrating several algorithms that perform this task from data gathered by sensors in the environment. These algorithms use theory from Sequence Discovery, Fuzzy Logic, Genetic Programming, Multi-Layer Perceptron and combinations of these techniques [12]. Other uses for machine learning is the discovery of rule sets to monitor and man-age the consumption of resources such as energy inside intelligent environments [13].

1.3 Context Awareness

Context-aware systems are a component of ubiquitous computing or pervasive computing environments. These systems consider information about location, environments, resources, users and relationships between each concept. It hopes to make informed and personalized decisions, based on contextual factors that might promote distinct decisions in similar situations with different contexts [14]. Universal models and information provide explanation about phenomena that may be accurate and useful. However, when there is a need to specialize to certain contexts, it may be needed to detail models making them more accurate according to a known context. On the other hand, their specialization often reduces their generalization which becomes a trade-off between increased accuracy and generalization. Nevertheless, methodologies employed may be repeatable among different environments even though they do not generate the same model for the same attribute. Context aware elements can be acquired by the use of information present in intelligent environments through direct sensor access, middleware infrastructure or, even, context servers, as detailed by Baldauf, Dustar and Rosenberg [7]. Sensors used in context aware systems may be classi-

fied in three groups: physical sensors, virtual sensors and logical sensors. Physical sensors refer to context gathered by physical devices sensing the environment. Virtual sensors are defined by the use of application and services as sources of contextual data. Logical sensors combine physical and virtual sensors to determine logical values for the attribute being sensed.
Elements of context are often gathered using all three types of sensor classification according to contextual nature inside intelligent environments. Strategies for the management of context models can be defined as Key-value models, Markup schemes, Graphical Models such as UML, Object Oriented models, Logic Based Models and Ontology based Models. Context in PHESS project is defined by sensor data models from the environment and status indicators in terms of sustainability indexes. Each of these factors provides important information saved in terms of context, towards the application of contextualized options in the PHESS project. Model development through machine learning is the methodology used to store information about sensors in the environment. So, with the help of sensor data, models, and user presence and sustainable indexes it is possible to assess the impact of users inside environments in a contextualized analysis.

1.4 Intelligent Environments

Intelligent Environments with applications towards user assisted living are already under study and object of discussion by the research community. Focus has been applied to the study of behaviors, routines, stress assessment, energy efficiency and task prediction. Ubiquitous environments present a significant opportunity for learning tasks and contextualized optimizations. The data and information shared between intelligent objects, environments and users entails a delicate balance that must be taken into consideration when assessing human comfort condition and planning interventions on the environment. Some implementations of intelligent environments are used to perform experiments on ambient intelligence theory. iDorm is an examples of such scenario, where sensors can gather data about temperature, occupancy, humidity, and light levels. The actuators can open and close doors, and adjust heaters and blinds. Other example is HomeLab [15] composed of a house filled with hidden cameras, microphones and a remote power control system able to operate switches and control lightning. This lab is used by researchers to assess social responses to different color schemes in lightning and monitor its users. Yet, another intelligent environment can be found in MavPad project, which uses a smart apartment created within the project [3]. This project consists of a living/dining room, a kitchen, a bathroom, and a bedroom, all fitted with different types of sensors to gather information from objects, users and contexts. Saves is a project that encompasses an intelligent environment designed to use building and user occupancy profiles to maintain and regulate temperature inside a building [1]. Sensor 9k acts as an intelligent environments middleware for creating and promoting intelligent environment applications [6].
The testbed I3A is composed by a sensor network displayed through a building sensing information about temperature, humidity, carbon, carbon dioxide, dust and electrical appliances [16]. This testbed is used to prototype solution for intelligent systems

as each sensor node can be independently programmed in the wireless sensor network covering the building.

The approach taken for intelligent environments embedded in this work use concepts shared from the environments and platforms already mentioned such as sensor network, profiling and sensorization of users and environments. Nevertheless, focus has been made in creating and maintaining machine learned models reduce dependence on constant sensorization and ease the data storage effort while providing context-aware computing.

2 PHESS – People Help Energy Savings and Sustainability

The PHESS project (People Help Energy Savings and Sustainability) is an integrated system to monitor and reason about environments and users with the objective of helping users save energy and ensure sustainability as well as their own comfort [17]. This system makes use of sensor networks, spread both on environments and users, acquiring data about user actions, environment variables and environment status to deliver a contextualized analysis. The PHESS project uses a layered architecture in which are included layer for sensors, models, reason. Each of these layers is responsible for a segment on the system's operation.

2.1 Sensor Layer

Currently, the PHESS project is able to integrate results from different sensors, using a multi-agent architecture where agents publish sensor interfaces for the consumption of other sensors. Sensor fusion is obtained creating virtual sensors that, instead of relying in physical hardware to provide sensor data, rely on the consumption of sensors already present in the platform which are processes according to the sensor fusion strategy in place. Sensor fusion is then obtained from specific virtual agents launched in the platform. These algorithms will be used in order to mitigate some characteristics of the devices: sensor inaccuracy, false readings or conflicting data. These virtual agents are the responsible for data fusion, creating new variables, such as thermal sensation and user occupancy.

2.2 Model Layer

The main goal of the layer dedicated to models is to reduce both the energetic impact of the sensing platform and the traffic flow, and, at the same time, optimize the general system response. Models are able to characterize behavior, anticipate and predict values for the attribute being studied and do so efficiently if properly built. Leveraging these properties it is possible to use models locally instead of demanding complex operations on databases such as aggregations and large quantities of storage space to record historic activity.

This layer is used to create models about environment, environment variables and user habits and preferences. Models are defined by intelligent agents present on the

PHESS project. According to the type of model, they may require information and data from other agents.

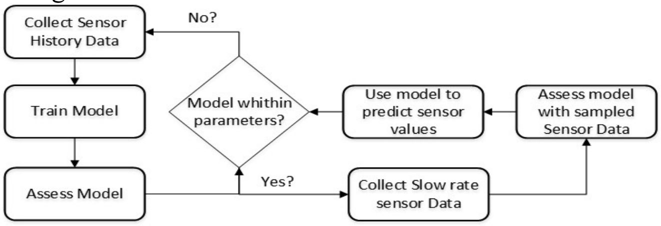

Fig. 1. Model Management

One type of models used encompasses mathematical models which use knowledge about attributes defined by mathematical and physic rules. Another type uses and combines data and information from other models on mature and accepted models that may also be described by mathematical rules. Lastly, from the data continuously gathered from the data layer, models that mimic the behavior of those attributes in order to provide description of their behavior and provide means to anticipate or predict the future state of the environment. These models require a constant validation in order to assess the validity of the models created in each environment. Also, due to possible high number of sensors and costs related to storage of records and historic data, these models may be used as historic descriptive models and as a sensor alternative in order to save in traffic messages as detailed in figure 1.

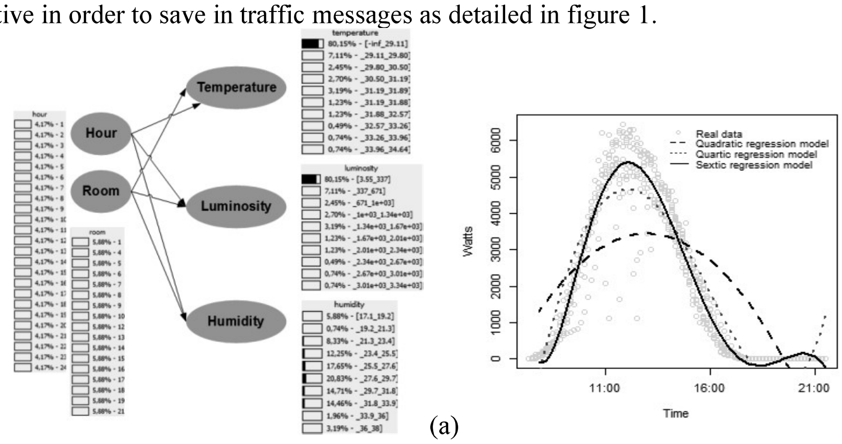

Fig. 2. Bayesian Network model describing an environment temperature, luminosity and humidity (a), Electrical Photovoltaic regression model (b)

Machine learning acts as a methodology to estimate sensor readings and, while doing so reduce the need to high sample rates in the sensor layer. With the combination of initial learning models and constant validation of its accuracy and significance in the system, refresh rates for sensor values can be dynamically managed. The usage of these schemes may also be relevant for sensor fusion tasks, since modeled sensors may be directly assessed in the server side of the platform, leaving the client side less demanding in terms of computational effort. As examples of agents in the model layer it can be considered electrical consumption, temperature, luminosity and solar exposure agents. Figure 2 (a) presents the representation of a Bayesian network model that stores a grid of conditional probabilities for the value of temperature, luminosity and humidity in an environment, according to the time of day and room. Figure 2 (b) details a regressive model to estimate photovoltaic electric energy production, according to weather (mostly cloudy in the case depicted) and time of day.

2.3 Reasoning Layer

The reasoning layer uses automated reasoning workflows, as well as on-demand simulation tasks taking the models created for the environment as reference and input variables. Examples of workflow methodology include automated case-based reasoning to find possible optimizations in terms of appliances, and behaviors through profile comparison. A first approach to reason about alternative solutions in the environment considers the use of case-based reasoning. In this approach, current models and environment specifications are compared to other known implementation and solutions in order to quickly assess optimized solutions for the environment. The static components in the environment, such as appliances or lightning bulbs, can be quickly assessed in order of efficiency in terms of energy consumption efficiency and whether changing them is beneficial to the overall process of energy optimization [18].
The final step of action of this agent is to use the newly calculated situations and use actuator agents to enforce the new plan or when such is not possible, send a report to the user so he can become aware of efficient changes in the environment without affecting its interaction with the environment.

3 Context Awareness in PHESS

The creation of context for intelligent agents on this platform is done as described in a survey on context-aware systems by Baldauf, Dustar and Rosenberg [7]. In detail, it is considered a context server, middleware and direct sensor access as a source of context. The context server is provided by an application server running PHESS modules in a multi-agent system which is responsible to keep information and profiles about environment, indicators defined and machine learning models updated with sensor information. The dependence on sensor data to create context was noticed and the impact of such workflow was present in terms of network messages between server and sensor nodes, energy efficiency due to active use of sensor nodes and storage size. With the aim to minimize such problem the concept of hybrid virtual sensors was adopted, where in the first stage an intensive use of sensors is performed to learn the behavior of the attributes being sensed through machine learning models and a second stage where these models substitute the sensor data keeping network messages, storage needs and active use of sensors down. Sensor are used at lower frequency rates to assure that the models created remain accurate within a defined error margin. The context server is used to push these models. For instance, one may consider solar

exposure where the model takes both location and time to contextualize the number of hours with solar exposure. Such model may be maintained in a context server, not requiring an active agent. Other examples created within the PHESS project includes photovoltaic panels output according to atmospheric conditions and hour of day and exterior temperature from known weather API's in the internet. Although this approach is able to maintain context scenarios it may lack alert and fast response as the data from sensor is not actively being measured and so should not be used where short term context is relevant but rather historic context.
Middleware access is used to obtain answers to dynamic models maintained for specific environments, users or objects and for direct sensor access. These models developed inside the PHESS project are accessible from external sources through communication APIs developed in JAVA[1], ANDROID [2] and JADE[3] systems which enable the integration of the information created inside this platform available to other initiatives. The communication is made through an ontology written to provide information and data about the environment encapsulating the information displayed by in each API [19]. Such API is used for related projects such as stress assessment, emotional control and gamification purposes.

4 Model Assessment

Over a period of three days a simple application with the PHESS project was evaluated, where sensors for environment luminosity, humidity and temperature were used. It was assessed aspects related to storage space used and reliability of the model created using the theory described in sections 2 and 3. Initial results demonstrated that by adapting the learning rate on attributes monitored, there are gains in terms of storage needed as well as active use of sensors while keeping results with over 70% relative accuracy.

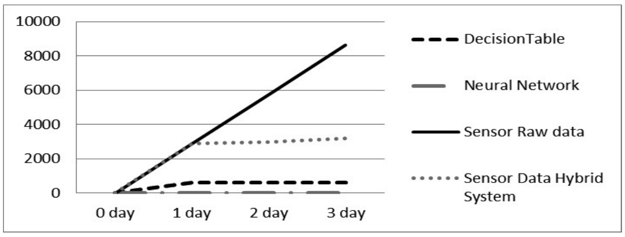

Fig. 3. Space required by each strategy

Figure 3, demonstrates potential savings with this approach, as less storage capacity is used to store sensor data and models being updated generally are fixed in size. The results presented refer to ambient luminosity which was modeled by a decision table algorithm and a multilayer perceptron using room location and time of day. Sensor

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1 Oracle Java. Source: http:// http://www.java.com/
2 Android Project. Source: http:// http://www.android.com/
3 Jade – Java Agent Development Framework. Source: http:// http://jade.tilab.com/

values were assessed for the case of continuous monitoring (raw data at 1min intervals) and a hybrid approach with sensor values validating the model created after the learning phase at 30 min. The models created can be used in context server through the PHESS project to simulate context where such models are determinant easing the need to use middleware API to query sensors or databases of historic values.
Table 1, it presented accuracy values for the machine learning models for luminosity, humidity and temperature using a decision table algorithm. These results gather the error which the models are subjected and within which models are not re-trained. The correlation values are the correlation between predicted and real values which was also used to assess models initially.

Table 1. Continous Model Assessment

Model Object	Mean Error	Relative Error	Correlation
Luminosity	102.75	27.04 %	0.88
Temperature	0.46	22.40 %	0.97
Humidity	0.86	23.76 %	0.96

The substitution of models instead of always requiring sensor data reduces message traffic between agents and increases system overall performance. Nevertheless, more precise studies are still necessary in order to maintain the stability of models found and their descriptive soundness. Overall, results are positive, with the approach demonstrated to be both feasible and adequate for the problems being targeted.

5 Conclusion

The work detailed in this paper describes how to take advantage of context awareness by using machine learning models in conjunction with concepts from information fusion inside intelligent systems. This approach, aims to reduce the impact of storage and sensor data problems while maintaining historic behavior description and preserving contextual information about the attribute. The results provided, show promise in maintaining storage levels contained and may be used as a proof-of-concept. The accuracy of models depends on their design, having detailed in this article some sample context models to be applied in these systems. Future development for the models created inside this system encompasses their use for multi-environments. The aim is to also reduce the learning cost of new environments with pre-trained models that are then contextualized in each environment with lifelong learning according to methods similar to ones presented in this paper.

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2.1.3 Ambient Intelligence: Experiements on Sustainability Awareness

Scope of the 17th Portuguese Conference on Artificial Intelligence

EPIA is the main Artificial Intelligence International Conference in Portugal. The purpose of the event is to promote research in AI and the scientific exchange among researchers, practitioners, scientists, and engineers in related disciplines. EPIA biennial conferences are supported by the Portuguese Artificial Intelligence Association (APPIA) and have been organized since 1989.

Following the standard EPIA format, it had thirteen Thematic Tracks, covering a wide range of AI topics. This diversity aims to promote different research sub-areas within AI and the cross-fertilization of ideas between researchers of different groups.

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Ambient Intelligence: Experiments on Sustainability Awareness

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Abstract. Computer systems are designed to help solve problems presented to our society. New terms such as computational sustainability and internet of things present new fields where traditional information systems are being applied and implemented on the environment to maximize data output and our ability to understand how to improve them. The advancement of richer and interconnected devices has created opportunities to gather new data sources from the environment and use it together with other pre-existent information in new reasoning processes. This work describes a sensorial platform designed to help raise awareness towards sustainability and energy efficient systems by exploring the concepts of ambient intelligence and fusion of data to create monitoring and assessment systems. The presented platform embodies the effort to raise awareness of user actions on their impact towards their sustainability objectives.

Keywords: Ambient Intelligence, Pervasive Systems, Sustainability, Energy Efficiency.

1 Introduction

The advent of computer science and its evolution led to the availability of computational resources that can better assess and execute more complex reasoning and monitoring of sustainability attributes. This led to the creation of the field of computational sustainability (Gomes, 2011). Coupled with sustainability is energy efficiency which is directly affected by human behaviour and social aspects such as human comfort. Fundamentally, efficiency deals with the best strategy to obtain the objectives that are set, however, when the concept of sustainability is added, several efficient plans might be deemed unsustainable because they cannot be maintained in the future.

While efficiency is focused on optimization, sustainability is mostly concerned on restrictions put in place to ensure that the devised solution does not impair the future. Not only, context hardens the problem but also the possibility of missing information which might occur due to same unforeseen event that jeopardizes an efficient solution. To tackle such event, computational systems are able to maintain sensory networks over physical environments to acquire contextual information so it can validate the conditions for efficient planning but also acquire information and, as a last resort, act upon the physical environment.

adfa, p. 1, 2011.

2 Related Work

The term computational sustainability is used by researchers such as Carla Gomes (Gomes, 2011) to define the research field where sustainability problems are addressed by computer science programs and models in order to balance the three dimensions of sustainability: economic, ecologic and social dimensions.

It is accepted that the world ecosystem is a complex sustainability problem, affected by human and non-human actions. Despite the use of statistical and mathematical models for the study of sustainability and computational models to address problems of environmental and societal sustainability, the term computational sustainability appeared around 2008. Nevertheless, the pairing between computer science and the study of sustainability is as old as the awareness of sustainability and as long as computing was available. It is a fact that, as computational power capacity increased over time, so did the complexity and length of the models used to study sustainability. The advent and general availability of modern techniques from artificial intelligence and machine learning allowed better approaches to the study of each dimension of sustainability and their overall impact for sustainability.

The types of sensors used in the environment may be divided into categories to better explain their purpose. In terms of sensing the environment, sensors can be dived into sensors that sense the environment or users and their activities. Generally, an ambient might be divided in sensors and actuators. Sensors monitor the environment and gather data useful for cognitive and reasoning process. On the other hand, actuators take action upon the environment performing actions such as thermostats to control the temperature, lightning switches or other appliances.

Different methodologies and procedures exist to keep track of human activities and to make prediction based on previous and current information gathered in these environments. Common approaches with machine learning techniques involve the use of neural networks, classification techniques, fuzzy logic, sequence discovery, instance based learning and reinforced learning as in (Costa, Novais &, Simões, 2014).

An approach to this problem using fuzzy logic algorithms is proposed by Hagras et al (Hagras, Doctor, Callaghan, & Lopez, 2007). Sequence discovery approach is at the heart of learning algorithm in (Aztiria, Augusto, Basagoiti, Izaguirre, & Cook, 2012), which demonstrates a system that can learn user behavioural patterns and take proactive measures accordingly.

The work presented considers the use of these types of sensor to assess and reason about sustainability and indicator design. This information will then be used to reason about user behaviour and their accountability.

3 Platform Engine

The focus of this project is, more than developing new procedures or algorithms to solving problems, putting these innovations on the hand of the user, with a clear purpose: that these innovative tools should be guided to assist people in the context of energetic sustainability.

3.1 Network Design

The PHESS platform supports heterogeneous devices by implementing middleware upon groups of devices to control data and information acquisition. Local central servers are viewed as decentralized by the platforms which access them to obtain data and implement their plans through the local network actuators.

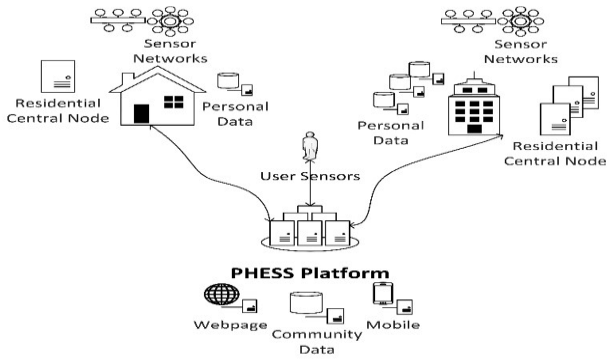

Fig. 1. Generic PHESS platform configuration.

Figure 1, details a generic composition of two different environment scenarios with users and their connection to PHESS platform. This residential central node is responsible for the middleware to connect local sensor networks to the PHESS platform using dedicated protocols for data acquisition and storing information.

The data gathered is summarized locally according to time and user presence models and synchronized with the central PHESS platform. It is also responsible for creating different user and environment profiles. Notifications are generated by the central PHESS platform to the project webpage or mobile application.

3.2 Data Fusion

The process of data fusion is handled by local central nodes where data is submitted to data fusion process according to the number of overlapping and complementing sensors. In this regard, there are strategies that can be followed according to the context and nature of the fusion process.

The first one is a weighted average of values, for the same type of sensors in the same context to get an overview of an attribute with multiple sensors to reduce measurement errors. The weights are defined manually by the local administrator. More sophisticated fusion is employed with complementary sensors which according to some logic defined into the system measure an attribute by joining efforts such as user presence with both RFID reader and wireless connection of personal devices such as smartphones. The last resource is the use of heterogeneous data to create attributes with some level of knowledge from the start. An example is the assessment of thermal comfort using default indicator expressed as mathematical formulae such as the PMV index (Fanger, 1970) for instance. Other application is the definition of sustainable

indicators according to custom mathematical formulae in the platform that shall process some attributes in the system to make their calculation.
The configuration of data fusion steps, the selection of sensors and streams of data is made on the initial step of the system by the local administrator. According to each area of interest and with specialized knowledge obtained by experts it is possible to monitor relevant information to build sustainable indicators.

3.3 Sustainability Indicators Generation

Indicators evaluate sustainability in terms of three main groups, namely economic, environmental and social. However, due to their impact, some indicators can be designed to influence more than one dimension of sustainability. For this reason it was chosen to have these indicators as the general analysis of sustainable principles instead of sustainability dimensions. In order to be directly comparable indicators are defined to use the same scale, and are based on the notion of positive and negative impact. The values of each indicator range from -1 to 1 and can be interpreted as unsustainable for values below zero and sustainable from there upwards.

Indicator definition is another configurable space inside the PHESS platform where monitoring indicators are defined using values from sensors and sensor fusion, and customized with mathematical formulas. All these indicators are calculated either locally, i.e., in a room basis, or they are evaluated for the entire setting which sums assessment of all different rooms. In this way, even if the environment is considered sustainable, the user may still assess changes in premises with low supportable standards. Environments are generally hosts to of many different users, which influence it with their behaviours, actions and habits. Tracking user activities is something that can be used to infer and establish cause and effect relationships. The PHESS system uses different dynamics to produce accountability reports on user actions based on environment and personal monitoring coupled user presence detection. Areas uncopied, are considered the responsibility of all people present in the environment, so that the coverage of the entire environment is assured by its occupants. In cases where the local context and local sensor values are indistinguishable based on location them, user accountability takes in consideration only user presence in the environment. The richer the environment is in sensor data acquisition the richer results and analysis is.

4 Case Study and Results

As a case study, results from five days in an environment are presented. In this case a home environment with a limited set of sensors, and a smartphone as a user detection mechanism. User notifications are made by actuator modules which push notifications to users in order to alert them based on notification schemes and personal rules. Sensors include electrical consumption, temperature, humidity, luminosity and presence sensing through smartphones and an indicator based on the sensation of temperature PMV used in thermal comfort studies (Rana, Kusy, Jurdak, Wall, & Hu, 2013).

The indicators are designed in the platform in order to perceive energy efficacy and as such the case scenario uses electricity to do this analysis. Therefore, a list of sample indicator was defined using data fusion available through PHESS modules. A sample of four indicators were defined and their expression is as follows:

- Unoccupied consumption – measures the deviation of consumption when no user is present in the environment from a user inputted objective.
- Activity based consumption - measures the deviation of consumption during the period of 1 hour from the objective value set by the user, in this case;
- Total consumption: measures the deviation of total consumption during the period of a day based on a default value defined for consumption;
- Comfort Temperature – based on the PMV comfort indicator obtained through data fusion process which is calculated by PHESS platform;
- Comfort Humidity – based on comfort values that define the normal range of values humidity in indoor environments.

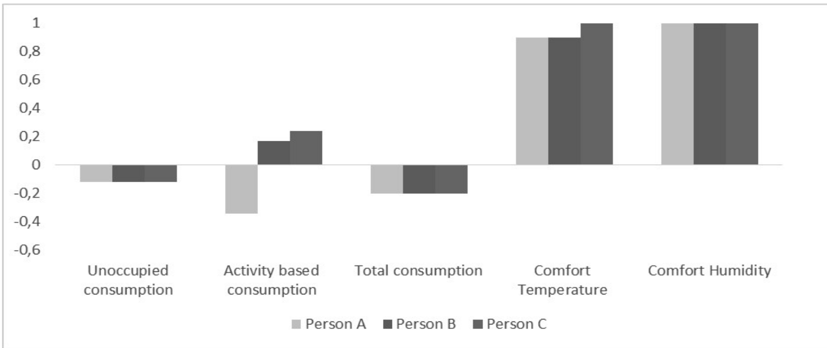

Fig. 2. Indicator values from the PHESS platform

As seen in figure 3, with the graphical representation of the indicators it is possible to analyse the behaviour of an environment based on user inputted indicators. These indicators are represented in the scale -1 to 1 as stated in section 3.4. While comfort values are being respected, consumption based indicator shows that the values set for the system are not yet being followed. As a result, indicators towards consumption analysis are performing below the accepted margin.
Accountability is based on the notion of user impact on the system. Results indicate a higher consumption when the environment is not occupied which demonstrates that the environment configuration has more impact than user actions. The person the longest in the environment each day has more impact towards the total consumption which is inputted to user actions.

This analysis allows the system to identify people with most impact on the system based on the attributes and indicators defined. There is the need to adapt each indicator set to the objectives and the areas to improve, but the generic platform allows for this configuration based on the layers of the PHESS platform.

5 Conclusions

Computational sustainability, although a new and interesting topic of research to the academic community, still presents a number of difficult challenges. The platform presented is the combination of modules which take inspiration from ambient intelligence and information systems to provide analysis and assessment of environment and their users, to identify and provide real time analysis of concepts based on sustainability and efficiency. Results indicate that modest configurations can yield meaningful results that may be used to take actions on the environment and user behaviour. The process of data fusion and indicator design are responsible to thoroughly analyse key situation of environment and user behaviour so they expression appears meaningful to produce not only user reports but also user suggestions.

With the mainstream use of interconnected appliances the possibilities for automatic actuation are increasing, mainly with the new internet f things standards being proposed by major companies. The PHESS project aim to increase its support by adding new features to their middleware layer and allow actuation in conjunction with sensorization. Moreover, it is expected to support multi environments for each user, increasing accountability to user behaviours regardless of location.

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2.2 User Awareness, Gamification and Communities

The process of motivate people towards an objective is often not obvious. Whether it is a group objective or an individual need, awareness presents itself as an elemental component. The process must be perceived by its user and it need to show him the current standings, overtime improvements and present sound suggestion towards the *status-quo*. Awareness can take different forms, there are direct and indirect methods but they all suggest its user the current standing and positive or negative points.

In the area of sustainability, there are indicators which are used not only as an awareness tool but also as a policy enforcement tool. It is often the case that awareness indicators are multi-purpose such as these.

The drive created by awareness takes plausible dependability in the subject it is focused on and creates social pressure if current standings are perceived as negative. Though it is, arguably, an interesting tool, by itself it does not promote improvement. It is not uncommon that solutions are perceived good enough for the time being and thus they are not improved. In this case, tools to promote development, action and continuous improvement. Among such, there are concepts such as gamification and communities which make use of social behaviours and social sciences to drive and motivate users. User standings in a gamification community creates not only a psychological pressure but also a social pressure by its peers to improve standings. Greed, envy and narcissism are elements of a human personality that may be triggered when users are compared to each other. These elements are considered negative elements in each personality, but the truth is that any healthy person possesses a portion of these elements and they are used subconsciously to different degrees according to each user. Therefore, selfish behaviours, if redirected, can actually be used to the greater good of communities. One example is the establishment of personal objectives that count towards a personal standing in a community. If these personal objectives are created according to the needs of the community then they drive their users towards the greater good of such community.

Implementation of user-awareness over gamification and communities acts as a motivational tool for continuous improvement of sustainable standings incorporating development and new methodologies towards self-improvement and community benefits.

In this section experiments based on the concept of user awareness and user profiling are detailed using the sense of community. From the application of recommendation systems supported by case based reasoning to the assessment of well-being in environments and users, methodologies are explored to increase sustainability parameters such as efficiency, comfort and well-being.

2.2.1 Social Networks Gamification for Sustainability Commendation Systems

Scope of the 10th International Conference on Distributed Computing and Artificial Intelligence

Nowadays, most computing systems from personal laptops/computers to cluster/grid /cloud computing systems are available for parallel and distributed computing. Distributed computing performs an increasingly important role in modern signal/data processing, information fusion and electronics engineering.

Particularly, applying artificial intelligence in distributed environments is becoming an element of high added value and economic potential. Research on Intelligent Distributed Systems has matured during the last decade and many effective applications are now deployed. The artificial intelligence is changing our society. Its application in distributed environments, such as the Internet, electronic commerce, mobile communications, wireless devices, distributed computing, and so on is increasing and is becoming an element of high added value and economic potential, both industrial and research. These technologies are changing constantly as a result of the large research and technical effort being undertaken in both universities and businesses.

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Social Networks Gamification for Sustainability Recommendation Systems

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Abstract. Intelligent environments and ambient intelligence provide means to monitor physical environments and to learn from users, generating data that can be used to promote sustainability. With communities of intelligent environments, it is possible to obtain information about environment and user behaviors which can be computed and ranked. Such rankings are bound to be dynamic as users and environments exchange interactions on a daily basis. This work aims to use knowledge from communities of intelligent environments to their own benefit. The approach presented in this work uses information from each environment, ranking them according to their sustainability assessment. Recommendations are then computed using similarity and clustering functions ranking users and environments, updating their previous records and launching new recommendations in the process.

Keywords. Sustainability, Ambient Intelligence, Reasoning, Gamification, Social Networks

1 Introduction

Sustainability is a multi-disciplinary area based in fields such as economy, environment and sociology. These fields of research are interconnected, but humans have different psychological approaches to them. Thus, is necessary to perceive the behaviors behind each multi-disciplinary area. A computational platform to support and promote a sustainable environment, together with an approach to the energetic and economic problems, must take the decisions as smoothly as possible so as not to cause discomfort to the user. This topic triggered several psychological researches [1], [2] and a common conclusion indicates that humans are not always conscious about their behavior [3]. This field, called psychology of sustainable behavior, despite focusing on measurement and understanding the causes of unsustainable behavior it also tries to guide and supply clues to behavior change. Manning, shows some aspects that are necessary to consider promoting and instilling in people sustainable behaviors [4]:

- All behavior is situational, i.e., when the situation or event changes, the behavior changes, even if exists intention to perform a certain behavior, circumstances can make it change;

- There is no unique solution, i.e, people are all different because they have different personalities, living in a specific culture, with distinct individual history;
- Fewer barriers leads to a great effect, i.e., when a person is facing social, physical and psychological obstacles, his attitude tends to flinch, for instance, the lack of knowledge about a procedure leads to a retreat;
- There is no single approach to make an action attempting achievement of sustainability, there are many sustainable possible options that a person can choose.

To overcome these barriers to sustainability, it is suggested the engagement of multiple users in a competitive environment of positive behaviors so that participants have the need to strengthen their knowledge of sustainable actions. In this work, elements of gamification and information diffusion are explored in communities of intelligent environments with the objective of achieving behavioral and physical change. Automatic selection of recommendations based on the known examples, assessed via sustainable indicators, inside such communities can be achieved by constantly comparing and ranking users and physical environment inside intelligent environments. The dissemination of this information helps user inside these communities of intelligent environment take advantage of it and increase the community overall performance.

1.1 Gamification

There are already many studies in regard to gamification, where people use IT to change the behavior of the systems in order to make them more efficient. Still, there is a common trait among them, they are oriented to efficient actions of a system and not to the efficient actions of the user [5]. Changing the former is determining what should be its behavior, while changing the latter means changing their habits, the behaviors that they acquired. In order to tackle this problem, two main concepts will be put in practice: Gamification and Information Diffusion.

In [6], gamification is applied in education where the authors try to take the elements from the games that lead to the engagement and apply them inside the school to the students to keep them motivated. Another example uses a framework that allows users to share their daily actions and tips, review and explore others people actions, and compete with them for the top rank by playing games and puzzles [7]. On another example authors developed a service-oriented and event-oriented architecture framework where all participants communicate via events over a message broker. This system is composed by a set of game rules that define game elements like immediate feedback, rank/levels, time pressure, team building, virtual goods and points (karma points, experience points). Completing game rule generates a reward event for the user over the message broker. There is also an analytical component that may be used to analyze user behavior in order to improve game rules and optimize long-term engagement [8].

As for the second concept, Information Diffusion, this will be applied specifically to social networks. What various studies have proven [9] [10] [11] is that social networks have the potential to diffuse information at a high rate. Besides this point, they can also influence other peers to participate by sharing content. The use of social net-

works, also mentioned above, has the goal of enhancing the engagement of the users to higher levels by bringing the results to public (respecting user's authorizations) and making each user responsible for his actions at the eyes of the respective network.
As we can see through the examples presented, the application of gamification can raise the levels of loyalty of the users and keep them engaged in our objective by making it more enjoyable.

1.2 Sustainability Indicators

Sustainability is a multidisciplinary concept related with the ability to maintain support and endure something at a certain rate or level. The United Nations have defined this concept as meeting the needs of the present without compromising future generation to meet their own needs.
Due to the importance of sustainability different author have defined measures to assess and characterize sustainability. A popular consensus is based on 3 different indicators used to measure the sustainability of a given environment [12]. This approach is based on three different types of indicators, social, economic and environmental with the specific restriction that until all those values are met a system cannot be deemed sustainable. From this perspective sustainability concerns a delicate equilibrium between different indicators which action to optimize one indicator might severely affect one of the other two.
The presence of indicators to assess sustainability is an established practice [13] and [14], however it does not give any information on how to guarantee or plan sustainability. In reality indicator only inform about the current status of a system.

2 Studies on Sustainability Assessment

2.1 People Help Energy Savings and Sustainability (PHESS)

PHESS concerns a multi-agent platform (figure 1) developed to perform sustainability assessment on both users and environments. The platform establishes an ambient sensorization routine upon the environment, constantly updating sustainability indicators. The use of sustainability indicators represents the current, real time assessment of the environment taking into account historic data. The aim of the platform is not only to assess and identify unsustainable practices but also act with the objective of improving sustainability indicators. For such to happen, user behavior and environment might need to be changed. However, how the change is conducted cannot be determined by sustainability indicators alone.

The data gathering level in the PHESS platform includes sensing agents responsible for controlling the access and delivery of ambient sensor data model and reason agents in the reason context level. Model agents are responsible to monitor changes in the environment creating models with patterns common pattern and predictors for sensor value. Moreover, model agents may also be responsible for maintaining user or environment sustainable indicators updated. Reason agents use context information to formulate hypothesis in order to create recommendation, optimize environments and behaviors. This knowledge inferred from agents is then used in acting agents in the Acting level in this platform.

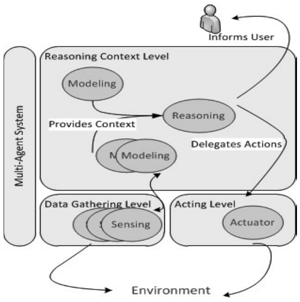

Fig. 1. Multi-Agent System for Deliberation and Sustainable Assurance

In this paper, the process of using indicators from different environments to create and promote recommendation that can be explained is detailed in next sections. An initial explanation about the sustainable indicators and sustainable assessment is necessary to understand the process of creating recommendations.

2.2 Sustainability Assessment

The sustainable assessment used in PHESS, uses different indicators within each dimension of the sustainability definition. This approach was also used by some authors, which used these indicators to guide strategic options and perform decisions based on the foreseeable impact of such measures [13], [14]. These indicators represent a ratio between a positive and negative contribution to sustainability and their values are computed in the -1 to 1 range, equation 1. As a consequence, all indicators use the same units of calculation and can be aggregated within each dimension through the use of weighted averages. The use of these indicators is made within each division in the environment and aggregated through average in the environment.

$$\text{Indicator}(\text{positive},\text{negative}) = \begin{cases} \dfrac{\text{positive}}{\text{negative}} - 1 \rightarrow \text{positive} <= \text{negative} \\ 1 - \dfrac{\text{negative}}{\text{positive}} \rightarrow \text{positive} > \text{negative} \end{cases} \tag{1}$$

In order to deliberate about sustainability performance it is needed to rank solutions rewarding each solution with a sustainable score, equation 2. Indicators within each dimension of sustainability are averaged according to weights defines in each dimension. The use of ranking formulas enables the use of fitness functions and distance functions to help calculate distances from one sustainable solution to another. Such approach in explored in section 3, integrated in a case based reasoning algorithm and custom sustainable indicators used to perform a proof-of-concept analysis on the proposed algorithm.

$$S_{index} = \alpha * I_{economic} + \beta * I_{enverinmen\,tal} + \gamma * I_{social}$$
$$\alpha + \beta + \gamma = 1 \wedge 0 < \alpha < 1 \wedge 0 < \beta < 1 \wedge 0 < \gamma < 1 \quad (2)$$

3 Case Based Reasoning to Promote Sustainability

The work here detailed is intended to help communities of intelligent systems let users promote practices from different physical environments with high sustainability indexes to others with a recommendation engine. In order to summarize each environment, it was designed a sustainability profile, stating environment and individual room sustainability. Environment indicators are calculated from the use of aggregated individual room indicators, taking advantage of the indicator structure detailed in section 2 and three sample indicators for each dimension of sustainability. For the social indicator a positive value is represented by the amount of time spend inside the room whereas the negative value is represented by the time outside. Likewise for economic indicator a positive value is represented by the current budget available and the negative the total amount spent. Regarding the environmental indicator, emissions are derived from the CO_2 emission derived from electricity report for the negative value and emissions avoided as the positive value. Each case is maintained in a profile database and it is updated using the PHESS multi-agent platform which includes an ambient sensorization framework.

The case based reasoning used in this situation uses a two-step process to evaluate and calculate new solutions for the user. As an initial step, the type of environment is contextualized, for instance, sustainable index, number of divisions and room indicators. A second step concerns the recommendation phase, and uses room indicators to obtain the best solution for the planning of energy use and appliance substitution.

The action flow is detailed in figure 2, where from an initial set of grouped environments a target environment can be compared to environments in higher ranked groups. The initial grouping of environments is made using K-means algorithm on the sustainable index of each environment with a fixed size for number of groups. The retrieval of comparative cases is extracted with the help of similarity functions. In this case, similarity is computed using environments from higher ranked groups and an average Euclidean distance from the distance value, computed for the three sustainability indicators, in every room. This procedure is used taking in consideration the room type, as distances are only calculated for rooms of the same type. The selection of environments favors the longest similarity distance for the value of the indicators in order to help the impact of possible recommendations in the environment. Finally, the list of alternative recommendations is obtained, comparing the room types of the target environment to rooms of the same type in the selecting environment. Any differences found are matched as possible change scenarios, favoring the options taken in the selected environment.

It is useful to remember that sustainable indicators are calculated from data acquired from each environment on a timely basis. The natural consequence is that as time progresses the values of these indicators which might result in environments exchanging the group they were previously.

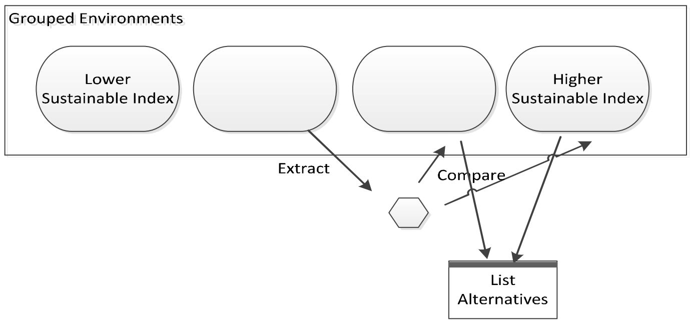

Fig. 2. User suggestion from social database

This dynamic works for the benefit of the system as the selected cases for comparison within each group are changed each time these variations occur enticing environments users to adopt behaviors that do not lead their environment to move to lower ranked groups.

3.1 Results

The results provided in this paper consider an implementation of different intelligent systems inside a community of users. For this purpose and due to current lacking infrastructures and users the environments were simulated defining different environments with different configurations generating user behavior inside them and creating sustainable index using the PHESS platform on such environments.
In order to test the recommendation system within communities, a set of environments was simulated. The setup recreated typical environments commonly found, such as apartments with a bedroom, living-room, kitchen, bathroom and a hall connecting all the other rooms. Inside each room, a set of appliances was also defined ranging from lights and computers to ovens and refrigerators with different consumption patterns. The consumption of appliances was defined from their active use and explicit turn on/off actions from user action simulated in the environment.
In this test 3 environments were defined and divided across 3 groups using the algorithm detailed in section 2.3. The initial step requires information about each environment, namely sustainable indexes for each environment and sustainable indicators for each room inside each environment. This was accomplished running each environment with sample users with sample routines inside each environment in the PHESS system. With information about sustainability on each environment groups was generated resulting with the first group concentrating two of four environments, and one for each of the remaining two groups. Focusing on one of the environment on group with poorer sustainable index, a comparison was made using the environment on the middle group in terms of sustainable index value. For each room possible changes were computed generating a report as defined in table 1 for the living room.
A total of six recommendations were proposed on the target environment in the living room, as seen on table 1, in the kitchen and in the bedroom areas.

Table 1. Example of Recommendations for Living Room

Appliance	Target Room (Average Consumption)	Best Case (Average Consumption)	Decision
Lights	120W	65W	Change
Computer	49W	55W	Remain
Television	60W	30W	Change
TV Box	55W	-	-

Using the PHESS system it was possible to assess that using recommendations on the living room alone was sufficient to improve the target environment sustainability index. In fact, iterating the recommendation algorithm one more time it can be found that if recommendations are followed and user behavior remains equal, the environment would be selected for the middle group, thus showing improvement.

3.2 Discussion

Recommendation calculated can be interpreted as using knowledge created within a community to its benefit. The best cases are used as examples to lower ranked cases which provide sense of sympathy from one to another. Also, with this approach, it is not necessary to maintain a database of efficient objects like appliances or lightning. As soon as they appear in the community they may tend to be selected for recommendation as part of someone's environment definition.

In order to further promote the adoption of recommendations and foster better behaviors, a social game could be devised using a points system where an environment has a default number of points due to the group it is fitted complemented with more points as recommendations purposed by the system were followed. It is believed that the devised algorithm for sustainability recommendation should work on gamification platform providing dynamic objectives and goals which are partial dependent on the acceptance of recommendations updated for every environment on a timely basis.

4 Conclusion

With the proliferation of social networks, users share significant amounts of information. Taking advantage of the number of users inside a community to develop a recommendation engine that promotes sustainability as global objective is the objective of the work here presented. The algorithm results and theoretical background support the idea that it possible to use such strategies to drive a social community of user to optimize itself if recommendations are followed.

Nevertheless, practical validation under real environments and a real user base is still needed to validate simulation results. This should be accomplished using field tests in a community focused on increasing their sustainability.

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2.2.2 Context-Aware Well-Being Assessment in Intelligent Environments

Scope of the 6th International Symposium on Ambient Intelligence

Ambient Intelligence is a recent paradigm emerging from Artificial Intelligence, where computers are used as proactive tools assisting people with their day-to-day activities, making everyone's life more comfortable.

ISAmI is the International Symposium on Ambient Intelligence, aiming to bring together researchers from various disciplines that constitute the scientific field of Ambient Intelligence to present and discuss the latest results, new ideas, projects and lessons learned.Brand new ideas will be greatly appreciated as well as relevant revisions and actualizations of previously presented work.

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Context-Aware Well-Being Assessment in Intelligent Environments

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Abstract. The implementation of concepts such as smart cities, ambient intelligence and internet of things enables the construction of complex systems that may follow users across environments through many devices. One potential application is the assessment and assurance of well-being of users within different environment with different configurations. This is a complex task that requires the capture of the state and context of both users and environments through sensors dispersed across environments and users. It's the opportunities created by the emergence of technology that provide enough information to intelligent autonomous systems. Adapting expectations of a well-being assessment system to task and context is possible using the new techniques imported from different fields such as sensor networks, sensor fusion and machine learning. This article encompasses the design and implementation of a platform to evaluate well-being according to each context and translate it to sustainable indicators.

Keywords: Sensors Networks, Ambient Intelligence, Sustainable Indicators, Well-Being

1 Introduction

The internet of things is a new paradigm, in which every device is digitally connected, regardless of their function and communicates with other devices and other people over communication protocols. It applies both to fixed devices and personal devices that accompany people [1].More examples can be enumerated by devices that are being incorporated inside the actual body, such as identification chips, smart tattoos and alike [2]. Smart city is a term applied to digital research using computational methods and systems that results in better, easier and faster management of services and goods inside inhabited areas. In this setup, the internet of things acts as a base service which enables smart cities applications to collect information directly from the environment and people and the integrated fusion of data and information. This benefits the planning of actions to improve the status quo. Among other concerns, health, comfort and well-being are topics being addressed in smart cities research [3].

If the technologies described under the concepts of smart cites and internet of things are perceived as social services, then it is possible to gain access to a new set of valuable information on both the environment and users. These trends, despite having

adfa, p. 1, 2011.

ethical challenges of their own, present a number of opportunities for society. Sensorization, monitoring and sharing of information are terms intimately connected to the new intelligent systems being created. Even more, applied research related to health organizations and also the well-being of populations or individuals is present in recent studies. Connected environments and the act of monitoring comfort parameters are not under active research but also regulated by governments. For examples, air quality is an area that is actually regulated by governments which define acceptable parameters. Concurrently, research conducted in the field of smart environments studies the impact of air composition in health, concentration tasks and psychological comfort. As expected, research directions are more specialized than government regulations and are being pushed forward by the quality of sensors and sensor networks which portrait better and better images of air composition across time and space inside environments. There are other examples with equal strategies that aim to better assess and diagnose unoptimised or harmful situations with focus on well-being and general health [4].

The quest for physical well-being is addressed under smart cities by the use of indicators from personal devices such as smartwatches, sport monitors or smart bands which among other things can monitor some health parameters such as heart rate, blood oxygen levels and sport activities. Research in the body response to environment parameters is also potentiated by these personal devices that act as personal sensors [5]. Their use to calculate more intrusive parameter such heat balance index for each individual helps perceive whether it is cold or warm in different situations. The environment condition alone is correlated to well-being and comfort status [6]. More importantly, there are decisions that can be made using such information that may affect both physical and psychological health. Using fixed sensors over specialized areas are of interest to assess environments and their impact on heath [7]. For instance, projects that monitor city or indoor air quality provide rich information about potential health risks that may impair both physical and psychological well-being. What is more, the availability of digital services allows a faster identification and actuation upon these threats. The difficulty gathering and constantly monitor such parameters leads to situations where interventions are planned later than they should and the problems worse. Social sustainable indicators developed to assess development of countries and populations can also be automated using sensory networks with devices directly connected with each other that can provide information that would normally require expansive survey, and field tests. In the health care community there are social indicators as well.

2 Related Work

According to the Oxford Dictionary of English, well-being is the state of being comfortable, healthy, or happy. In order to assess it, the three subjects should be covered by the process conducting such evaluation.

In a professional environment, according the World Health Organization a healthy job is likely to be one where the pressures on employees are appropriate in relation to their abilities and resources, to the amount of control they have over their work, and to the support they receive from people who matter to them. As health is not merely the absence of disease or infirmity but a positive state of complete physical, mental and social well-being, a healthy working environment is one in which there is not only an absence of harmful conditions.

Environment and physical working conditions are important organizational risk factors [8]. Previous approaches to this work focused on the physical attributes predicament such as heart rate, and comfort due to environment conditions. The assumption that comfort equilibrium calculation was too complex to perform on a recurrent analysis [9] are mostly proved wrong in an intelligent environment equipped with smart sensors. Although, some of the algorithms might still be considered complex, most mathematical can be used fairly easy by computational systems. From this perspective it is possible to perform scoring systems to rate the degree of comfort a user experiences. Traditional studies use ergonomic research to estimate ideal parameters that are adequate to the space, the people and the task performed. Considering these variables, in this study, we can analyse traditional attributes such as temperature, humidity, luminosity, relevant attributes like CO, CO2 and airborne dust. However, it is possible to increase the precision of these models, not only estimating individual assessments but also correlated assessments through dedicated indicators with sensor and data fusion techniques. As an example there are a number of indexes that can be created, namely, perfected temperature, percentage of people in discomfort and stress related with heat perception [10] and adequate luminosity for each task. These sensors monitor the environment and its attributes looking for suboptimal attributes, however relate these attributes with user discomfort or user stress is still a relative study. There is another layer, physical human sensors which, in this case, monitor the heart rate for each individual inside smart environments. Whenever suboptimal values are detected, it will be possible to relate the physical state of each person to the environment attributes. Psychological and physiological adverse ambient conditions can produce significantly changes in a person. However authors orient this topic to a set of variables. In this particular approach sound, temperature and luminosity are studied as external factors that affect well-being and mood states. Previous authors have debated the influence of such variables in the impact of mood change in people [11]. Related studies between stress and well-being and stress recognition can also be found. In [12] we can see a wearable system for ambulatory stress monitoring recording a number of physiological variables known to be influenced by stress. In [13] author gathers values from a skin temperature sensor, a heart rate sensor and a skin conductance sensor. The signals from the sensors are input into a microcontroller where all the processing takes place and carried out though ZigBee technology. Data are stored in a computer it is stored for data analysis and feature extraction for emotion recognition.

Comfort is subjective directly related to a person's personality, beliefs and habits. There are however ergonomic studies that provide the necessary background to create an environment which satisfies the most common needs to keep both the people and environments healthy. Although not being an extensive review of possible attributes it does indicate a minimum set of possible attributes to start comfort and well-being assessments [14].

3 Context Aware Well-Being System Architecture

A combination of personal and environmental attributes provides a better representation of the information required to assess well-being and hypotheses about user condition, its relation to environment attributes and the activities being performed. Such information though not being medically considered as hard prove to diagnosis may be used as soft information about condition and habits of living. This system depends on the number of sensing devices and attributes considered to make decisions more accurate and expressive. It is also important to adapt the notions of comfort and safety according to the context of tasks and activities being performed. Taking knowledge from a knowledge base about each environment, for instance relations between sensor and event records, it is actually possible to estimate the state of well-being, both currently and in the future.

3.1 Environment Evaluation

A home environment is a particular setup, with a very personal context. Depending on job state, a person may spend most of the time in this environment or only after work hours. Taking into consideration a typical residence with working people, it is possible to assess comfort condition and monitor and predict values of comfort.

From the installation of different sources of sensorization through the environment it is possible to measure the impact of each individual attribute in the environment. As a personal environment those should be the best suited to assess what each user deems as comfortable. However as users can have different meanings for comfort, there might exist some exceptions to this assertion. An environment, though not always equal it is generally categorized by a population of individuals sharing the same environment. Each environment has different requirements according to the specific tasks its users perform. An experience to demonstrate the findings of the system proposed was designed with a sensors network in place to monitor environment variables. During this experiment a presence control was instituted to add user presence as an attribute. The description of the summary of the data gathered is available in table 1.

Table 1. Summarized data retrieved from the environment sensor network

	Mean	Standard Deviation	Max	Min
Temperature	19,98 ºC	1,68 ºC	24,88 ºC	17,99 ºC
Luminosity	122,53 lux	102,49 lux	632,00 lux	0,00 lux
Humidity	45,69 %	7,39 %	63,19 %	38,86 %
Number of People	2,27	1,70	10,00	0,00

The analysis of well-being is inherently different from home and professional configurations due to the fact that the context alters comfort values. Though some of the alterations remain within the acceptable range they can be used to introduce differences in the well-being analysis.

3.2 Personal Assessment

Well-being through environment alone is an incomplete study as it disregards the effects of user interaction and user behaviour. Under normal circumstances, well-being should generate values inside the satisfactory range for attributes being measured. Considering one individual alone, the existence of normal range values for environment and abnormal for the personal sensing might lead to the suspicion of something not right with the individual thus impairing well-being.

On table 2, a set of indicators gathered from a personal sensorization hardware reveals the normal range of attribute date for a given individual. His historic data reveal how comfortable he is by assessing most common values after some period of time. As the indicator values go up or down the mean and standard deviation being considered it detects abnormal behavioural pattern and uses majority votes to decide whether it is really an uncomfortable behaviour or not.

A practical validation test can be made using records from environment and testing them against such data. It was perceived that environment conditions only directly affect personal attributes the most when they differ significantly under normal circumstances that is avoiding considerations about individual's state of mind. Environment variables ranging inside the comfort zone are less likely to produce chances in the normal values from personal sensorization.

Table 2. Summarized data retrieved from the user sensor network

	Mean	**Standard Deviation**	**Max**	**Min**
Steps	4177,80	7537,96	5080,00	3245,00
Blood Pressure	78,42 bpm	19,11 bpm	125,00 bpm	58,00 bpm
Oximetry	97,45 %	1,02 %	100,00 %	95,00 %
PMV	-0,79	0,86	1,20	-1,72

3.3 Well-Being Assessment

Well-being assessment is employed in a two-phase strategy. First, the analysis of critical conditions through environment sensory data and secondly, the analysis of comfort. At the initial phase, a thorough analysis about each individual attribute is made to make sure that each of the sensorized values are non-risk values towards human. This evaluation is made both to environment and personal attributes as shown in table 3. It is important to deal with information quality and validity. If the evaluation fails at this stage the uncomfortable setup is immediately generated. Even if there is only one of the attributes outside what is considered safe range, the resulting classification is deemed non satisfactory and a 0% well-being is issued as life might be endangered.

Following on to the second phase, with each user profile and environment profile, a match between activities and each attribute available is analysed. In the sample test, the temperature and luminosity of environments where chosen. Different comfort rules are created according to the dominant activities in each environment and the ideal configuration is assessed through ranges of values from medical, thermal and ergonomic studies present in configuration databases in the system. From this point, a weighted percentage is loaded from the database to allow different comfort attributes to have more or less impact in the well-being value. The final value of well-being is the weighted majority of the satisfaction comfort for each attribute. A percentage, less than 100% denotes that at least some attribute being measured is not within comfort values for a given time. Finally, a daily assessment considers the average of well-being satisfaction between measures.

Table 3. Comfort Reference Values

Comfort Attribute	Lower Limit	Upper Limit
Humidity	20 %	60 %
Temperature	18 ºC	25 ºC
Luminosity	50 lux	107527 lux
Temperature perception (PMV)	-1.5	1.5
Heart Rate (Woman)	60	78
Oximetry	90%	100%

Table 4 presents the relative percentages of time the environment was considered good for well-being according to the algorithm described with the analysis of the attributes and their matching to each other. It is shown that environment configurations are generally portrayed as good in well-being standing but the personal attributes are lacking more often. In the case of this experiment that is due to non-activity, and sedentary lifestyle. Its implications are that, although the environments appear well configured, the activities of users are not being considered as good for well-being. Although with this setup, if the conditions verified are not directly correlated between both environment and personal attributes, the weighted average among all attributes decides the category of well-being.

Table 4. Well-Being Assessment Experiment Analysis

	Environment Well-Being	Personal Well-Being	Well-being Assessment
Environment	97%	78%	83%

Historical data about environment and both environment and people can be addressed making up profiles of aggregated information through the use of dashboards. These dashboards should contain valuable information for healthcare institutions and its professionals to help with patient consult for instance. More than the experience a verbal consult with a patient can produce, a virtual conversation is something that includes virtual data according to sensing system available. Though the system may be assessed with simulation data, it is in the real world data applied to each scenario that it usefulness can be extensively validated. For healthcare institution it is possible to navigate, through time windows and select only values of selected attributes and obtain both a measurement dashboard as well as a well-being classification. The input in the system are dependent in the number of attributes measured by the sensor network in place and the capability of its devices. The further specialized the devices and information is the further the quality of information and the validity of these analysis.

4 Conclusion

The development of our well-being as human beings is something that should not be overlooked. Like other important subjects to our daily life, continuous development and improvement is desirable and an objective. Systems such as these are starting to appear through the research community and as exploratory projects within large enterprises. While not identifying themselves as health organizations, their goal is to promote the investigation of well-being through the population whilst increasing the information available. Consequently, this leads to building large databases about user behaviour and environment conditions. This also starts the study of communities and the impact of behaviours and environment on health and comfort through large sets of population strengthening existent knowledge with large validation test, but most importantly creating the opportunity to generate new and improved knowledge by analysing these records. Seemingly close behaviour in different conditions can generate different results, it can be comparable to the butterfly effect, where a small change can have great implication on the whole system towards a positive or negative result. The categorization of these conditions may improve not only well-being but health as well. The promises and the large research body around these themes indicates that these technologies and these research considerations are valid. They are even today the object of pursuit by society as a mean to improve living conditions.

A future approach to this study should include distribution analysis between the historical data on a given time window and the sensorized values. This envision may also help annotate different states of comfort through building and the people inside to better map how the environmental attributes of such buildings affect the well-being of people. As tried in the experimental framework to detect stressful moods (Silva et al., 2013), where a testbed was used to perceive different room states during the day and the classification of probable well-being.

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2.3 Affective Computing and Sustainability

Humans have the need to control their surroundings and to believe that they are auto-effective. The lack of these features can produce negative affect, reducing motivation [92]. In a domestic environment, there are variables able to apply stress, thereon refereed to as stressor variables, that its users can not control or predict such as noise [93], heat [94] even air pollution [95].

A behaviour like aggression may be provoked by extreme condition, for example, a very noisy room. Also, these stressors may influence the process of decision making [96] and in psychological and physiological adverse ambient conditions can produce significantly changes in a person. As each person have different sensitivities to sound volume, people with high sensitivity to sound have more predisposition to be more anxious [97]. Others, if provoked, can be aggressive or hostile [98]. In hot places, psychological changes occur if temperature increase to high degrees, such irritability, fatigue and discomfort. Very high temperature can even provoke hostile or violent attitudes [96]. When a system can access this type of information from the environment, it is possible to estimate the type of emotional actions may arise as a consequence.

Emotions are influence by the personality of people. Personality determines how a person reacts intrinsically to certain events. It is like a long-term emotion, because it is formulated in the early years of life and remains almost unchanged during lifetime. The Big-Five Personality (BFP) theory, also called Five Factor Model (FFM) [99] is a common definition of personality traits that indicates that is possible to separate it into five properties: Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism (OCEAN) [100]. In order to map the personality of an individual into FFM, authors use empirical methods such as surveys or questionnaires. There are various types of self-reports questionnaires such as $NEOPI - R^{TM}$, The revised Neuroticism, Extraversion and Openness (NEO) personality inventory is a measure of 240 items to assess to the Big Five traits. This questionnaire has a duration of 30 to 40 minutes plus 15 minutes to obtain a result. Other, $NEO^{TM} - FFI - 3$ NEO Five Factor Inventory is a short version of the self report above, that has 60 items, a duration of about 10 to 15 minutes, and takes 5 minutes to have a score [99]. As yet another example, NPA - Newcastle Personality Assessor is based on all the above questionnaires, with 12 items [101]. However, the number of questions in this self report has an impact on the accuracy of big five values, the more questions to answer, more accurate the results will be.

Experiments based on the reaction of users to environment attributes may be able to estimate some mood states. One in particular, stress, was perceived by a research experiment in a laboratory setup in the context of this doctoral thesis. In order to increase precision, mood states in these experiments are aggregated into positive and negative moods. The experiments, follow simple approach in order to demonstrate the feasibility of the theories. The first experiment evidences the study of stress through environment and physiologic sensors and the second takes the case of urban driving to estimate drivers mood. While the first experiment focus on machine learning, the second applies emotion systems based on literary review with models to estimate emotions.

2.3.1 Ubiquitous Sensorization for Multimodal Assessment of Driving Patterns

Scope of the 5th International Symposium on Ambient Intelligence

This interdisciplinary meeting, with focus on the interplay between Nature and Computation, expands the scope of neural computation at the physical level to cope with symbols and knowledge level models of cognitive and social processes. The global purpose is to offer a forum for discussion and exchange of ideas between scientists and engineers from fields such as Electronic Engineering, Artificial Intelligence, Knowledge Engineering, Physics, Mathematics, Computation, Artificial Vision, Situated Robotics, Neurophysiology, Cognitive Science, Linguistics and Philosophy, trying to contribute to the answer of two basic questions: from computation to sciences of natural and from sciences of natural to computation.

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Ubiquitous Sensorization for Multimodal Assessment of Driving Patterns

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Abstract. Sustainability issues and sustainable behaviours are becoming concerns of increasing significance in our society. In the case of transportation systems, it would be important to know the impact of a given driving behaviour over sustainability factors. This paper describes a system that integrates ubiquitous mobile sensors available on devices such as smartphones, intelligent wristbands and smartwatches, in order to determine and classify driving patterns and to assess driving efficiency and driver's moods. It first identifies the main attributes for contextual information, with relevance to driving analysis. Next, it describes how to obtain that information from ubiquitous mobile sensors, usually carried by drivers. Finally, it addresses the multimodal assessment process which produces the analysis of driving patterns and the classification of driving moods, promoting the identification of either regular or aggressive driving patterns, and the classification of mood types between aggressive and relaxed. Such an approach enables ubiquitous sensing of personal driving patterns across different vehicles, which can be used in sustainability frameworks, driving alerts and recommendation systems.

Keywords: Driving Profile, Mobile Sensors, Sustainability

1 Introduction

Ambient Intelligence (AmI) is a very active area of knowledge and constitutes a multi-disciplinary subject which takes advantage of advances in sensing systems, pervasive devices, context recognition, and communications. Nowadays, AmI applications can be found in fields ranging from home, office, transport, tourism, recommender and safety systems, among many others [20]. In the case of transport applications, an area also known as Smart Cars [2], the AmI system must be aware not only of the car situation, but also of the driver's intention, of his physical and physiological conditions and of the best way to deal with them [19], [17]. The driver's behaviour is, thus, of key importance: several authors have used machine learning and dynamical graphical models for modelling and recognizing driver's behaviours [22].

There are examples of applications integrating AmI and ubiquitous principles in driving and traffic analysis. In [13], it is described a monitoring and analysis system to approach personalized driving behaviour, for emerging hybrid vehicles. The system is fully automated, non-intrusive with multi-modality sensing, based on smartphones. The application runs while driving and it will present personalized quantitative information of the driver's specific driving behaviour. In [18] a mobile application assesses driving behaviour, based on critical driving events, giving feedback to the driver. The Nericell system [15], from Microsoft Research, monitors road and traffic conditions using the driver's smartphone and corresponding incorporated sensors, but it can also detect honking levels and potholes on roads. The I-VAITS project [19] is an example that pretends to assist the driver appropriately and unobtrusively, analysing real-time data from the environment, from the car and from the driver itself, by the way the driver uses the different elements of the car, their movements or image processing of their face expressions. In [3], in the context of a car safety support system, an ambient agent-based model for a car driver behaviour assessment is presented. The system uses sensors to periodically obtain information about the driver's steering operation and the focus of the driver's gaze. In the case of abnormal steering operation and unfocused gaze, the system launches proceedings in order to slow down, stop the car and lock the ignition.

2 Related Work

Driving analysis can be a complex problem depending on the degree of information used and the number of categories being analysed. The analysis presented is described based on sustainable principles assessing driving patterns and their impact on sustainability and sustainable behaviour.

2.1 Driving Pattern Detection

Usually, driving pattern is defined and associated to the speed profile of the driver, but it can be expanded to other variables, as gear changing, and big changes on the acceleration [6]. In 1978, Kuhler and Karstens [12] introduced a set of ten driving pattern parameters. Later, in 1996, André [1] reviewed those parameters, and reviewed some of the most common parameters such as action duration, speed, acceleration, idle periods and number of stops per kilometre. In other studies [5], [6] other parameters were used to collect data from ordinary drivers in real traffic situations, such as wheel rotation, engine speed, ambient temperature, use of breaks and fuel-use. In these studies, GPS data was also monitored, where each driving pattern was attributed to street type, street function, street width, traffic flow and codes for location in the city (central, semi-central, peripheral). It was concluded that the street type had the most influence on the driving pattern. The analysis of the 62 primary calculated parameters, resulted in 16 independent driving pattern factors, each describing a certain dimension of the driving pattern. When investigating the effect of the independent driving pattern factors on exhaust emissions, and on fuel consumption, it was found that only 9 factors had a significant effect.

Table 1: Relevant attributes to driving analysis according to previous studies

Attribute	Ericsson [5]	Kuhler and Karstens [12]	Nericell [15]
Wheel rotation	+	+	-
Motor RPM	+	+	-
Pedals Monitoring	+	+	-
Street type	+	+	+
Fuel Consumption	+	+	+
Velocity	+	+	+
Acceleration	+	+	+
Standard deviation of acceleration	+	+	+
Trip duration	+	+	+
Hour of day	+	+	+

Table 1 provides an analysis of the main attributes identified. These studies share most of the identified attributes to analyse and classify driving patterns. With exception of attributes such as motor rotations per minute and pedals monitoring that are obtained directly from the physical vehicles, driving analysis with mobile and non-mobile sensors take interest in the same subgroup of attributes.

2.2 Sustainable Driving

Computational methods that allow the balancing of economic, environmental and social factors needed to a sustainable development, a newly emerging and interdisciplinary area, known as Computational Sustainability, solve problems which are essentially decision and optimization problems. The concept of sustainability and sustainable behaviours is important to ensure the welfare and well-being. Due to its importance, some researchers have discussed about quantification methods, and modelling sustainability [23], [11]. In the case of transportation systems, the assessment of the impact of a given driving pattern is made over sustainability factors, like fuel consumption, greenhouse gas emissions, dangerous behaviour or driving stress.

A system to estimate a driver profile using smartphone sensors, able to detect risky driving patterns, is proposed in [4]. It was verified whether the driver behaviour is safe or unsafe, using Bayesian classification. It is claimed that the system will lead to fuel efficient and better driving habits. In [9], and in addition to car sensory data, physiological data was continuously collected and analysed (heart rate, skin conductance, and respiration) to evaluate a driver's relative stress. The CarMa, Car Mobile Assistant, is a smartphone-based system that provides high-level abstractions for sensing and tuning car parameters, whereby developers can easily write smartphone applications. The personalized tuning can result in over 10% gains in fuel efficiency [7]. The MIROAD system, Mobile-Sensor-Platform for Intelligent Recognition Of Aggressive Driving [10], is a mobile system capable to detecting and recognizing driving events and driving patterns, intending to increase awareness and to promote safety driving, and thus possibly achieving a reduction in the social and economic costs of car crashes. The system uses Dynamic Time Warping and smartphone based sensor-fusion to detect and recognize actions without external processing.

3 Multimodal Assessment System

The implementation of the ubiquitous multimodal driving analysis system is depicted in this section. Ubiquitous monitoring is achieved by the use of smartphones equipped with accelerometer, GPS, compass, microphone and light sensors. These come as standard in most smartphones sold today. While it is not the main function of a smartphone, driving analysis can be achieved using some of the limited processing capability of low-end smartphones. Additionally, its connectivity options allow for better analysis on a server side location. The proof-of-concept system is illustrated by figure 1, where data flow is illustrated.

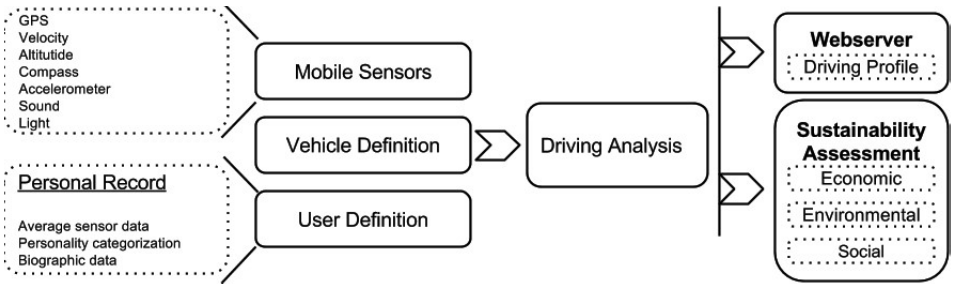

Fig. 1: Model describing the driving analysis in the system.

After obtaining information about driving patterns, vehicle and driver definition, the driving analysis module will synchronize its data with an external server and derive a report assessment on the sustainable impact according to its 3 dimensions is built. Such knowledge is useful to update sustainability frameworks such as PHESS [21] which monitor and assess sustainable impact through performance indicators based on the same three categories.

The economic and environmental assessment is derived from the estimated impact of current driving patterns on the vehicle fuel consumption and gas emission. The social component is assessed by the effect of driving patterns on the social and psychological response from drivers. Although, sensor analysis by itself can answer if an event can or cannot be considered aggressive, it is still a reactive and instantaneous concept. With such information it is possible to map optimal to suboptimal configurations as well as infer which emotions these conditions produce on human beings. In a computational system it is still a challenging process to acquire rich information in this domain, but there are some approaches proposed in the research community that have had broad acceptance. In regard to the representation of a personality, the OCEAN structure used is similar to the approach adopted by the ALMA framework to represent the personality of people and initiate mood states in [8]. In the OCEAN approach, personality are defined by a set of variables (o, c, e, a, n) which represent five personality traits: Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. On the other hand, the PAD space [14], is a computational friendly representation of mood states. A person's mood is represented using the three variables that define PAD space, Pleasure, Arousal and Dominance respectively. Contrary to the personality which is almost regarded as static during people lifetimes, mood is a temporal state of the human mind that can last for minutes, hours or even days.

3.1 User Driving Pattern

The analysis of driving patterns is made with the help of profiles. These structures are created individually for each driver and maintained in a web-server through the use of restful web-services. Although not using the internal data from vehicle sensor as in past research [5], the approach followed in this work uses smartphone data for ubiquitous and pervasive monitoring. An illustration of the application devised to record driver's attributes is detailed in the left part of figure 2. Data gathering is made through sensors, which is pre-processed internally with data fusion methodologies to enrich data and provide richer information. The number of variables used to assess driving patterns is based on the information gathered in the literature and adapted to ubiquitous sensors. As such, a total of 6 basic attributes are monitored: accelerometer, velocity, altitude, time of day, compass and position. From the fusion of these attributes, it is possible to infer standard deviations for each attribute according to each driver, the number of breaking and accelerations and its mean duration and intensity. These are the characteristics used in each driver profile in order to assess its regular driving behaviour. Aside from the regular driving pattern, the system will also classify aggressive driving patterns, which are categorized by higher frequency of breaks and accelerations with high intensity and shorter duration than the driver regular behaviour. The rigth part of figure 2 shows a graphical

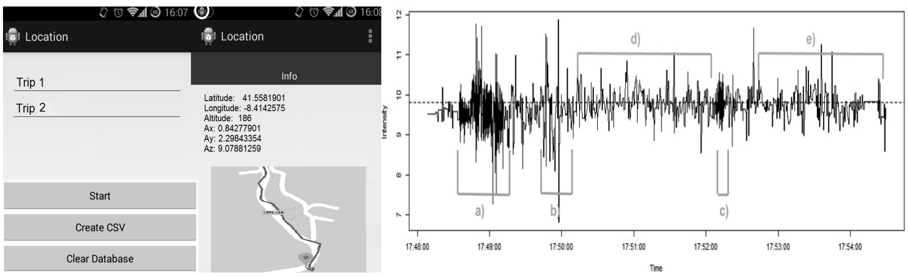

Fig. 2: Mobile Driving Patterns Extraction

representation of the intensity of the accelerometer sensor annotated with information gathered by other sensors according to driving pattern of a test driver. Event $a)$ represents low velocity and high variation of accelerometer which can be deduced to be parking or congested traffic driving. Events $b), c)$ represent aggressive events where velocity was kept high and sudden changes of direction result in high amplitude variation of accelerometer forces. Events $d), e)$ do not offer significant variation from common driving pattern thus identified as regular driving events. It is the identification of these events that will play a major role to detect the current mood of the driver. The pattern identified and its duration will provide information to assess the current driver's mood.

3.2 Driving Mood Classification

Mood classification is based on the analysis of the number of breaks and accelerations detected by mobile sensors: aggressive driving styles are connected with high frequency of breaking and accelerating actions; relaxed driving is correlated with stable velocity and low breaking and accelerating actions. The computational representation of mood states is done according to the Pleasure, Arousal, Dominance framework described by Mehabian (PAD) [14] and the PAD space extended by Gehbard in [8], where the initial P, A, D variables are initiated according to each user's personality assessment. The initial assessment of a driver's personality is achieved by an initial questionnaire, filled the first time the mobile sensing application is used. In this case the Newcastle Personality Assessor (NPA) questionnaire was used [16].

$$M_{actual} = M_{actual} + (M_{final} - M_{actual}) * emotionalWeight \quad (1)$$

Following this approach, two final states are defined representing aggressive and calm states so that a driver's mood may be updated towards one of these states. The equation 1 represents the current driver's state moving in a vector space at a velocity defined by the $emotionalWeigth$. This is dependent on values from the OCEAN personality representation and the assessment of the emotional response to a driving pattern. If positive update (relaxed pattern) $emotionalWeight = (e + 1.0) * const$ otherwise $emotionalWeight = (n + 1.0) * const$.

This study is limited to a classification of mood states oscillating between aggressive and relaxed moods. The classification of additional mood types increases not only complexity but also the error rate, as it becomes difficult to distinguish between them.

4 Conclusions and Future Work

In this article it is present an analysis of some state of the art related ubiquitous sensing of driving patterns. The approach with this work allows for pervasive monitoring through common objects such as smartphones in order to record and analyse driver's actions. Although limited by the sensors of each device, realist results can be extracted by standard hardware. The assessment of current driving mood is robust to sporadic deviant events as only a series of continuous negative or positive patterns does change the mood assessment while still reacting instantly to aggressive or relaxed events.

As a future work, the ubiquitous application will be extended allowing the sharing of information between drivers. With these abilities, gamification elements will try to moderate driving patterns by adding positive and negative points to a driver's profile. Additionally, the information shared allows for instantaneous information about nearby drivers such as emotion classification. The analysis will also add route classification based on an aggregated knowledge of driving patterns for each route, as well a It will also be used in future recommender systems and navigation applications. It will also allow automatic identification of driving actions through sensor analysis, thus requiring no user input at the start of driving records, enhancing the ubiquitous and pervasive nature of this work.

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2.3.2 Experimental Study of the Stress Level at the Workplace using a Smart TEstbed of Wireless Sensor Networks and Ambient Intelligence Techniques

Scope of the 5th International Work-Conference on the Interplay Between Natural and Artificial Computation

This interdisciplinary meeting, with focus on the interplay between Nature and Computation, expands the scope of neural computation at the physical level to cope with symbols and knowledge level models of cognitive and social processes. The global purpose is to offer a forum for discussion and exchange of ideas between scientists and engineers from fields such as Electronic Engineering, Artificial Intelligence, Knowledge Engineering, Physics, Mathematics, Computation, Artificial Vision, Situated Robotics, Neurophysiology, Cognitive Science, Linguistics and Philosophy, trying to contribute to the answer of two basic questions: from computation to sciences of natural and from sciences of natural to computation.

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Experimental Study of the Stress Level at the workplace using an Smart Testbed of Wireless Sensor Networks and Ambient Intelligence techniques

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Abstract. This paper combines techniques of ambient intelligence and wireless sensor networks with the objective of obtain important conclusions to increase the quality of life of people. In particular we oriented our study to the stress at the workplace, because stress is a leading cause of illness and disease. This article presents a wireless sensor networks obtaining information of the environment, a pulse sensor obtaining hear rate values and a complete data analysis applying techniques of ambient intelligence to predict stress from these environment variables and people attributes.Results show promise on the identification of stressful situations as well as stress inference through the use of predictive algorithms.

Keywords: Ambient Intelligence, Intelligent Environments, Wireless Sensor networks, Body Area Networks, Environmental Monitoring, Stress Detection

1 Introduction

Ambient Intelligence (AmI) is considered one of three emergent technologies: Ubiquitous Computing, Ubiquitous Communication and Intelligent User Interfaces. AmI systems aim to change how people interact with technology and the environment integrating concepts from psychology, social sciences and artificial intelligence to increase the quality of life. AmI makes this possible by anticipating and predicting future needs and desires while taking in consideration aspects like safety, economy and comfort. One concept usually linked to AmI is ubiquitous computing, a concept proposed in [1] by Mark Weiser. In this environment, computational units are embedded in its surroundings functioning and hidden from view.

Directly connected with ambient intelligence is also how the sensing of the environment is done. In order to deliberate which actions an intelligent system may do in an environment it is necessary to obtain the information of the environment needs. Significant levels of data must be constantly and ubiquitously collected to provide the data and information needed.

Body Area Networks (BANs) allow the integration of miniaturized and low power sensor nodes in, on, or around the human body to monitor body functions and the surrounding environment [2][3]. BANs provide long term health monitoring of patients under natural physiological states without constraining their normal activities. The typical architecture of a BAN includes sensor nodes deployed in, on or around the body and a BAN coordinator that gathers data coming from all the sensor nodes. This BAN coordinator can store the information for further analysis or can forward it to an intermediate network that serves as a gateway to send the data through the Internet to the expert user (i.e., nurses, doctors, ...) placed in a smart space. Our experiments will use a wireless sensor testbed to emulate this intermediate network. A testbed of wireless sensor nodes provides a reliable platform where to test new protocols and applications in a controlled way.

BANs enable continuous measurement of physiological parameters, such as heart rate, muscular tension, skin conductivity, breathing rate and volume, during the daily life of a user. Those parameters can be combined with contextual information extracted from the environment through wireless sensor networks (temperature, humidity, light, etc.), and all together could be used to infer emotions, mood, depression, and levels of stress and anxiety. Using BANs for emotion, mood, stress or depression recognition is an open research problem and requires development of novel signal processing techniques to interpret and fuse the data collected by multiple sensors [4].

In this work we are going to use a testbed of wireless sensor networks and a BAN. The testbed of 43 fixed nodes is continuously gathering different environment parameters (temperature, humidity, light and CO2). The BAN, composed of a pulse sensor node, is continuously gathering heart rate values. This two networks work together with the objective of detecting possible situations of stress at the workplace using ambient intelligence techniques. This work join two interesting research lines (sensor networks and ambient intelligence) with the purpose of achieve innovative conclusions.

According the World Health Organization a healthy job is likely to be one where the pressures on employees are appropriate in relation to their abilities and resources, to the amount of control they have over their work, and to the support they receive from people who matter to them. As health is not merely the absence of disease or infirmity but a positive state of complete physical, mental and social well-being, a healthy working environment is one in which there is not only an absence of harmful conditions but an abundance of health-promoting ones [5].

Environment and physical working conditions are important organizational risk factors [6]. Our research takes the evaluation of different important parameters related with environment and physical working conditions, using a testbed of wireless sensor network and the extension of the testbed, with sensors installed in mobile elements (BANs). The whole wireless network transmits the data to the right base station to store data for a following data analysis. This paper focuses on both, the evaluation with the tesbed and the data analysis.

The rest of this paper is organized as follows: Section 2 summarizes some related work. The testbed used is detailed in Section 3. Section 4 describes the analysis of environment and user data. Finally, Section 5 gives some concluding remarks and interesting future works.

2 Previous work

2.1 Stress monitoring using wireless sensor networks

There are some interesting works about emotion recognition and stress monitoring with wireless sensors. In [7] we can see a wearable system for ambulatory stress monitoring recording a number of physiological variables known to be influenced by stress. This system is not ZigBee based, it employs a radio module from TI (Texas instruments Inc.), a connection-based low-power lightweight sensor network protocol for small RF networks supporting two basic topologies: strictly peer-to-peer and a star topology. The authors use a star topology where all sensor (leaf nodes) are connected to a sensor hub (the root). If this root node fails the system would support permanent disconnections. Regarding this issue, our mobile nodes send data to the testbed nodes actuating as parents. If a failure is produced in one node, any other node can act like a parent node. In [8] author gathers values from a skin temperature sensor, a heart rate sensor and a skin conductance sensor. The signals from the sensors are input into a microcontroller where all the processing takes place and carried out though ZigBee technology. Data are stored in a computer it is stored for data analysis and feature extraction for emotion recognition. The four basic emotions observed in this project are happy, sad, angry and neutral. The system can be used by anyone sitting within a range of 30m of a computer. The sensor used on this system are not too much "wearable". There is an special surface with sensors where a person has to put his hand. Subjects chosen to take part in the experiments have are sitting for neutral state.

2.2 Ambient intelligence techniques

Monitor people well being and increases in stress are with the problems covered by ambient intelligence and ubiquitous monitoring. As such, there are model proposals to explain and potentially predict any undesirable effects considering a series of factors believed to influence user/occupant behaviour [9]. Other approaches, relate environment attributes to people attributes such as heart rate which may be used to infer thermal comfort levels and detect stress induced by environment attributes and unoptimised values [10].

In Paola et al. [11], ambient intelligence is used within a sensor network testbed to derive useful from sensor spread across the environment. The data retrieved from sensors is used to derive rich information such as user attendance, perceptible temperature, user activity and user preferences. All this information is learned unobtrusively by the system fusing sensor data without requiring user attention or direct user input.

Learning in ambient intelligence is often made using machine learning algorithms such as time series algorithms, evolutionary algorithms and statistical inference. These methods sanction the acquiring of past and current trends and predict future results. From information assembled from different environments, machine learning techniques may derive models of behaviour and interaction based on specialized backgrounds (e.g., users, environment, social interaction or consumption). For such analysis the use of statistical programs such as R [12] and machine learning workbenches such as Weka [13] is common. Such knowledge about environment and user attributes is usually stored in knowledge databases which are used in deliberative actions or to derive reactive rules to be applied in the system.

3 The testbed as a powerful and continuous smart tool

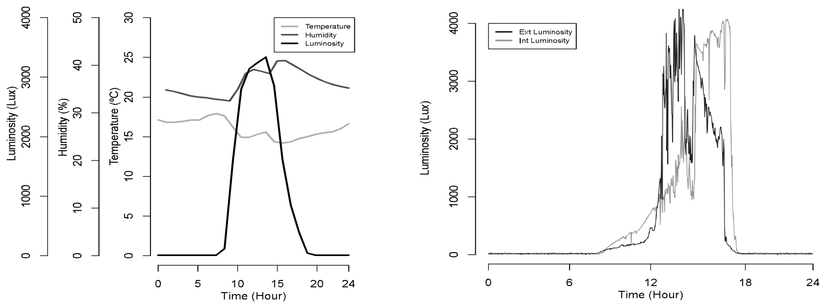
The Albacete Research Institute of Informatics (I3A) has its own testbed of wireless sensor network deployed in its facilities, known as I3ASensorBed [14]. This allows researchers to test in controlled environments. The testbed consists of 43 fixed nodes including temperature, humidity and light sensors, opened/closed doors and windows, movements, air condition (CO, CO2 and dust) and power consumption. All these sensors allow I3ASensorBed monitor weather conditions and the possibility to add mobile nodes with additional sensor, as hearth [15] rate, the status of workers in a workplace.The distributed nodes are TelosB from Crossbow, TmoteSky from Sentilla and MTM-CM5000-MSP from Maxfor. It also uses nT-A3500 computers from Foxconn, known as supernodes, to redirect data. To facilitate re-program of nodes and debugging of tests, nodes are connecting through USB cable to the nearest supernode, this supernode is the responsible to redirect information the central server. Along with the existing wiring, the nodes have the standard 802.15.4 (ZigBee) for wireless communications emulating realistic environments. The use of the testbed that covers a large work area with multiple workers allows the collection and study of data that is of interest in several areas, especially in the creation of an appropriate working environment for the workers. This is an ideal smart space to contribute to the measurement and experimentation of people health, safety and well-being

4 Analysis of environment and user data

In this section the use of ambient intelligence to unobtrusively detect and assess stress situations is made using information gathered by the sensor network detailed in section 3. The data was collected under real work conditions from an wireless pulse sensor, and embedded temperature, luminosity and humidity sensor for periods of time ranging from 10 minutes to 2 hours. Using these values, an heart rate change algorithm was validated and used to learn about stressful conditions in the environment.

4.1 Preliminary Study

It is possible to observe that values for environment attributes values are constantly changing throughout the day, see figure 1(a), and it even possible to detect human actions to correct values such as luminosity during some periods of the day, see figure 1 (b). Those corrections are made with artificial lightning to increase luminosity values during work hours and reach comfortable values for people. Such action are taken in order to decrease stress caused by poor environments and facilitate the activities being made.



(a) Temperature, Luminosity & Humidity (b) Artificial & Natural Luminosity

Fig. 1: Environment Monitoring

In the literature review, it is possible to infer a range of ideal values for attributes that while not being directly responsible for health risks, they should increase stress on people. Table 1 demonstrates the use of information about the activity are performing and the values for luminosity deemed acceptable.

Table 1: Luminosity values required by activity [16]

Activity	Luminosity Required
Short Visit	[50, 100]
Working areas with few visual tasks	[100, 150]
Office Work	[250, 500]
Mechanical Workshops, Office Landscapes	750
Normal Detailed Work	1000
Detailed Work	[1500, 2000]

Likewise, thermal comfort is an area of study that has seen important contributions to assess thermal discomfort and thermal stress in people. The equation of human heat balance is one theory commonly used to derive algorithms that capture the thermal sensation from people, rather than just environment temperature. One theory based on these principles is the Predictive Mean Vote

(PMV), a scale from -3 to 3 that classifies thermal sensation and has a correspondence to thermal discomfort [17]. Other approach uses an index that translates temperature readings in an environment to a set of stable conditions inside a room environment obtaining what is known as Physiological Equivalent Temperature (PET) [18]. Relationships from both algorithm are explored in Table 2 [19], as well as, indication of thermal stress. The relationship with real temperature values in the environment is dependent on variables such as air speed, clothing, temperature and humidity which change human thermal perception. Studies confirming an influence of thermal conditions and variations in heart rate in people are found in Liu et al, where a medical exam ECG to confirm such relationship between these attributes [10].

Table 2: Temperature Perception [19]

PMV	PET	Thermal Sensation	Stress Sensation
< -3.5	< 4	Very Cold	Extremely cold stress
$[-3.5, -2.5]$	$[4, 8]$	Cold	Strong cold stress
$[-2.5, -1.5]$	$[8, 12]$	Cool	Moderate cold stress
$[-1.5, -0.5]$	$[12, 16]$	Slightly cool	Slight cool stress
$[-0.5, 0.5]$	$[16, 24]$	Neutral	No thermal stress
$[0.5, 1.5]$	$[24, 28]$	Slightly warm	Slight warm stress
$[1.5, 2.5]$	$[28, 32]$	Warm	Moderate warm stress
$[2.5, 3.5]$	$[32, 36]$	Very Hot	Strong warm stress
> 3.5	> 36	Very Hot	Extremely warm stress

In order to validate stress levels with thermal and luminosity values, values from heart rate of people can be used to evaluate if significant changes are occurring.

The use of different sensors enables the application of sensor fusion projects empowered by sensor networks that produce information contextualized to the environment and the people on it. As such, preliminary tests conducted in order to assess the viability of the analysis undertaken. For these analysis, a test subject was monitored in different thermal conditions, comfortable and felling cold. Statistical t-tests were conducted assuming a normal distribution for the values of the heart rate, a 95% significance value and hypothesis concerning an increase, decrease and no change in the average heart rate of the test subject using the R statistical program [12]. Tests found statistical evidence that heart rate increased when the test subject felt cold with a $p < 0.05$, thus accepting the hypothesis that the heart rate average increased. It is important to notice that the test subject did not change its emotional state or other factor that could affect heart rate values. Changes in heart rate averages are concluded to have been caused from environment induced stress that raises the test subject heart rate. Such analysis corroborates other studies in similar conditions and validates the ability for the testbed to produce significant values that can be used in the analysis of stress using values from existing sensors [10]. The same approach with similar sensors was also developed to infer people emotional states from skin temperature sensors and heart rate sensors [20], adding evidence that people react to changes in attributes such as temperature.

4.2 Detection of Change in Attribute Values

In order to detect changes in monitored attributes it is necessary to identify points in time that show increases or decreases that have statistical significance for the analysis. Taking heart rate of people as an example, the statistical t-test assuming a normal distribution for heart rate values can be use to create a time series algorithm to detect changes in the average of heart rate. The approach undertaken uses windows of data gathered by a testbed and continuously assesses whether or not the average heart rate is increasing, decreasing or neutral over windows of data with t-test with a significance of 95%, see figure 2.

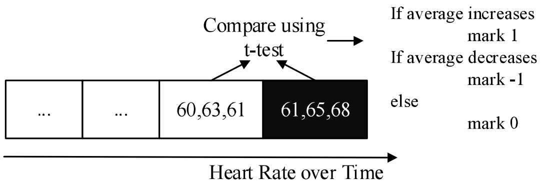
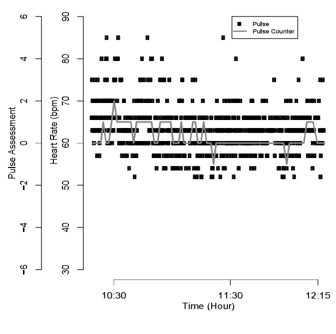


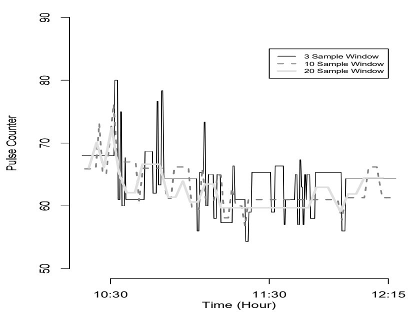
Fig. 2: Window Analysis

Using this strategy it is possible to create a counter variable, adding the all the marks created over time, that provides a contextual information on the balance between increases and decreases in heart rate. An illustration of these counters can be observed in figure 3(a). Substituting the counter value for the average heart rate being used we can produce the same graph but in relationship to real heart rate values, figure 3(b).

The size of the windows of data is important as it influences the number of detections. Big windows detect less changes while smaller windows detect more changes. Moreover, it is also observed that the bigger the window of data the more stable change detections are. Table 3 demonstrates the number of detections using different windows of data for different attributes monitored in the environment.



(a) Heart Rate vs Change Counter



(b) Heart Rate Average Detection over Different Windows of Data

Fig. 3: Heart Rate Monitoring and Assessment

Table 3: Number of change detection by windows size and attribute

Size of Window	Heart Rate	Temperature	Luminosity	Humidity
3	41	306	104	281
10	22	79	49	77
20	15	36	24	36

4.3 Predicting Stress through Environment and People Attributes

A person's heart rate is influenced by a number of factors such as emotional state, stress or physical activity. In the study presented, evidence suggests that environmental variables affect heart rate. Comfort values for attributes such as temperature, luminosity or humidity affect the heart rate of people inside an environment. Furthermore, it is possible to link changes in temperature, luminosity and humidity with changes in people's heart rate thus validating the use of comfort values for human well being and stress reduction.

Using datasets created using the attributes monitored from the environment and change markers derived from the attribute change detection algorithm it is possible to train predictive classifiers to predict according to current environment condition how people heart rate will respond. For instance using classifier algorithm from the Weka workbench [13] it is possible to assess with relative precision whether the average heart rate will increase, decrease or maintain. Aside the use of a counter variable to the balance between changes, indicator marking the moment an increase and decrease on the average of each attribute, temperature, humidity luminosity and heart rate as well as the 1 heart rate value. With the dataset generated, some experiments were used on machine learning algorithms, namely the Naive Bayes and J48 algorithms to predict the increases and decreases in heart rate average using. The first algorithm is probabilistic and it builds conditional probability structure to classify instances of data. On the other hand, the J48 is an implementation of the C4.5 decision tree algorithm which uses an decision tree to classify instances. Both algorithm provide an internal structure that is understandable an may be used to see how changes in attribute values change the output attribute.

Table 4: Heart rate change prediction from environment attributes

Data window	Algorithm	Correct	Correct Up	Correct No Change	Correct Down
3	Naives Bayes	88.7%	0%	100%	0%
3	J48	88.5%	0%	99.7%	0%
10	Naives Bayes	63.25%	0%	77.5%	36.3%
10	J48	72.5%	0%	100%	0%
20	Naives Bayes	62.2%	37.5	77.2%	37.5%
20	J48	70.3%	57.1%	86.3%	37.5%

Table 4 demonstrates the results from a cross-validation test on the trained classifiers. It is possible to observe that dataset with lower values for the window of data yield poor predictive values, however the larger the windows the better the predictive ability. These results indicate that a there may exist a balance between the number of detected changes and the predictability of the heart rate changes. Smaller windows identify more changes but are not easy to predict, larger windows give fewer change detentions but improve predictive tasks.

4.4 Analysis

Analysing the results presented, it is possible to correlate heart rate of people with environment conditions, as non-comfortable conditions result in higher heart rate suggesting discomfort to the user. The window analysis used with tests with statistical significance has shown to identify changes in the heart rate condition of people. However, the results also evidence that there are some balances that must taken into consideration when building systems for monitoring and identification of stress induced by the environment. Smaller windows of data result in less stable analysis with more change identifications and less predictive accuracy in the algorithms tests. Nevertheless, bigger windows of data decrease change identifications and increase predictive accuracy. This balance between the size of the window of data, number of change identifications and predictive accuracy determines the overall sensitivity and predictive accuracy of the system. Computational analysis show that it is possible for the sensor node inside the sensor network to handle the workload from detecting change in attribute averages and performing predictions using trained classifiers. However, the initial classifier training should be handled by a central server with more computational power as it perform intensive computational operations.

5 Conclusion and future work

In this paper, it is presented a study that correlates thermal comfort to environment induced stress through the use of ambient intelligence techniques and sensor networks. Results show promise on the identification of stressful situations as well as stress inference through the use of predictive algorithms. Though for predictive tasks and hypothesis making it is needed a learning phase for each person while stress identification can be made in real time without a learning context as it can be inferred by the context provided by other sensors. Future work should extend the capabilities of the purposed algorithms o take into consideration, user activities, emotion detection and emotion on stress assessment. From the literature, it said to be possible to distinguish emotion through temperature and pulse sensors.

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2.3.3 Mood Estimation from the Smart TEstbed of Wireless Sensor Networks

The approach described in the paper *Experimental Study of the Stress Level at the Workplace using a Smart TEstbed of Wireless Sensor Networks and Ambient Intelligence Techniques* presented in 2.3.2 is complemented by work on mood simulation, implemented as a module for estimating user comfort based on the estimation of mood, according to the perceived environmental attributes.

2.3.3.1 Environment Assessment

From the literature, there are a number of attributes that can be monitored through the use of sensor platforms. There are ergonomics, medical and comfort values that can be used together with sensor data to infer useful information and produce knowledge about an environment. On table 2.1 are represented the medical and structural values for humidity, CO, CO_2, and dust within buildings for acceptable human work conditions. Values outside the ranges presented are responsible for stress, mood alteration and health risks to people.

Table 2.1: Variable correlation

Confort Variable	Lower Limit	Upper Limit
Humidity	20%	60%
Temperature	18°C	25°C
Luminosity	50lux	107527lux
Dust	$0\mu g/m^3$	$50\mu g/m^3$
CO	0ppm	35ppm
CO_2	0ppm	600ppm

Likewise, it is possible to infer a range of ideal values for attributes which while not being directly responsible for health risks, may increase stress on people. The range of values presented considers an ergonomic analysis of desirable conditions for people, and values outside this range may also result in stress condition on average people.

Using data from sensor networks and sensor platforms it is possible to use sensor fusion to produce data and information with higher quality and more contextualized to the environment variables. Table 2.2 demonstrates the use of information about the activity of people inside a building or environment and the values for luminosity that are deemed acceptable. Energy efficiency projects could take this information into account to regulate artificial luminosity inside buildings while avoiding inflicting stress on people due to poor lighting.

The use of different data from different sensors enables the application of sensor fusion projects empowered by sensor networks and sensor platforms that produce information contextualized to the environment and the people on it. Generally, the information analysed may also present higher quality in terms of interpretation and application.

Taking into consideration the values obtained from the sensor network presented in 2.3.2, it is possible to assess them using the reference values presented.

Table 2.2: Luminosity required according to task

Task	Optimal Values (lux)
Public Areas	$[20, 50]$
Short Visit	$[50, 100]$
Working areas with few visual tasks	$[100, 150]$
Warehouses, Homes, Theaters, Archives	150
Easy Office Work	250
Normal Office, Study Library, Laboratory	500
Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Normal Detailed Work	1000
Detailed Drawing Work, Detailed Work	$[1500, 2000]$
Prolonged tasks and exacting visual tasks	$[2000, 20000]$

2.3.3.2 Mood Assessment

People's mood is a subjective concept which should take in consideration complex information people's beliefs and routines, what is familiar to them, external conditions and also their inherent personality. In order to perform this work, mood assessment is based on the evaluation of a person's personality and current environment conditions and the assumption that ergonomic studies are well accepted. With such information it is possible to map optimal to suboptimal configurations as well as infer which emotions these environment conditions produce on human beings.

In a computational system it is still a challenging process to acquire rich information in this domain, but there are some approaches proposed in the research community which had broad acceptance. In regard to the representation of a personality, this work uses an OCEAN structure [45] similar to the approach adopted by the ALMA framework, to represent the personality of people and initiate mood states. In this theory, personality is defined by a set of variables, as in 2.1.

$$\begin{aligned} &personality(o, c, e, a, n) \\ &let\ o, c, e, a, n \in [-1, 1] \end{aligned} \tag{2.1}$$

This o, c, e, a, n variables represent five personality traits meaning Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism respectively. The process of acquiring the personality from real people is made through their answers to questionnaires used by psychologists in psychological studies. For instance, in this particular case, it was used the summarized version of the Newcastle Personality Assessor (NPA) as a reference questionnaire [101]. Contrary to the personality which is almost regarded as static during people lifetime, mood is a temporal state of the human mind and can last for minutes, hours or even days. It is seen as medium-term emotion. Personality also influences mood, therefore the personality attribution on agents has a key role over other human individual features. Moreover, with personality traits defined, initial mood assessments can be made considering the predominant mood state for each personality, as well as take individual personality parameters into consideration for mood updates over time for each person.

The mood recognition module is responsible for assessing the current mood state of each person using their personality structure and the perception of environmental variables such as sound, temperature and luminosity. Mood representation was based on the PAD space computationally designed by Gehbard in his work ALMA [45]. A person's mood is represented using the three variables that define PAD space, P, A and D for actual pleasure, arousal and dominance respectively. These variables are in the interval $[-1, 1]$ to create the representation of the eight moods that are possible: hostile, exuberant, disdainful, docile, bored, anxious, dependent and relaxed. Other variables included on mood are the $emotionalWeight$ to represent the weight of the emotions related with each personality and $const$ which represents the velocity of the mood update.

All people are different and like the literature suggests, people with high trend of neuroticism (n) have more probability to be negative emotionally i.e. they have predisposition to feel emotions like hate, anger or distress more often than people with low score of this trend. In other hand extraversion (e) awakens in people, more often, feelings more positives like joy, love and gratitude. As a consequence, the weight calculation is made by knowing the signal of emotion, if it is positive then $emotionalWeight = (e + 1.0) * const$ else $emotionalWeight = (n + 1.0) * const$. This variable is in the range $[0, 2]$ turning $emotionalWeight$ positive to facilitate future calculations. The constant $const$ may be used to reduce or increase the velocity when mood is crossing from state to state. In the context of this work, the value used was 0.1. One of Mood's parametrized constructors receives as parameters personality's values o, c, e, a, n. To initiate mood in relation to personality in the PAD space an weighted reference was used as in equation 2.2.

$$\begin{aligned} &P = 0.59a + 0.19n + 0,21e; \\ &A = -0.59n + 0.30a + 0,15o; \\ &D = 0.60e - 0.32a + 0.25o + 0.17c; \\ &let \quad o, c, e, a, \in [-1, 1] \end{aligned} \tag{2.2}$$

This creates an initial mood state different from agent to agent, giving them a mood foundation that allows agents to deal with different emotion types during life time. These variables represent the mood state relating it with emotions triggered by events. The events are triggered by the current environment's sound, luminosity and temperature conditions for which it is calculated the final mood. This final mood state is the predicted value for the exposure of people to those environment conditions after an infinite amount of time. The transition between mood states is assessed by applying an increment in the mood variables in the order and direction of the predicted final mood state after an event is triggered. To calculate the displacement vector for each portion of time is used an expression that makes the update of the current value with the displacement times the weight of emotion such as in 2.3

$$\begin{aligned} \overrightarrow{M_{actual}M_{final}} &= M_{final} - M_{actual} \\ M_{actual} &= M_{actual} + \overrightarrow{M_{actual}M_{final}} * emotionalWeight \end{aligned} \tag{2.3}$$

The vector $\overrightarrow{M_{actual}M_{final}}$ is divided in small pieces that are relative to $emotionalWeight$ and this causes mood state moves more or less slowly, depending on each person's personality, over the time, thus preventing the instant passage from one state to another which does not happen in real life. Emotions are mapped in the PAD space using the OCC model [43] for emotion representation and ergonomic studies on the effect of the state temperature, luminosity and sound in emotion states [102]. From these studies and the current assessment of environment state, a final mood state can be calculated mapping the emotion derived and the current mood state using the PAD space and equation 2.3. The equation assures that the mood state does not react instantly to new emotions but it is gradually affected by them.

The mood evaluation is made taking in consideration each individual studies in the literature about each component of the environment being sensed. Each individual assessment is in the end fused together using an weighted average according to the importance of the attribute in relationship to the others. The fusion chain used for this work is depicted in figure 2.1.

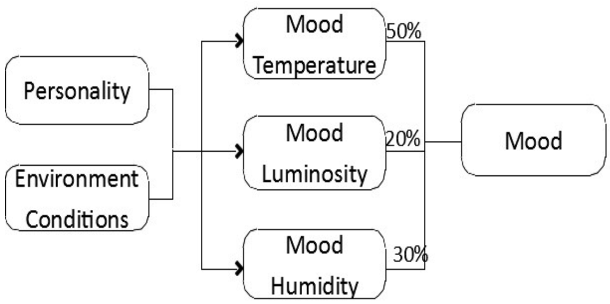


Figure 2.1: Fusion of Mood States from Environment Conditions

2.3.3.3 Comfort Assessment

Following the updates from every sensor present in the environment and in individual people, it is possible to constantly monitor and assess the well-being and comfort state. The analysis is made using 3 components for evaluation: environment, physical perception and emotional attributes.

Environment uses as reference ergonomic values of comfort for each sensor value, such as the values presented in sub-section 2.3.3.1. Physical indexes are related with each person, it is considered health values for the heart rate sensor and the physical perception of temperature (an analysis that includes the physical activity and clothing factors). Emotional response, is based on some model of emotions, OCC and PAD space, section 2.3.3.2, and is solely derived from the documented emotions certain conditions predispose on people. It is not a full emotional recognition, as it does not yet include other variables, but it is possible to get an idea of the emotion the environment conditions inflicts on people. The representation is inspired by a semaphore:

- green when all 3 components are satisfied;

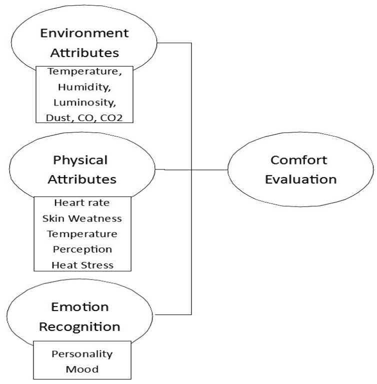


Figure 2.2: Comfort categories being addressed.

- yellow when 1 of the 3 is not satisfied;
- orange when 2 of the 3 are not satisfied;
- red when none is satisfied.

Although the analysis consider only a subset of possible interest attributes, it represents the strategy implemented in this work to use such information. More sensors and indexes can be added in order to generate a richer analysis considering even specifics of each environment and people.

2.3.3.4 Experiment Scenario

The usage of the test environment is done through the daily routines of its inhabitants. Traditionally, it is referenced as an office where workers work 7:30 to 18:30, in an acclimatized environment filled with sensors in every room of the first flour. In terms of individual people assessment, it was represented a typical person with a typical clothing factor of engaged in office activity. Physical attributes were assessed through wearable sensors of test subjects that volunteered for this experiment.

In order to carry out the experiment, the assessment was made monitoring each category of comfort enumerated: environment, physical and emotional during the period of work at the Albacete Research Institute of Informatics (I3A)[1]. This experiment used as an example a reference person for clothing indexes, personality considerations and metabolic energy spent through its daily activities. With this approach, using the comfort algorithm we can easily assess a degree of comfort for each room. Although the sensor list is not very diversified in terms of sensor types, it covers the building extensively.

In figure 2.3, two snapshoots were taken in the system where the classification of each room demonstrated through a multi-color semaphore indicator. It is possible to see that some rooms do not fulfil the complete set of conditions for comfort, but its explanation might be

[1]The Albacete Research Institute of Informatics (I3A) is located at the Universidad de Castilla La Mancha. This is institute welcome these experiments from January to April of 2013 and it is where the main laboratory where experiments were based. `http://www.i3a.uclm.es/site/`

quite diverse. For one, the acclimated environment can be slightly misprogramed and thus the temperature is not always within the range acceptable. The low luminosity values in rooms do not comply with comfort, might indicate that the current rooms are not being currently occupied. These analysis take an impact in the assessment of the environment, but it is their durations and severity that might affect the other two categories: physical perception and mood state.

(a) Assessment at 8:00 (b) Assessment at 18:00

Figure 2.3: Comfort assessment in the test case scenario

Table 2.3, consideration about the time each room remained comfortable are store. In this view it can be seen the percentage of time each positive state lasted.

After analysing the results it becomes clear that the physical perception and environment sensing are different, as with adequate clothing it can be more forgiving than the basic ergonomic analysis. Such results demonstrate even in an unoptimized environment it is still possible to have some degree of comfort. Also, the analysis varies through the day, demonstrating the benefit of a sensor testbed to quickly detect unoptimised configurations or situations. A careful analysis of the data produced by the sensor network indicate that there are points of concern considering excessive or extreme temperatures being registered, which are demonstrated to be constant and affect the mood state of people. Moreover, The configuration of environment conditions is sometimes perceived discomfortable by the predicted mean vote (PMV) index.

2.4 Analysis of Experiments

As part of the research plan and the investigation methodology of choice, this chapter portraits initial experiments that make foundations for the elaboration of archetypes to answer

Table 2.3: Room average

Room	Comfort Environment	Comfort Physical	Comfort Emotional
1	28%	29%	100%
2	17%	57%	83%
3	36%	46%	100%
4	17%	100%	76%
5	16%	65%	63%
6	0%	51%	100%
7	24%	86%	94%
8	0%	27%	100%
9	33%	0%	100%
10	16%	52%	92%
11	28%	100%	53%
12	17%	93%	56%
13	0%	26%	28%
14	16%	99%	62%
15	0%	100%	5%
16	3%	100%	20%
17	22%	44%	100%
18	32%	11%	100%
19	3%	100%	29%
20	0%	0%	16%

both the research hypothesis and research questions.

The experiments detailed in this chapter demonstrate the use of sustainable indicators as a means to assess sustainability in intelligent environments. They were conducted in different phases of the research plan but they demonstrate with use of proof of concept, laboratory experiments and computer simulation applied to applications of sustainable indicators with sensory networks and ubiquitous computing.

In the case of the article, *Information Fusion for Context Awareness in Intelligent Environments*, sub-section 2.1.2 research to ease the sensory process and, as consequence, diminish the energy demand for sensory networks. Results indicate that it is possible to achieve positive outcomes using dynamic sensorization which relies on machine learning to estimate sensor values when they are behaving as the model expects.

The demonstration of these examples, helped shape the definition of the PHESS platform towards the application of the methodologies experimented, from the definition of indicators to the establishment of sensorization strategies.

User awareness plays an important role when behavioural modification is intended. From the studies presented in the field of energy efficiency, user awareness influences the adoption and following suggestions towards efficient practices.

The construction of profiles, gamification elements and suggestion models is explored both individually, user by user and as a community of users which interact with each other. The research conducted incorporates proof of concept applications and laboratory experiments to test workflows and suggestion at both user and community levels. In the article *Social Networks Gamification for Sustainability Recommendation Systems*, in sub-section **??**, a community system is supported by a suggestion mechanism that fuels competition between users dividing then into clusters so suggestions can be more effective. The article *Context-Aware Well-Being Assessment in Intelligent Environments*, in sub-section 2.2.2, evidences the use of user awareness and contextual information to classify profiles of users and environments according to well-being assessment. It is based on indicators, but provides a contextual aware feedback by user and environment.

From the paper presented in sub-section 2.3.2, affective computing and comfort assessment were introduced to further develop the strategy of studying the effects of environmental parameters in user reactions. In this article, an experiment to estimate stress is demonstrated by determining elevated pulse with environmental attributes. In the sub-section 2.3.3, the stress takes the shape of positive and negative mood states which were implemented with the help of affective computing frameworks to estimate user mood.

In the article *Ubiquitous Sensorization for Multimodal Assessment of Driving Patterns*, in sub-section 2.3.1, positive and negative mood states are assessed with the interpretation of driving indicators such the number of accelerating and decelerating events.

These experiments complement each other, the first identifies instant stress while the second perceives comfortable environments. In the other experiment positive and negative mood states are assessed with the interpretation of driving indicators such the number of accelerating and decelerating events.

A common link from these studies is the use of sensory networks, data fusion and machine learning algorithms to estimate the response of users to environment. These assessments can be used as a social indicator for sustainable assessment in the field of computational sustainability. The application of affective computing in computational sustainability is a relevant contribute towards this doctoral plan.

These experiments implemented proof of concept research which the People Help Energy Savings and Sustainability (PHESS) platform embodied. The use of this strategy to estimate the affective reaction of the user according to the environment configurations is a dynamic assessment, that can be adapted to each person and environment according to expert rules and initial input.

Results obtained from these experiments were compiled, deliberated and integrated into the PHESS platform. With the goal to support and to promote sustainability and sustainable behaviours in intelligent environments the PHESS archetype platform was designed taking into account these experiments.

Chapter 3

Design and Implementation

3.1 People Help Energy Savings and Sustainability

The PHESS archetype platform is designed to make use of computational sustainability in computer applications. Its application goes further than just a workflow, it details an archetype process for data acquisition, data fusion, modelling and reasoning. Automated tasks are assured by a multi-agent design at the core of the development server. Assessments are based on the definition of indicators developed according to each case scenario. The art of indicator definition is used according to developer specification, but examples provided already layout the foundation for its use. It is of some importance to refer that indicators by nature are either specific to the field of application or generic and thus can be used in many implementations. Though its usefulness can be argued and may demonstrate advantages and disadvantages on both sides. Behavioural change is promoted by user-awareness, user-profiling and gamification which are based on the indicators defined. The structure of this platform is generic and can be applied to complex structures allowing intensive customization for specific applications.

As this system is aimed to intelligent environments, machine learning models are part of the core modules of the archetype. Its development promotes workflows to interpret and modify data according to the algorithmic needs. These processes run as back processing jobs and not directly controlled by users. Rather, they are used to obtain information about environments, user routines or specified by the other objectives.

This archetype is also an open platform, therefore, it can grant access to data, models and indicators to external applications provided that they are authorized to do that. This enables and complements the modular structure of the archetype enabling more customization by the user who wishes to implement the archetype or simply connect to an existing implementation. Communications are processed either directly to the multi-agent system or in alternative through a gateway of restful webservices. The application of the archetype may also be used both in closed or open environments such as cities. The structure of indicators and the organization of user and environment sensors only needs to be re-arranged to each scenario.

The characterization of the overall architecture, main modules and applications of this archetype are described in the following sections. The modules are divided into essential modules to ensure communication, data acquisition and persistence, modelling data, notification of users, and add-on modules which can be used with the platform to provide external features such as gamification platforms and mood assessment.

In the end of this chapter, the deployments of the archetype and the research conducted are presented in the form of scientific publications.

3.1.1 Architecture Overview

The experiments explained in chapter 2 resulted in the proposal of a platform archetype embodied by the PHESS platform. The intention is to combine structures from computational sustainability, modelling and information fusion, implementations of user awareness and behavioural modification such as gamification in an archetype platform intended to foster the development of such applications.

In order to support an iterative development, the archetype platform was organized into modules. The core archetype platform modules create the multi-agent system, mediate communications and permissions of core elements. Other modules can be used independently or with a dependence list. This development applies known engineering methods to organise and integrate different developments into a platform. The initial process began with the setup of a multi-agent system that would be able to use data and information about an environment to make decisions in order to improve its efficiency [103]. This leads to the creation and monitoring of different indicators, assessing not only efficiency but also well-being [104]. The requirements grew as experiments and new research was conducted. From the experience acquired, a physical representation of the structures required for archetype were compiled.

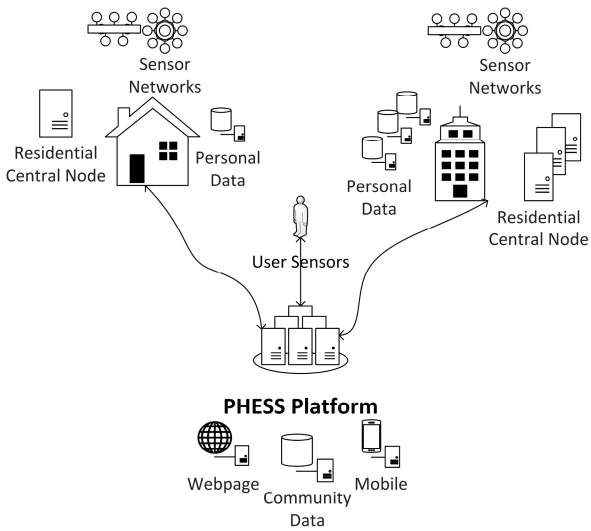


Figure 3.1: PHESS hardware archetype

Figure 3.1, illustrates PHESS psychical archetype representation. It is intended to be a decentralized sensor network with a central data analysis platform. Each location contributes with raw data that is then used by the central system to deliver solutions as a service to each local installation. The core modules handle the data communication between endpoints and the central system. The development modules are deployed in the central unit and used as a service with authorization and authentication management systems.

Local endpoints are used for data collection, and they manage data acquisition and requisition from the central platform. This is handled by software agents which autonomously handle the communication. A choice of implementation makes use of either dedicated APIs or restful webservices which translate information to the same agents.

At the central endpoint resides server instances which are responsible for storing user and environment information, and it is where dedicated agents model and maintain sustainable indicators, machine learning models and apply data fusion techniques. The agents present on the platform are divided into classes which separate their function in the archetype platform. However, users can communicate with each other through publish and subscribe strategies based on location, function or custom declaration of services. Modules may be allowed to publish software agents in the multi-agent system to handle the interaction of the core services and other modules. Alternatively, information may be brokered by webservices, in which case access is more restricted and the isolation of the module from the core system increases.

3.1.2 Core Services

Core PHESS modules include the multi-agent system, as stated in figure 3.2, to support the agent based implementation and management of different resources. Additionally, there are webservers designed to complement communication between the multi-agent system and external applications, act as a front-end application for the information processed by the system and enable the development of web based applications that make use of the services in this archetype [105].

As a core module, sensor fusion is used not only to improve environment sensorization but also to save storage space. Hybrid techniques can be used which, although not being a lossless process, models the environment with enough accuracy to explain the behaviour of attributes, such as explained in 2.1.2 and in [103].

Communication protocols are developed by establishing a multi-agent system inside the core platform. This eases the process of building specific ontologies that can be used in message exchange communication. In this way, local end-nodes can authenticate to the central system and send sensor data in the form of agent communication with dedicated ontologies or through dedicated webservices. In listing 3.1 a specification for the registry of a sensor from a end-node in the platform is provided as a sample.

In an agent information exchange, they must share the same language and vocabulary, besides the ones available by following the FIPA (Foundation of Intelligent Physical Agents) standards such as the communicative acts. Because of this, it was defined a vocabulary and language, in terms of an ontology, for the message contents exchanged between our agents.

Data representation and display is another core module to enable rapid development of monitoring centric applications. With ease, it is possible to setup and view live and historic data extracted from an environment or its users [106]. The visualization is supported by a simple web application that prototypes user and environment sensors and their records. Customization of the interface is possible through redesign, and external implementations of visualization are also supported.

In the following sub-sections it is presented the structure and functionalities of the multi-agent system and, in sequence, an explanation of data storage and indicator design inside the platform.

Listing 3.1: Webservice for service registration

```
registerSensor
Method: POST
User scope: USER
http://islab.di.uminho.pt:10001/PHESS/rest/api/registerSensor

Content: {
user:example@example.ex,
sensor:{
nome: sensor1 ,
strategy: monitor,
refreshRate: 1min,
sensing: noise
}

Response: {
user:'example@example.ex',
sensor_id:'1'
}
```

3.1.2.1 Multi-Agent System and Communication

The Multi-Agent System (MAS) here proposed is composed by agents to sense, reason and act upon an environment. The MAS is designed to calculate and favour sustainability parameters through indicators. For such, the MAS is composed of four different types of agents:

- Model Agents, which model variables and assist the reasoning agent in the platform;
- Sensing Agents, responsible for obtaining information from sensors or passing actions to actuators;
- Reason Agent, based on the data from sensing agents and model these agents plan actions in the intelligent system to assure their objectives;
- Acting Agents, which perform changes through actuators in the environment.

A sensing agent is responsible for gathering information about the sensor present in the environment. This agent is responsible for controlling one or a set of sensors and retrieve information when necessary from them. Its behaviour is cyclic and waits for data created in the sensors. It can operate on two different modes:

- Periodically - the sensing agent has the ability to periodically monitor the values returned by a sensor, for instance temperature, light and electric current sensors;
- React to events – the sensor agent reacts to events generated by a sensor, for instance the detection of movement or the detection of an RFID tag.

These two behaviours offer different sample periods which are necessary to gather data about an environment. In terms of agent organization, the use of a multi-agent system allows the possibility to arrange sensing agents in different formats to provide data to model agents. As so, sensing agents are able to control one or more physical sensors at a time and can even arrange themselves in a federal organization where there is a sensing agent which acts as a facilitator, gathering the data from other sensing agents.

The model agent is the one responsible for controlling the variables being modelled in the environment and ensure that the values retrieved from such models are in accordance with the current context information gathered by the sensing agents or by physics rules. The model agent can actually possess a model defined just by physic rules like to model the movement of the sun in relationship to a location on Earth or the physical environment being modelled. One objective for this agent is to provide means to estimate and predict future behaviour of the object being modelled so the reason agent is able to predict the influence of its choices in each individual model and assess its global impacts. Other approach to model agents is to use them to maintain and store indicator data in the PHESS platform. In the following list there are some representations of the models which these agents may maintain:

- User Occupancy – expect user occupancy of the environment;
- Expected Energy generation – expected energy generation for the time period;
- Expected Energy consumption – expected energy consumption for the time period;
- Lighting Model – lighting needs of the environment according to user preferences;
- Temperature Model – temperature model to control HVAC systems;
- Driving Acceleration and Deceleration - model to predict acceleration and deceleration from user driving.

The approaches stated will be used to automatically build models in the multi-agent system. Error and accuracy rates should be assessed before launching these approaches in real model agents in the system. However, the model agent will keep track of its performance by continuously analysing its prediction against real data when it becomes available to him. This way, if the accuracy rate of the model drops or is consistently low, the agent removes itself from communication with the reason agent.

The reasoning agent is responsible for designing, informing and implementing changes in the environment so that it becomes more efficient. An example approach would be to reason about alternative solutions in the environment considering the use of case based reasoning. In this approach, we may consider energy efficiency a target, and current models and environment specifications are compared to other known implementation and solutions in order to quickly assess optimized solutions for the environment. The static components in the environment can be quickly assessed such as appliances, light bulbs and other relevant energy consuming devices in order of efficiency and if changing them is beneficial to the overall process of energy optimization [107].

Other reason agent may be added to the platform through add-on modules, such as a notification manager for user awareness, gamification manager or affective control of the environment. These agents can be integrated as the modules are installed or reside inside the modules.

The final step of action of agents is to use the newly calculated situations and use actuator agents to enforce the new plan or, when such is not possible, send a report to the user so he becomes aware of efficient changes in the environment without affecting its interaction with the environment.

The acting agent uses the information created by the reasoning agent to perform actions on the environment. In order to perform such actions the acting agent must be connected to an appropriate actuator, this means, one that is able to perform one or some of the desired actions. When such interaction is not possible, the user is notified making him conscious of alternatives.

These agents are defined in the archetype as template agents which may be extended to account for each project specificity. In this order, initial communication primitives, services and ontologies are already defined to allow rapid development of computational sustainability projects. The template also provides means to export sample libraries and also, agents can be exported from different implementations provided they are useful. This is particularly useful for sensor data acquisition which means that a sensor can be managed by an agent that acts as middleware.

In figure 3.2 a conceptualization of the multi-agent system elaborated for this archetype is illustrated, where it is possible to see the structure of the system and the flow of information.

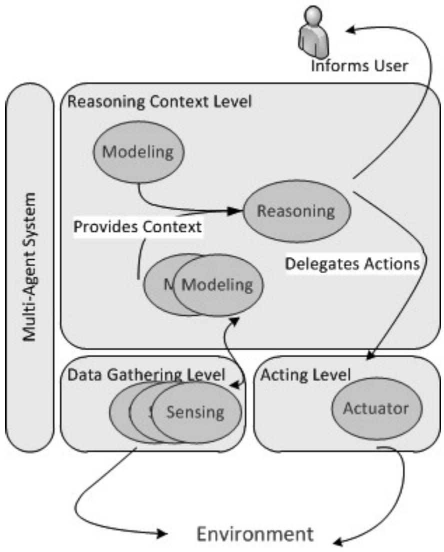


Figure 3.2: PHESS multi-agent system archetype

3.1.2.2 Indicator Analysis

Indicator based analysis in founded on the definition of model agents with the implementation of indicators definition, such as data needed and its calculation. Based on the location of sensors, indicators may be managed globally, with aggregating values according to rules defined for each sensor, or specialising in portions of the environment or users. Information fusion can be used to manage accountability for indicator values associating user to indicator values for later use.

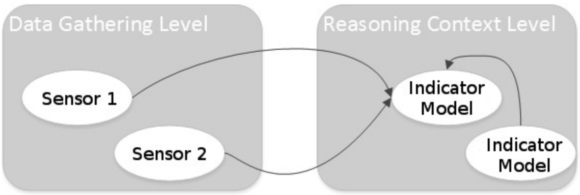


Figure 3.3: Sample workflow for indicator management.

In figure 3.3 a sample flow of data can be seen inside the PHESS multi-agent system. These samples demonstrate that indicators can access information present in other agents. Moreover, it is also possible to assess content in external services from other applications through internet communication and the databases on the PHESS archetype.

For the application of the archetype to home environments in [107], a database was built as illustrated in figure 3.4. For convenience in this sample, indicators were calculated and then categorised as a positive or a negative impact which was stored in a database to create a history of values.

Indicators can be based on expert knowledge and may have different categories and span across multiple dimensions of sustainability. However, they are a valuable source of information towards sustainability parametrization and optimization. Realizations of indicator definitions are added to the systems through extensions and new modules for the archetype. This design allows the use of the indicators and re-use indicators between implementation which increase the development of solutions.

3.1.3 Additional Services

Besides the core modules, the PHESS platform includes other complementary modules, such as gamification [107], mood estimation [108] [109], cost-benefit analysis, optimization tasks and scenario simulation [110]. Although sharing the same core modules, these complementary modules are designed to be independent of each other to make it possible to run all of the modules at the same time or a subset of them, without compromising the platform.

3.1.3.1 Simulation Environment

A simulation environment makes use of known information to build and test hypothesis over controllable actuator in the environment. Actuators are interpreted as devices that can alter environment attributes or influence behaviours. Communication protocols are used to transmit the solutions found into the actuators inside the PHESS archetype.

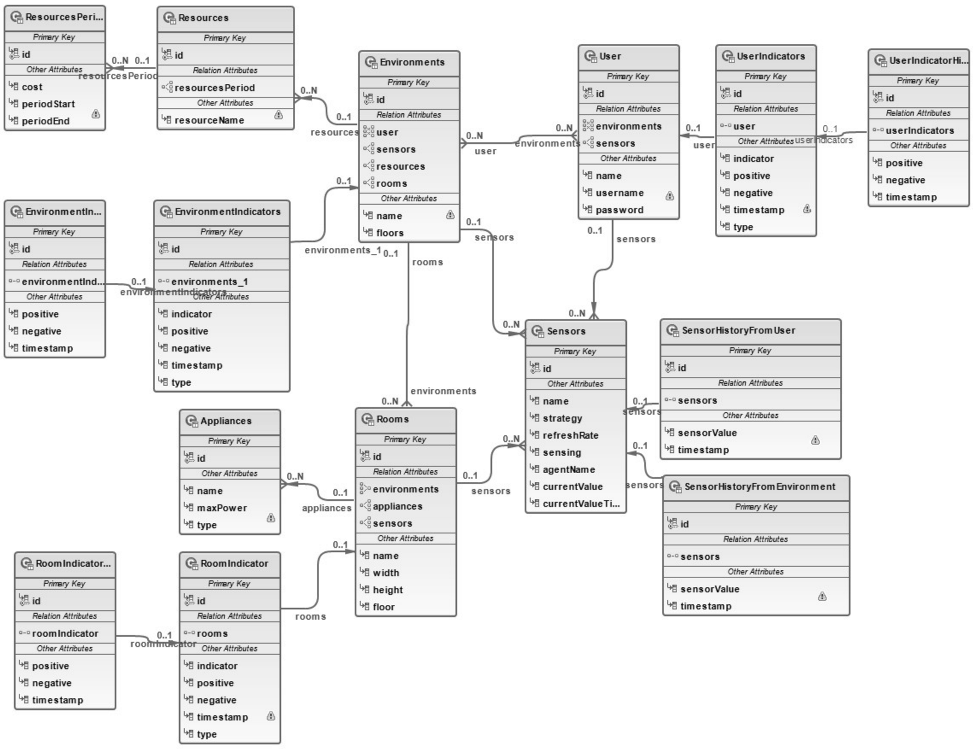


Figure 3.4: PHESS basic database diagram

The simulation environment uses two fundamental concepts that interact with each other independently. One is the environment configuration with a description of the physical environment and the contracted energy sources, appliances and activities. The second is the users and their behaviours. They interact with each other running user behaviours inside the environment. The simulation follows the KISS principle (Keep It Simple and Stupid) which only records the outcome of each interaction without further deliberation.

Associated to each environment, there are attributes such as temperature, luminosity, sound and humidity that are controlled with models in the model database. These models are built from live systems under expert rules to connect models from one to another.

The simulation environment is able to reproduce past conditions through models with accuracy, this means that the results from simulations can be achieved using the models obtained in live environments. Due to the use of learning models the relationship between models and reality can be interpreted as equation 3.1, the representation is not 100% identical to the actual sensor values but significant with good results if well prepared.

$$Reality \quad = \quad Model - Error \tag{3.1}$$

This environment acts as a testbed for improvements proposed both on user behaviours or environment configuration. Solutions found are then disseminated across their users and are used for other environments.

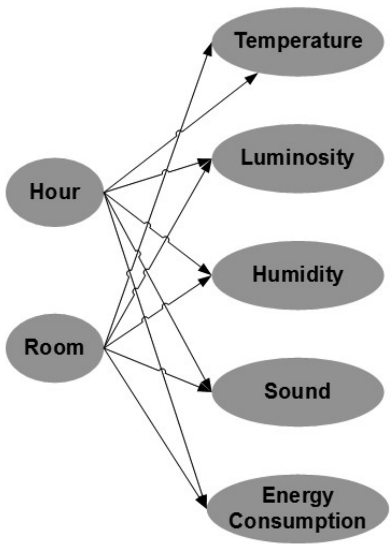
A comparison between simulation results and real results was made to verify and prove that this technique is feasible with satisfactory results. Furthermore, it can be said that the models adapt to reality and, although lacking responsiveness to real world results, they can deliberately predict long term behaviour.

3.1.3.2 Database for Machine Learning

One of the key contributes of machine learning is the ability to learn from past experience. Models are the result of the learning process and represent what was possible to learn from experience. It is an active research area, as better models that ease and improve the learning process are of key interest for this area. From the development of models it is possible to, not only reduce the number of data used to store past events, but also recreate conditions through simulation. Of course, the quality of these models is a key question which needs to be addressed and constantly monitored.

The approach taken on the use of models considers different approaches. The use of machine learning is justified to obtain complex models that relate user behaviour, environment attributes and interaction between environment attributes. Figure 3.5a illustrates a Naive Bayes model for continuous well-behaved environment attributes. Increasing the number of such attributes leads to a bigger probabilistic network that can be used to derive environment context during simulation tasks.

The second approach uses known mathematical formulae to model attributes such as appliance consumption for example. This latter category is usually used directly in the simulation environment as it has a static definition. Our model database includes mathematical formulae that simulates appliance consumption based on their specification, and user behaviour based on the history of past evidences.



(a) Environment Model


```
"Name":"0107ee7ec1",
"Actions":[
  {  "Action":"Move",
     "Contexts":[ "ISLAB" ],
     "Date":1334584662081,
     "Duration":5,
     "Event Occurred":"False"
  },
  {  "Action":"On",
     "Contexts":[ "Light" ],
     "Date":1334584662800,
     "Duration":5,
     "Event Occurred":False
  },
  {  "Action":"On",
     "Contexts":[ "Computer2" ],
     "Date":1334584662900,
     "Duration":5,
     "Event Occurred":False
  },
  ...
```


(b) User Model

Figure 3.5: Models from environment sensorization

The models presented are a representation of the resulting models produced by the PHESS system. First is the categorization of attributes and the selection of learning algorithms. For convenience, in this example, the weka toolkit was used which has a number of learning algorithm which can be exported. In well-behaved attributes such as continuous attributes, it is possible to achieve a low error rate when compared with the actual data. Figure 3.5b represents a custom use of learning algorithms which record user movement inside an intelligent system, in this scenario an office room.

The models presented are only examples, as the PHESS allows the rapid acquisition and processing of data. Machine learning itself relies on external libraries to execute learning algorithms.

3.1.3.3 Cost-Benefit Analysis

Analysis of cost-benefit is done taking into consideration the comparison of different scenarios and choosing the better outcomes considering efficiency and personal preferences.

Management of temperature inside rooms through Heating, Ventilating, and Air Conditioning (HVAC) systems or manual interactions are common inside these projects. The approach is to have the system measure the cost of increasing and decreasing temperatures to meet defined budgets or user preferences. The analysis is based on the equations presented in 3.2 for the assessment of temperature modification.

$$Cost = BTU(temp_{actual}, temp_{desired}, air_{volume}) \quad (3.2)$$

For the cost-benefit to work, the optimized attribute is user comfort which implies a dedicated budget for HVAC control and the analysis of the comfort of users inside the environment. This is implemented through the predicted mean vote (PMV) indicator developed in [111]. Closely correlated with the temperature, this indicator gives important clues about user comfort and each decision for HVAC control should also satisfy such parameter.

Behaviour modification is based on the perception that there is better scheduling of tasks such as turning on lighting, adequate lighting for work conditions. Taking into consideration a list of activities such as equation 3.3, then it is possible to calculate the cost of each activity. In this setup, through a list of behaviours the cost is analysed based on the energy tariff. Two perspectives are used with regard to this, a reactive analysis and deliberative analysis. The first checks that the activity is on a high priced period, suggesting to wait for a better period, while the second calculates the alternative energy tariff available and their impact on cost saving scenarios. The first alternative, uses time-allocation to move behaviour upwards or downwards.

$$\begin{aligned} S &= \{s_1, s_2, s_3, ..., s_n\} \\ s_i &= \{comfortAssessment, energyConsumption\} \end{aligned} \quad (3.3)$$

From the cost of each behaviour it is possible to calculate its inherent energetic cost and impact. Alternatives are proposed based on the definition of cost and impact. This approach is used to derive unique simple variables that can rank different approaches and solutions. The objective is to build a set of possible solutions with the outcome already calculated to the user. Automatic intelligent procedures can act autonomously if given the necessary clearance from the user.

3.1.3.4 Gamification

Gamification was applied in the PHESS archetype as module applications which take information and use it in the representation of gamification. In this section, it will be shown how it was decided the application the knowledge acquired about gamification and what were the gamification elements and dynamics implemented.

However, before detailing, it is important to refer some considerations made, mostly due to the fact that this project tries to solve a problem for the greater good. This factor can have several impacts since the intention is to make people adopt sustainable behaviours but keep the intrinsic motivations. The following description will analyse, in detail, each gamification element or dynamic implemented.

Points The choice of starting with this Gamification element is also a way of explaining its importance. Points is one of the most common elements associated with Gamification and one of the most used, in fact, it is believed that they are so fundamental that they chosen as default to force the administrator to select it. This decision can be justified by the fact that the attribution of points is a clear and easy to understand way of rewarding a player, providing feedback, displaying progression and giving him a way of comparing himself to other players; additionally, some other elements and dynamics can make use of this element to improve the mechanics of the platform. Taking this into consideration, it was needed to develop easily configurable rules for players and environments to score points while also giving some complexity to these rules. As so, a rule which awards points is composed by a given action or indicator, a condition to be fulfilled, a number that determines how many times the rule must be fulfilled to be considered completed, an attribute to set the rule as hidden or visible, the number of points to be awarded when the rule is completed and the target of the rule, to whom this rule is applied. With this, it is the intention to diversify the way points are awarded, imbue the player with the necessity to keep improving and be able to provide rules to a specific entity, players or rooms or environments. The attribute hidden is, usually, appealing to the psychological aspect of a player since he cannot see the rules defined as hidden and if he completes them, the surprise of this event will act as a motivator.

Levels Levels are another common gamification element and frequently applied. It can also be called Status since both work in the same way, grouping players within the same tier. This element is important because it can set more reachable goals, determine the difficulty curve of the platform, provide a better sense of progression and set players in the same level according to their performance and distinguishing the ones who have a better performance. The increase of the points needed to a new level as the level becomes higher is a good example of these characteristics and are present in many games. Once again, it was provides the administrator with the possibility to set these rules accordingly to his intentions. These rules are composed by a name that identifies the level, a value representing the number of points needed to achieve the level and a target. In the specific case of the platform, if the levels element is active, it was opted to show a progress bar where the player can see the percentage of his current level that is completed and how much is missing until the next level, providing a goal and acknowledging what has been done until that moment.

Achievements The achievements element was introduced in order to allow the administrator of the platform to set specific tasks for the players, rooms or environments or they can be used as a way of defining global goals that he wants the environments as well as players to accomplish. For this element, there is no real reward when someone fulfils a rule; what the entity gets is the acknowledgement of a good work through the display of the achievement's name in the profile's page. In some specific cases, a star is used as a virtual representation of the difficulty of the achievement. The achievements can be viewed as challenges and are expected to work as a signal of importance and, for this reason, they are displayed in the profile's page of each player, room and environment. Another important way in which players can envisage achievements is as a collection since each achievement can only be completed once by a given player, motivating them to collect all the achievements. The rules regarding the achievements are the most complex when comparing to the rules for points and for levels. These rules are composed by an action, from the available "Indicator value", "Points Achieved" and "Feedback Provided", a title to identify the achievement, a condition to be fulfilled, a value to determine the number of times the rule must be fulfilled to be considered completed, an attribute to set the achievement as hidden or visible, a target to identify the entity to whom the rule is applied and, optionally, a badge which acts as a visual representation of the achievement. As it can be said above, badges have the sole purpose of providing a visual representation of an achievements' difficulty and a better acknowledgement of the players' good behaviour.

Leaderboards Even though leaderboards were implemented, this is a problematic element since it can motivate a player to be at the top of the leaderboard when he is nearly reaching it or, in the same way, can demotivate a player for being far away from the top. Despite this problem, leaderboards are a great way of giving feedback on the player status and his competition by comparison. After the study made to gamification and its elements, it was attempted to soften the problem, mentioned at the beginning, by showing a personalised leaderboard to each player where the position of the player is automatically shown with other four players with a close score. Obviously, the player can see the whole leaderboard if he wishes to do so but, this way, he can set his mind to outmatch the players who are closer and only worry about the players with top score later on.

Community Feedback The concept of community and feedback are related to the dynamics of gamification and it was decided to analyse them together because they are closely tied. One of the primary goals for this platform was to foster a good community since peer pressure can have a strong influence in the adoption of new behaviours and the social interaction is very important for players to keep using a determined platform. These reasons can have increased strength when applied on projects developed for the greater good. Besides, Gamification is not only applied by appealing to competition among players but also to cooperation and the platform inherently provides cooperation, between players, every time we refer to rooms or environments given the fact that these entities are always composed by a group of players and their score is dependent of this group's actions. When a good community has been promoted, players providing feedback is a dynamic that appears naturally. Reaching this state is the objective. However, in the beginning, it can be difficult for players to start giving feedback and, even if it is not the case, providing help should always be rewarded so the administrator is able to reward the good feedback by setting the action of a points' rule or achievements' rule to "Feedback Provided".

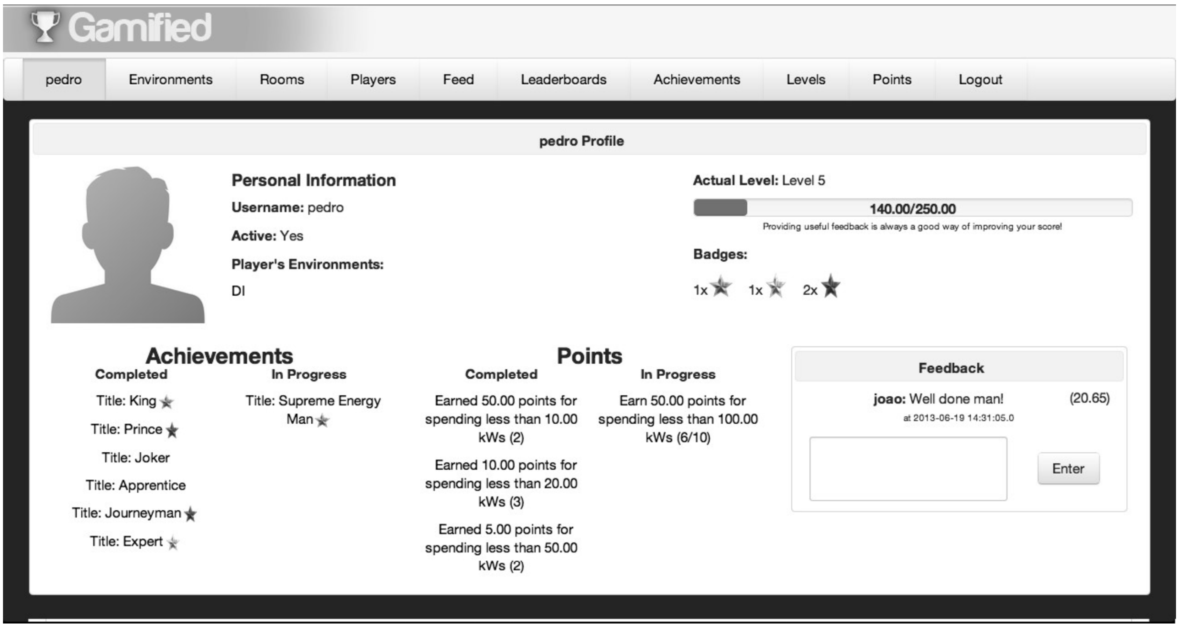


Figure 3.6: PHESS gamification application

The application of gamification was integrated in the realization of the PHESS archetype with the template provided. Nevertheless, gamification elements were applied to two implementations of the PHESS archetype, one for the home domain and the other for the promotion of sustainable driving[1]. In both cases, the gamification module is able to integrate each gamification element according to the indicators defined in each platform.

3.1.3.5 Affective Computing and Mood Estimation

The module to perform emotional simulation is launched on the multi-agent system of the PHESS archetype. The main agent (M) is a model type agent which implements with a psychological layer and a physical layer to determine what are the conditions to provoke an emotion change, for example, calculating if a physical condition such as temperature of the ambient is appropriated to a certain context.

[1]A live sample of the implementation of the PHESS archetype, in this case PHESS driving can be found in: `http://islab.di.uminho.pt:10001/Phess_Driving/faces/UserHome.xhtml`. This implementation does make use of the gamification elements for its work.

- Psychological Layer – composed by four independent pieces, the beliefs, desires and norms, responsible for choosing their knowledge about economic, environment and social, and the knowledge about the limitation of Agent. This layer will communicate with the emotional control component responsible to attribute an emotional state and update the agent.
- Physical Layer – responsible for controlling agent's physic limitation. It will communicate with psychological layer that will perceive if the physical limitations cause discomfort or an enjoyable state.

Besides the main agent (M), another agent, the perceive agent (PA), is responsible for gathering data about the environment the user is located. Such is done subscribing sensor agents by the sensor category, currently temperature, luminosity and noise. This data is streamed to the main agent that will be responsible for updating mood estimation.

In order to process mood estimation, a representation of the personality and beliefs about environmental attributes are used. They will be explained in the following paragraphs.

Personality The personality was defined like OCEAN structure similar to ALMA framework [45]. The o, c, e, a, n variables represent five personality traits and mean Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism respectively. This structure is saved in a XML file to be accessible externally through the platform, and easy to access specific information. To create and manage personalities, the XML file is loaded and gets the OCEAN values or instead creates a new personality file. In 3.2 is an example of a personality based on XML representation.

Listing 3.2: XML for saving user personality

```
<persona>
    <ocean>
        <openness value="0.20"/>
        <conscientiousness value="0.70"/>
        <extraversion value="-0.55"/>
        <agreeableness value="-0.52"/>
        <neuroticism value="0.70"/>
    </ocean>
</persona>
```

In this module the influences of the personality on the mood state has more relevance. Therefore, the personality attribution on agents has a key role over other human individual features. Personality is acquired from real people through their responses to questionnaires as referenced in section 2.3 [101].

Mood Mood is a temporal state of the human mind, it can last for minutes, hours or even days, and can be seen as medium-term emotion. This step was based on the PAD space, computationally designed by Gehbard in his work ALMA [45]. First, the three variables that define PAD space, stands for pleasure, arousal and dominance respectively, must be in the domain $[-1, 1]$ to create the representation of the eight moods that are possible as specified in table 3.1.

Table 3.1: Emotion represention in the PAD space

Emotion	P	A	D	Classification
Joy	0.40	0.20	0.10	positive
Pleased	0.20	0.10	0.10	positive
Hope	0.20	0.20	-0.10	positive
Relief	0.20	-0.30	0.40	positive
Pride	0.40	0.30	0.30	positive
Gratitude	0.40	0.20	-0.30	positive
Love	0.30	0.10	0.20	positive
Distress	-0.40	-0.20	-0.50	negative
Displeased	-0.20	-0.10	-0.25	negative
Fear	-0.64	0.60	-0.43	negative
Disappointment	-0.30	0.10	-0.40	negative
Remorse	-0.30	0.10	0.60	negative
Anger	-0.51	0.59	0.25	negative
Hate	-0.60	0.60	0.30	negative

Another variable included in mood is the $emotionalWeight$ which represents the weight of the emotions related with personality. All people are different and as suggested in the literature, people with a high trend of neuroticism (n), taken from the OCEAN model, have more probability to be negative emotionally. For instance, if they have predisposition to feel emotions like hate, anger or distress more often than people with low score of this trend. On the other hand extraversion (e) awakens in people, more often, feelings more positives like joy, love, gratitude.

Therefore, the weight calculation is made by determining a signal for the emotion, if positive then the following expression shall be used $emotionalWeight = (e + 1.0) * const$ otherwise $emotionalWeight = (n + 1.0) * const$. This variable is in the set $[0, 2]$ turning $emotionalWeight$ positive to facilitate calculi. The constant $const$ is used to reduce or increase the velocity when mood is crossing from state to state. The value used was 0.1 which helped to ensure a reasonable speed.

One of mood's parametrized constructor receives as parameters personality values o, c, e, a, n 3.4.

$$\begin{aligned} &P = 0.59a + 0.19n + 0,21e; \\ &A = -0.59n + 0.30a + 0,15o; \\ &D = 0.60e - 0.32a + 0.25o + 0.17c; \\ &let \quad o, c, e, a, n \in [-1, 1] \end{aligned} \tag{3.4}$$

This creates an initial state different from agent to agent, based on personality input. A mood's foundation allows agents to deal with different emotion types during a lifetime. The PAD space intends to keep mood within a three-dimensional space so that it circulates from type to type, there are also the variables P_{fina}, A_{final} and D_{final}, defining the final state of mood relating with a emotion triggered by an event. Mood states are changed over time and not instantaneously, therefore the mood in a PAD space is a continuous variable.

Let the variables P, A, D from a point $Mood_{actual}$ in the space and the variables $P_{final}, A_{final}, D_{final}$ from another $Mood_{final}$ so it is possible to calculate a vector from on point to another using the expression 3.6.

$$\overrightarrow{M_{actual}M_{final}} = M_{final} - M_{actual} \tag{3.5}$$

(3.6)

To calculate the displacement vector for each portion of time an expression is used that makes the update of the current value with the displacement times the weight of emotion such as in 3.7.

$$M_{actual} = M_{actual} + \overrightarrow{M_{actual}M_{final}} * emotionalWeight \tag{3.7}$$

The multiplication operation is done to divide the $\overrightarrow{M_{actual}M_{final}}$ in small pieces that are relative to $emotionalWeight$ and this causes the mood state to move more or less slowly, depending on the person.

Modelling External Events for emotions The PHESS archetype provides a set of data obtained through the use of sensors attached in the ambient. Sensors such as temperature, luminosity and sound, provide information in real time. This data is used as events that change the behaviour and emotions because the ambient conditions have impact on the human actions.

In this sense, it is necessary to assign an emotional state to each value received. These values are real numbers in $\mathbb{R}$ so there are an infinite number of possibilities for the agent to trigger different types of emotions. As an example, the temperature values vary from negative values such as -20.4 °C to positive values such as 45.2 °C , the noise values can vary between 0.0dB to 55.5dB or the luminance can vary from 0.0lux to 995.8lux, therefore, the values have to be treated as is this module discretizes these values. To do this step, reference values were used according to experts that are specialized in green engineering for temperature comfort and ergonomics for luminance values and for noise.

Table 3.2 shows the temperature values according to the reference of the European Climate. The configuration of table 3.2 is denominated ConfT and represents the relationship between mood states and temperatures.

According to this information, high temperatures cause hostile emotions like Anger and Hate, and low temperatures cause less hostile but still negative emotions, like Distress and also Anger. In ConfT, values Slightly Hot or Slightly Cold cause a Pleased emotion where

Table 3.2: Mood derived from temperature (ConfT)

Temperature	in celsius degrees($^{\circ}C$)	Emotion
Very Cold	<4	Anger
Cold	4 and <8	Distress
Slightly Cold	8 and < 16	Pleased
Acceptable	16 and < 24	Joy
Slightly Hot	24 and < 27	Pleased
Hot	27 and < 32	Anger
Very Hot	32	Hate

Table 3.3: Mood derived from noise (ConfN)

Noise	in decibel (dB)	Emotion
Acceptable	<40	Joy
Noise	40 and <54	Distress
Very Noise	>54	Anger

the idea is that is still positive with respect to Joy of Acceptable value, but causes a lower impact.

Table 3.3 presents the reference values for comfort for a given noise of an ambient. These values were discretized yielding three types of noise levels like Acceptable for silent place, Noise for places somewhat noisy and very noise for very noisy places. After analysing information about the effect of the sound on human emotional response and the OCC model, it was decided that emotions like hate were extreme to Very Noisy places, so an emotion like Anger satisfied this condition which has lower negative impact than Hate.

Table 3.4: Mood derived from illuminance (ConfI)

Illuminance	in lux (lx)	Emotion
Dark	< 400	Fear
Acceptable	400 and <1000	Joy
Light	<1000	Hate

In table 3.4 is shown the treatment that was given for luminance values and how they could be put on clusters. The reference values point to three groups, dark for Dark places, Acceptable for places where lighting is adequate and Light for places where excessive lighting causes discomfort. The same considerations made in ConfN were taken in ConfI. In this case Dark could trigger fear and Light could trigger Hate emotion, this is because the excessive light or no light at all have an extreme impact on a human being in an ambient where this work was developed.

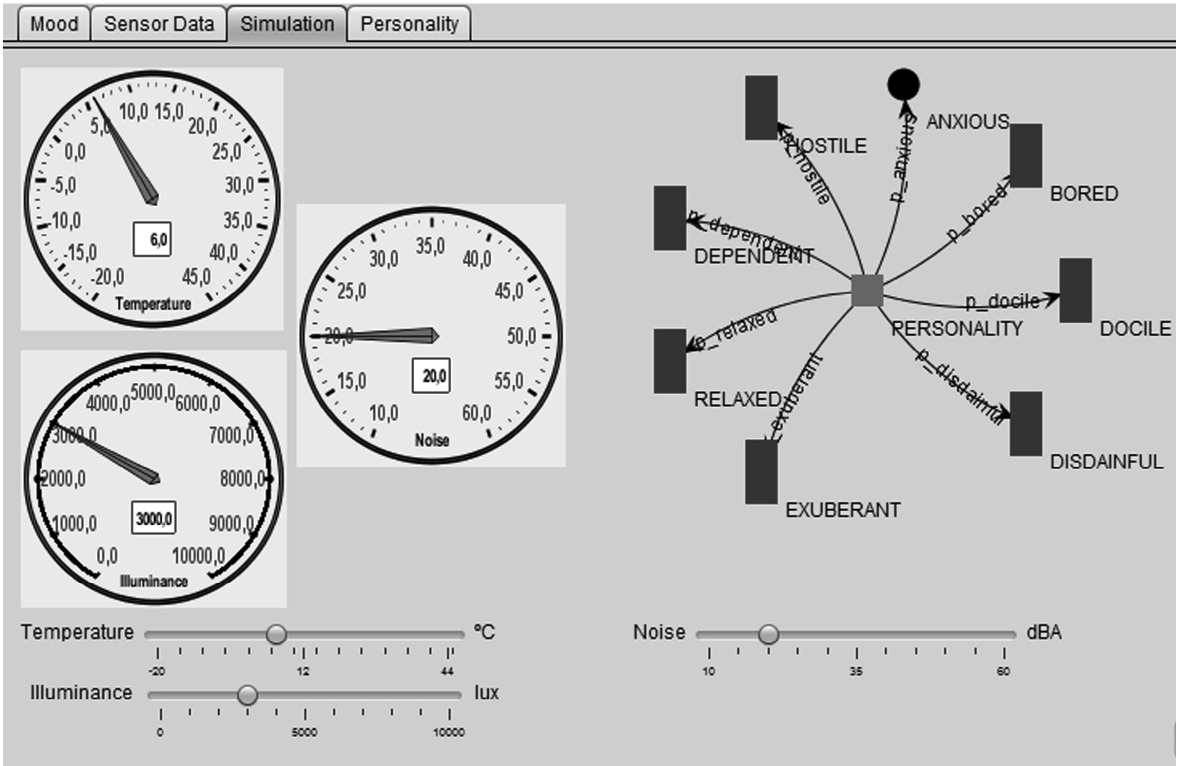


Figure 3.7: PHESS mood estimation sample interface

The resulting module from the application of these parameters estimates mood states according to environment configuration and user personality. This module can be suitable to be used as an indicator in sustainable assessment and can demonstrate user response to environment state.

A sample interface stating user state can be seen in figure 3.7 which was built using this module. In this figure, are represented the eight emotion the module supports with the indication of the predominant mood for the current time-being inferred from environmental conditions.

3.2 Dissemination of Publications

The results from the application of the archetype are presented in the form of scientific publications in journal articles and international conferences. In this section, different applications of the PHESS archetype are presented ranging from environment applications, urban transports application and well-being assessment.

3.2.1 Gamification, Social Networks and Sustainable Environments

Scope of the International Journal of Interactive Multimedia and Artificial Intelligence

The International Journal of Interactive Multimedia and Artificial Intelligence (IJIMAI) provides an interdisciplinary forum in which scientists and professionals can share their research results and report new advances on AI tools or tools that use AI with interactive multimedia techniques.

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Gamification, Social Networks and Sustainable Environments

Fábio Silva, Cesar Analide, Luís Rosa, Gilberto Felgueiras, Cedric Pimenta

Abstract — **Intelligent environments and ambient intelligence enabled systems provide means to gather rich information from both environments and its users. With the help of such systems, it is possible to foster communities of ambient intelligence systems with community driven knowledge, which is created by individual actions and setups in each of the environments. Such arrangements provides the potential to build systems that promote better practices and more efficient and sustainable environments by promoting the community best examples and engaging users to adopt and develop proactive behaviors to improve their standings in the community. This work aims to use knowledge from communities of intelligent environments to their own benefit. The approach presented in this work uses information from different environments, ranking them according to their sustainability assessment. Recommendations are then computed using similarity and clustering functions ranking users and environments, updating their previous records and launching new recommendations in the process. Gamification concepts are used in order to keep users motivation and engage them actively to produce better results in terms of sustainability.**

Keywords — **Ambient Intelligence, Gamification, Sustainable environments**

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I. INTRODUCTION

Sustainability is a multi-disciplinary area based in fields such as economy, environment and sociology. These fields of research are interconnected, but humans have different psychological approaches to them. Thus, is necessary to perceive the behaviors behind each multi-disciplinary area. A computational platform to support and promote a sustainable environment, together with an approach to the energetic and economic problems, must take the decisions as smoothly as possible so as not to cause discomfort to the user. This topic triggered several psychological researches [1], [2] and a common conclusion indicates that humans are not always conscious about their behavior [3]. This field, called psychology of sustainable behavior, despite focusing on measurement and understanding the causes of unsustainable behavior, it also tries to guide and supply clues to behavior change. Manning [4], shows some aspects that are necessary to consider promoting and instilling in people sustainable behaviors:

- All behavior is situational, i.e., when the situation or event changes, the behavior changes; even if exists intention to perform a certain behavior, circumstances can make it change;
- There is no unique solution, i.e, people are all different because they have different personalities, living in a specific culture, with distinct individual history;
- Fewer barriers leads to a great effect, i.e., when a person is facing social, physical and psychological obstacles, his

attitude tends to flinch; for instance, the lack of knowledge about a procedure leads to a retreat;
- There is no single approach to make an action attempting achievement of sustainability; there are many sustainable possible options that a person can choose.

To overcome these barriers to sustainability, it is suggested the engagement of multiple users in a competitive environment of positive behaviors so that participants have the need to strengthen their knowledge of sustainable actions.
Energy efficiency, which represents optimal use of energy to satisfy the objectives and needs from users, environments and interactions between them, is also an important topic to sustainable environments, although not the only one. According to Herring studies [6], over the last 25 years, the increase in the efficiency of domestic appliances has been nullified by the increase of the use of energy consumption devices. Initial results from energy efficiency policies state that small changes in habits can save up to 10% in home energy consumption [7]. On the other hand, sustainability represents the assurance that environments, users and interaction between them can be endured and, as a consequence, the future replication of the current patterns is not compromised. Both concepts, sustainability and energy efficiency, are not opposed to the use of energy, but they do remind people to be effective on how resources are used and the fact that sustainability concerns the viability of current actions in the present and in the future.

A. Computational Approach to Sustainability

Currently, different approaches to measure and assess sustainability are addressed in the literature. Some focus on an economic perspective while others emphasize environmental or social perspectives [8]. On a computer science perspective, although not being able to directly solve the sustainability problem, it can plan and develop solutions to measure and assess sustainability automatically from an environment. This is not due without obtaining information about the environment and its users. The scientific research field of Ambient Intelligence provides a wide spectrum of methodologies to obtain such information in a non-intrusive manner.
The types of sensors used in the environment may be divided into categories to better explain their purpose. Generally, an ambient might be divided by sensors and actuators. Sensors monitor the environment and gather data useful for cognitive and reasoning processes [9]. Actuators take action upon the environment, performing actions such as controlling the temperature, the lightning or other appliances. In terms of sensorization, environment sensors can be divided into sensor that monitor environment or sensor that monitor the user and its activities. This division of sensor classes can also be presented in a different form, taking into consideration the role of the sensor in the environment [10]. In this aspect, sensors might be divided into embedded sensors are installed on objects, context sensors provide information about the environment, or motion sensors.
Envisioning the potentials from computational systems to promote and guarantee sustainability requires all types of sensor classes, as present in some initial project that perform real-time sustainability and energy management [11], [12].

B. Sustainable Indicators

Sustainability is a multidisciplinary concept related with the ability to maintain support and endure something at a certain rate or level [13]. The United Nations have defined this concept as meeting the needs of the present without compromising future generation to meet their own needs.
Due to the importance of sustainability different author have defined measures to assess and characterize sustainability. A popular consensus is based on 3 different indicators used to measure the sustainability of a given environment [13]. This approach is based on three different types of indicators, social, economic and environmental with the specific restriction that until all those values are met a system cannot be deemed sustainable. From this perspective sustainability concerns a delicate equilibrium between different indicators which action to optimize one indicator might affect the other two.
The presence of indicators to assess sustainability is an established practice [14],[15], however it does not give any information on how to guarantee or plan sustainability. In fact, indicators only inform about the current status of a system. Common problems with this practice are enumerated in the literature, [15]. The definition of global sustainable indicators, as a means to compare environments, is difficult since environments have different characteristics. Selection and formal definition of indicators is, also, a matter of concern as it has to be agreed by all participants and must have a series of properties, in which the indicators express their relevance. Some authors approach this problem characterizing these properties as dimensions, where some indicators are more important in some dimensions than in others, while

monitoring the same object. One other problem is the definition of measuring units and metadata. If not defined accordingly, it may be impossible to compare indicators of the same type. Measuring data makes it possible to obtain an indicator which might have a range of optimal values and a range of non-optimal values.

The use of indicators for sustainability assessment is a common practice across many researchers. Nevertheless, the definition of a sustainable indicator is sometimes difficult and it may differ from environment to environment. In intelligent buildings, there are proposals to build Key Performance Indicators (KPIs) to monitor sustainability and act as sustainable indicators [11]. It has also been identified that indicators are useful at pointing unsustainable practices but not so accurate nor useful to define and guarantee sustainability [16]. Frameworks to evaluate energy efficiency through sustainability in the literature use similar approaches. The goal of energy efficiency was obtained optimizing sustainable indicators which monitor a set of specific energy sources [15]. Industrial environments are also object of energy efficiency projects. In Heilala et al. [11], an industrial AmI is proposed to optimize energy consumption. The main technique used by the AmI system is based on case based reasoning, comparing the data gathered and processed in the AmI with EUP values to assess and diagnose possible inappropriate energy usages. An intelligent decision support model for the identification of intervention needs and further evaluation of energy saving measures in a building is proposed Doukas et al. [7]. The demonstrated concept shows that it is possible to have an intelligent model to perform energy management on a building, combining aspects like ambient climate conditions, investment rates, fuel, and carbon prices, and, also, past experiences.

C. *Gamification and Information Diffusion*

The current and more consensual definition, and one with which we agree and chose to follow, is "the use of game design elements in non-game contexts" [17]. While the concept is recent, the idea from which it is based is not. The notion that the design of the user interface can be built by other design practices has some tradition in HCI (Human-Computer Interaction); during the first peak in the development of computer games, in the early 80s, some authors [18], [19] analyzed game designs in order to create more interesting and pleasing visual interfaces.

The interest in gamification is due to its influence to change people behavior through gamification elements. There are already many studies in regard to gamification, where people use IT to change the behavior of the systems in order to make them more efficient. Still, there is a common trait among them, they are oriented to efficient actions of a system and not to the efficient actions of the user [20]. Changing the former is determining what should be its behavior, while changing the latter means changing their habits, the behaviors that they acquired. In order to tackle this problem, two main concepts can be put in practice: Gamification and Information Diffusion.

In [21], gamification is applied in education where the authors try to take the elements from the games that lead to the engagement and apply them inside the school to the students to keep them motivated. Another example uses a framework that allows users to share their daily actions and tips, review and explore others people actions, and compete with them for the top rank by playing games and puzzles [22]. On another example authors developed a service-oriented and event-oriented architecture framework where all participants communicate via events over a message broker. This system is composed by a set of game rules that define game elements like immediate feedback, rank/levels, time pressure, team building, virtual goods and points (karma points, experience points). Completing game rule generates a reward event for the user over the message broker. There is also an analytical component that may be used to analyze user behavior in order to improve game rules and optimize long-term engagement [23].

As for the second concept, Information Diffusion, this can be applied specifically to social networks. What various studies have proven [24] [25] [26] is that social networks have the potential to diffuse information at a high rate. Besides this point, they can also influence other peers to participate by sharing content. The use of social networks, also mentioned above, has the goal of enhancing the engagement of the users to higher levels by bringing the results to public (respecting user's authorizations) and making each user responsible for his actions at the eyes of the respective network. As we can see through the examples presented, the application of gamification can raise the levels of loyalty of the users and keep them engaged in our objective by making it more enjoyable.

II. STUDIES ON SUSTAINABILITY ASSESSMENT

A. People Help Energy Savings and Sustainability

People Help Energy Savings and Sustainability (PHESS) is a project currently being developed at Intelligent Systems Laboratory at University of Minho [15], that was used to conduct preliminary studies in sustainability assessment. It concerns a multi-agent platform (fig. 1) developed to monitor environments as well as its users and perform sustainability assessments, actions and recommendation. The platform establishes an ambient sensorization routine upon the environment, constantly updating sustainable indicators built upon raw data from environment sensors and contextual information.

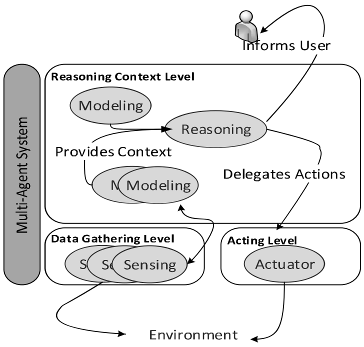

Fig. 1 - PHESS architecture

In order to facilitate management and operational coordination, the system was divided into modules and sub-routines, implemented as software agents acting collaboratively in a multi-agent system. There are a total of 3 modules in the PHESS system:

- data gathering level, responsible for obtaining information about the environment and its user using dedicated hardware and software services available;
- reasoning and contextual level, responsible to use information gathered and update machine learning model, profile users and environment, maintain indicators and perform reasoning tasks upon the information acquired in order to deliver actions plans and recommendation to users;
- acting level, responsible to communicate with environment users, informing user of possible recommendations and controlling actuators in the environment according to user consent and preferences.

Sustainability indicators are used to translate the performance of environment and user actions into numeric values that can be used to perform rankings and assessment on recommendation created in the reasoning and contextual level. They represent the current, real time assessment of the environment taking into account historic and real time data. The aim of the platform is not only to assess and identify unsustainable practices but also act with the objective of improving sustainability indicators. For such to happen, user behavior and environment might need to be changed. However, how the change is conducted cannot be determined by sustainability indicators alone.

As a multi-agent system, in the data gathering level in the PHESS platform includes sensing agents responsible for controlling the access and delivery of ambient sensor data model and reason agents in the reason context level. Model agents are responsible to monitor changes in the environment creating models with patterns common pattern and predictors for sensor value. Moreover, model agents may also be responsible for maintaining user or environment sustainable indicators updated. Reason agents use context information to formulate hypothesis in order to create recommendation, optimize environments and behaviors. This knowledge inferred from agents is then used in acting agents in the Acting level in this platform.

The process of using indicators from different environments to create and promote recommendation was developed upon the PHESS to provide familiar recommendations backed up by members of a community. This development is part of the work described in this paper and will be detailed in section 3 with its advantages and disadvantages. Before detailing the recommendation system, an initial explanation about the sustainable indicators and sustainable assessment is necessary to understand the process of creating recommendations.

B. Sustainability Assessment

The sustainable assessment used in PHESS, uses different indicators within each dimension of the sustainability definition. This approach was also used by researchers, which used these indicators to guide strategic options and perform decisions based on the foreseeable impact of such measures [14], [15]. The indicators used in this work are devised to be directly comparable to each other regardless of units or the specificity of each indicator. These indicators represent a ratio between a positive and negative contribution to sustainability and their values are computed in the -1 to 1 range, equation 1. As a consequence, all indicators use the same units of calculation and can be aggregated within each dimension through the use of weighted averages. The use of these indicators is made within each division in the environment and aggregated through average in the environment. Examples of indicator are provided in table I where the variables used as positive and negative values in equation 1 are displayed.

$$Ind(positive, negative) = \begin{cases} \frac{positive}{negative} - 1 \rightarrow positive <= negative \\ 1 - \frac{negative}{positive} \rightarrow positive > negative \end{cases} \quad (1)$$

In order to deliberate about sustainability performance it is needed to rank solutions rewarding each solution with a sustainable score, equation 2. Indicators within each dimension of sustainability are averaged according to weights defines in each dimension.

TABLE I INDICATOR DEFNITION

	Positive	Negative
Economic	Budget	Consumption
Environmental	Emissions	Estimated Emissions
Social	User inside	User outside

The use of ranking formulas enables the use of fitness functions and distance functions to help calculate distances from one sustainable solution to another. Such approach in explored in section 3, integrated in a case based reasoning algorithm and custom sustainable indicators used to perform a proof-of-concept analysis on the proposed algorithm.

$$S_{index} = \alpha * I_{economic} + \beta * I_{enverinmental} + \gamma * I_{social}$$
$$\alpha + \beta + \gamma = 1 \wedge 0 < \alpha < 1 \wedge 0 < \beta < 1 \wedge 0 < \gamma < 1 \quad (2)$$

Provided with data from the PHESS system it is possible to use such formulas to characterize environments and users according to the same indicator, as well as identify their performance accordingly. As demonstrated in table II and table III, it is evidenced that the performance of each room in a sample environment is affected differently according to how they are used, as well as, user behavior affects their indicator values. These results were obtained using the sample indicators in table I across a sample environment for a period of 3 days.

TABLE II
SAMPLE RESULTS FROM PHESS SYSTEM

	Social	Economic	Environmental
Kitchen	-0.9011	-0.6859	-0.3263
Bedroom	0.1818	0.9936	0.9024
Living Room	-0.5294	0.1040	-0.2963
Hall	-0.9690	0.9968	0.9954
WC	-0.9900	0.9968	0.9858

TABLE III USER ASSESSMENT

	Social	Economic	Environmental
User 1	-0.004	0.3241	0.281
User 2	0.500	0.927	0.422

C. System analysis

Although the PHESS system is able to extract information from environments and users with significance to perform assessments and recommendation tasks. It was found that the utility of the system depended on how well suggestion are followed and how user adhere to the suggestions being made. Moreover, the use of sustainable indexes is a fast way to categorize action and identify improvement needs but user stimulation to correct such problematic areas is not present. In fact, most systems do not account for the need to motivate user to take action preferring only to make assessments and suggestion to present their findings to users.

There is an opportunity to use computational methods to promote user action on the system, namely with the use of social networks and concepts of gamification. As the improvement of environments and user action is dependable on how user follows recommendations it is of significant importance to improve justification for recommendations and promote them. Over the next section a social recommendation engine is detailed as well as a gamification implementation based on the data retrieved by PHESS.

III. Recommendation Engine

A. Social Recommendation Engine

The recommendation engine is intended to help communities of intelligent systems let users promote practices from different physical environments with high sustainability indexes to others with a recommendation engine. In order to summarize each environment, it was designed a sustainability profile, stating environment and individual room sustainability. Environment indicators are calculated from the use of aggregated individual room indicators, taking advantage of the indicator structure detailed in section 2 indicators for each dimension of sustainability.

The case based reasoning used in this situation uses a two-step process to evaluate and calculate new solutions for the user. As an initial step, the type of environment is contextualized, for instance, sustainable index, number of divisions and room indicators. A second step concerns the recommendation phase, and uses room indicators to obtain the best solution for the planning of energy use and appliance substitution.

The action flow is detailed in figure 2, where from an initial set of grouped environments a target environment can be compared to environments in higher ranked groups.

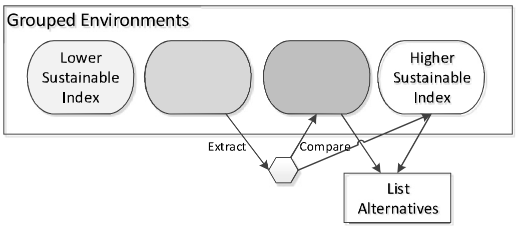

Fig. 2. Social recommendation engine

The initial grouping of environments is made using K-means algorithm on the sustainable index of each environment with a fixed size for number of groups. The retrieval of comparative cases is extracted with the help of similarity functions. In this case, similarity is computed using environments from higher ranked groups and an average Euclidean distance from the distance value, computed for the three sustainability indicators, in every room. This procedure is used taking in consideration the room type, as distances are only calculated for rooms of the same type. The selection of environments favors the longest similarity distance for the value of the indicators in order to help the impact of possible recommendations in the environment. Finally, the list of alternative recommendations is obtained, comparing the room types of the target environment to rooms of the same type in the selecting environment. Any differences found are matched as possible change scenarios, favoring the options taken in the selected environment.

It is useful to remember that sustainable indicators are calculated from data acquired from each environment on a timely basis. The natural consequence is that as time progresses the values of these indicators which might result in environments exchanging the group they were previously.

This dynamic works for the benefit of the system as the selected cases for comparison within each group are changed each time these variations occur enticing environments users to adopt behaviors that do not lead their environment to move to lower ranked groups.

B. Gamification Implementation

In this section, the implementation of gamification elements is provided as a means to promote healthy competitions between users and their environment in terms of sustainability and energy efficiency.

Management of user standings and performance is done through web interfaces in which the user is able to monitor the gamification elements devised for him.

The following list details each Gamification element or dynamic implemented. Gamification elements implemented:

- Points, awarded daily according to metrics defined in the system;
- Levels, user standings according to the number
- Achievements, personal objectives launched to user which grant them extra points if followed;
- Leaderboards, visual demonstration of users' rankings according to each other.

These elements were integrated into the developments of PHESS as a mean to promote completion between user with the general objective of increasing sustainable indicators in each environment and user action. As so, the points rewarded in the gamification side are based on the sustainable indicators retrieved by PHESS on a daily basis. Levels group player according to their experience and similar point base. Achievements for each player are based on the recommendations obtained by the social recommendation engine from which suggestions are turned into achievements. Finally leaderboards represent the list of players with their current standings. Communication with the PHESS system is made asynchronously through communication agents responsible for data synchronization. It is expected that by implementing such mechanisms user suggestion acceptance increases, and that user take continuous efforts to improve even when changes rewarding changes are not proposed through the recommendation engine but they are perceived by human intellect.

IV. RESULTS

In order to provide results from the application of each component and their benefits a controlled case study was devised. As such, 4 environments were used with the PHESS system implemented using simulation tools available in the PHESS framework. All environments were assessed using the same group of sample indicators. For the social indicator a positive value is represented by the amount of time spend inside the room whereas the negative value is represented by the time outside. Likewise for economic indicator a positive value is represented by the current budget available and the negative the total amount spent. Regarding the environmental indicator, emissions are derived from the CO_2 emission derived from electricity report for the negative value and emissions avoided as the positive value. Each case is maintained in a profile database and it is updated using the PHESS multi-agent platform. Environment appliance configuration and user behaviors simulate different configurations and user profiles simulating a heterogeneous community. The setup recreated typical environments commonly found, such as apartments with a bedroom, living-room, kitchen, bathroom and a hall connecting all the other rooms. Inside each room, a set of appliances was also defined ranging from lights and computers to ovens and refrigerators with different consumption patterns. The consumption of appliances was defined from their active use and explicit turn on/off actions from user action simulated in the environment.

A. Recommendation Engine

In order to test the recommendation system the environments in the test scenario were divided across 3 groups using the algorithm detailed in section III. The initial step requires information about each environment, namely sustainable indexes for each environment and sustainable indicators for each room inside each environment. With information about sustainability on each environment groups was generated resulting with the first group concentrating two of four environments, and one for each of the remaining two groups. Focusing on one of the environment on group with poorer sustainable index, a comparison was made using the environment on the middle group in terms of sustainable index value. For each room possible changes were computed generating a report as defined in table 1 for the living room.
A total of six recommendations were proposed on the target environment in the living room, as seen on table 1, in the kitchen and in the bedroom areas.

TABLE IV RECOMMENDATION SYSTEM REPORT

Appliance	**Target Room (Average Consumption)**	**Best Case (Average Consumption)**	**Decision**
Lights	120W	65W	Change
Computer	49W	55W	Remain
Television	60W	30W	Change
TV Box	55W	-	-

Using the PHESS system it was possible to assess that using recommendations on the living room alone was sufficient to improve the target environment sustainability index.
In fact, iterating the recommendation algorithm one more time it can be found that if recommendations are followed and user behavior remains equal, the environment would be selected for the middle group, thus showing improvement.
Observing the behavior of the community it is possible to assess that the recommendation system is based on the knowledge present within the community.

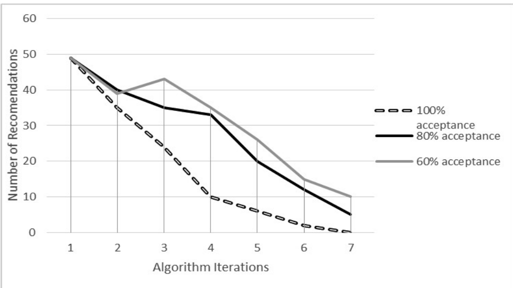

Fig. 3 Number of recommendations by algorithm iteration according to user acceptance

If recommendation are always followed, (100% acceptance) the number of changes proposed converges to zero when environment setups become identical, a point where further improvisation is compromised. Depending on the rate of acceptance of the suggestions this convergence can be slower or faster as showed in figure 3.

A. Gamification

In order to test the dynamics of the gamification elements proposed, tests were simulated using the PHESS system and the gamification system. The points were calculated based on economic sustainable indicator values in the environment and user behavior.

In order to further simulate typical situation inside communities within the four environments the first two were setup with more efficient appliances than the latter two. However, through the different days of use, the first two environment neglected the recommendation proposed as achievements while the others followed them. As it can be seen in figure 4, the gamification elements favor environments were recommendations are followed but the initial efficiency is also taken into consideration as through the first days although recommendations were followed it was not enough to surpass the first two environments.

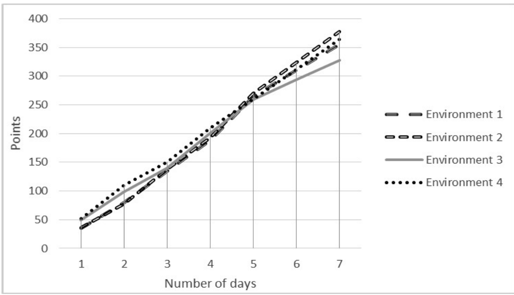

Fig. 4. Environments evolution in the gamification process

B. Improvement of sustainable indexes

Recommendation calculated can be interpreted as using knowledge created within a community to its benefit. The best cases are used as examples to lower ranked cases which provide sense of sympathy from one to another. Also, with this approach, it is not necessary to maintain a database of efficient objects like appliances or lightning. As soon as they appear in the community they tend to be selected for recommendation as part of someone's environment definition.

In order to further promote the adoption of recommendations and foster better behaviors, gamification elements are applied, which in turn, reward sustainable and efficient actions in the community of users and environment. Such rewards are heavily influenced by sustainable indicator devised in the PHESS system, and to climb leaderboards ultimately means to improve such indicators. Additionally, the implementation of recommendations rewards instantaneous points but in order to maintain the benefits such recommendation need to provide long term effects in the system after applied.

Nevertheless, the work detailed needs to catch the user's attention in order to promote its sustainable completion. As there is no safe way to do such thing our implementation is also dependent on user reaction to recommendation and gamification elements to keep improving their standings. But assurance was made to guarantee that in the better gamification results also mean better sustainable environments.

V. CONCLUSION

Ambient intelligence, social networks and gamification present an opportunity to innovate on how to guide and manage resources and human actions making them both more efficient and sustainable. Users share significant amounts of information and by taking advantage of both data gathered by sensorization platform and user input it is possible to build communities and maintain evolutionary recommendation engines that promotes sustainability. The algorithm results and theoretical background support the idea that it possible to use such strategies to drive a social community of user to optimize itself if recommendations are followed. Concepts from gamification also help stimulate competiveness between users resulting in a desire to achieve the global objective with more determination and proactively. Nevertheless, a wide practical validation of results, under a greater set of environments and a user base, is still needed to thoroughly validate findings. This should be accomplished using field tests in a community focused on increasing their sustainability. Furthermore, in order to provide data for the system engine it is needed some specific hardware in order to sense an environment current conditions. Thus, the cost of sensorization and hardware needed should be minimized in large tests as to reduce management costs.

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3.2.2 Context Time-Sequencing for Machine Learning and Sustainability Optmisation

Scope of the 9th International Symposium on Intelligent Distributed Computing

The emergent field of Intelligent Distributed Computing focuses on the development of a new generation of intelligent distributed systems. It faces the challenges of adapting and combining research in the fields of Intelligent Computing and Distributed Computing. Intelligent Computing develops methods and technology ranging from classical artificial intelligence, computational intelligence and multi-agent systems to game theory.

The field of Distributed Computing develops methods and technology to build systems that are composed of interacting and collaborating components. The symposium welcomes submissions of original papers on all aspects of intelligent distributed computing ranging from concepts and theoretical developments to advanced technologies and innovative applications.

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Context Time-Sequencing for Machine Learning and Sustainability Optimization

Fábio Silva and Cesar Analide

Abstract Computer systems designed to help user in their daily activities are becoming a norm. Specially, with the advent of the Internet of Things (IoT) where every device is interconnected with others through internet based protocols, the amount of data and information available has increased. Tracking devices are targeting more and more activities such as fitness, utilities consumption, movement, environment state, weather. Nowadays, a challenge for researchers is to handle such income of data and transform it into meaningful knowledge that can be used to predict, foresight, adapt and control activities. In order to this, it is necessary to interpret contextual information and produce services to anticipate these conditions. This project aim to provide a system for the creation of information and data structures to generate user models based on activity and sensor based contextual-information from IoT devices and apply machine learning operations to anticipate future states.

1 Introduction

Contextual lifelong information is becoming a reality with the increasing number of devices that allow constant environment and user sensorization. From fitness trackers to household consumption utility monitors, sources of data are diverse and allow different contextual analysis. With concepts and processes from data and information fusion t is possible to not only improve measurement but also improve the quality of information using different heterogeneous sources. Internet of Things (IoT) provides the infrastructure network needed to share data across devices, while growing research areas like smart cities and smart things aim to democratise the use of

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such infrastructures to, among other things improve living conditions and access to services that may help users in their daily lives.

One application for these concepts can be found in the creation of on-line sustainability reports and the implementation of sustainability indicators on communities of users. In these analysis, sustainable indicators are generally relative to the sustainability dimensions: ecological, social and financial, though, indicators that span across dimensions are also possible. Furthering this idea, the data sources and methods of measuring and assessing sustainability continue non-standardized and dependent on the subject, objective of analysis and area of study. As a result, it seems that no broad framework for dealing with such problem has become relevant, but rather, small implementations specialized implementations dependent on the area of study.

Taking lessons from ambient intelligence, ubiquitous computing and the current availability of data sources as a consequence of the development the interconnection of services and devices through internet protocols, it is possible to think about these problems as computational problems. It means that, computational resources to sense monitor and act upon the environment have become available. This led to the creation of the field of computational sustainability [3]. This field aim to use computational resources to monitor, plan and optimize attributes related to sustainable problems which have application beyond the traditional computational system.

Sustainable problems such as energetic sustainability and energy efficiency are directly affected by human behaviour and social aspects such as comfort. While efficiency is focused on optimization, sustainability is mostly concerned on restrictions put in place to ensure that the devised solution does not impair the future. For instance, a deliberative system that pre-heats a room in the afternoon taking advantage of solar radiation and maintains it warm so it can be occupied in the evening, might conduct an energy efficiency procedure, in order to spend less energy to make that room comfortable later in the day. Considering the cost of heating the same room later in the evening from a lower temperature to a comfortable temperature the energy might be best spent with the previous strategy, but it will not be clear to all users because such action are dependent on context and some user might only see an empty room spending energy on a heating process.

This projects aim to deliver contextual time-sequence actions based on user contextual information. These will use different devices and services connected to data networks to provide organized data input for machine learning models and deliberative tasks. Data operations are based on the streams of time-sequence data which are also defined to according to the learning tasks. The end objective is to provide an automatic work flow that recognises user habits and contexts to control and adapt contextual information to user needs and sustainable objectives.

2 Related Work

2.1 Human tracking

Different methodologies and procedures exist to keep track of human activities and to make predictions based on previous and current information gathered from these environments. Some of the most common approaches with machine learning techniques involve the use of neural networks, classification techniques, fuzzy logic, sequence discovery, instance based learning and reinforced learning.

Sequence discovery approach is at the heart of learning algorithm in [1], which demonstrates a system that can learn user behavioural patterns and take proactive measures accordingly. The theory developed consists in the discovery of pattern of user behaviour. Such system is composed by three modules, the representation of patterns, the learning patterns and the interacting system. These three modules are predicted to be capable of interacting with the user in natural language, learning patterns of user's behaviour and representing the contents of each discovered pattern in a simple if-then-when rule. Other approach is found in [9] where events are grouped into activities under an ambient intelligence scenario, with sensors spread across a domestic environment. Not only does it target activities of daily living, it also targets the cluster of activities and relationships between them based on mathematical formulations over sets of activities.

Human activity tracking algorithms demonstrate potential for intelligent environments in order to adapt to specific user preferences or environment specific objectives taking in consideration the habits of its users.

2.2 Environment tracking

Smart cities is a research area under development that aims to provide a technological infrastructure to measure and monitor attributes relevant to city management. Furthermore, it is being used to develop services based on the platforms such as internet of things (IoT), smart grids and public services [6], [8]. These developments enable the constant monitoring of city attributes such as weather, air, living conditions and traffic for example. These are often aggregated in units of time ranging from every few seconds to days, months and years. An historic record is, among other things, used to provide context or even factual data for problems such as global warming, flood control, public health and energy savings.

Every city citizen is subjected to the conditions being monitored and, as such, these services become an interesting context data to analyse behaviours and specially behaviour dependent on context. On a sustainability analysis, this means assessing behaviour impact on sustainability and sustainability indicators.

Our take in environment tracking makes use of dedicated hardware and web-services to gather contextual data as activities are produced. The objective is to create time-sequence strips that can be evaluated on a time basis and used as historic data to perform prediction using models with machine learning technology.

2.3 Machine Learning and Profiling

Models and machine learning often require past evidence to compute, predict and provide insights. The objective is to rely on proof from past events so future occurrences can be estimated ahead of time. This, of course, translates to valuable knowledge, specially when certain outcomes need to be avoided such as uncomfortable environments or unsustainable behaviours. It is in growing demand the need of forecast to prevent and assure compliance.

Projects such as The People Help Energy Savings and Sustainability (PHESS) [10], HVAC control systems based on people estimation [5] and adaptative agents [7], look for means to predict behavioural action of its users based on environment configurations and their current states. To this end, the use ambient sensorization, data fusion techniques, ubiquitous monitoring and smart actuators make it a technological project with benefits for both compliance of policies and an attempt to solve some sustainability assurance. The use of the expression attempt is due to the nature of the definition of sustainability, which for this work was based on the assumption that past and current actions should not impair the future of the execution of such actions in the future. If there is lack of data or information then the analysis may become incomplete, but even worse is the case for uncontrollable factors that impair sustainability without remediation available.

3 User Time-Sequence Context Fusion

The PHESS project, for which this time-sequence context was developed, is intended to, by helping people, make them intervene in the society, in the context and with the purpose of contributing for the energetic sustain-ability of their world. There is perception and desire, in the society and in people, to discuss this matter. In order to make the data design robust enough for consecutive updates, the PHESS system was design to track contextual factor on base units of interest. Raw data is preserved at central data storing nodes with reliable and fault tolerance mechanisms in place and then pre-processed to make meaningful journals of contextual information. This contextual information acts as a middle data preparation which can suffer operations such as slice to decrease contextual information, aggregation to operate on higher base units, and time-sequence to determine the number of days, epoch and period of interest of the analysis. After these operations, the data is ready to become the input of multiple machine learning and ranking algorithms.

Intentionally, the main objective is the re-organization of contextual information so as to provide tailored suggestions to users on sustainable parameters based on evidence form environment parameters and behaviours. In test scenarios, the consumption of utilities electricity was used to perform sustainable assessments. Better yet, the contextual information from structured services inside the PHESS project allow the inclusion of direct context based on what happened and indirect context based on what could have happened if realistic and feasible modifications were made on the base context. This indirect context is dependent on expert knowledge to devise possible scenarios such as the availability of solar energy sources to decrease the environmental and financial cost of grid powered electricity. Such metadata can be used to fuel the assessment of alternative scenarios, which is useful when considering the optimisation or assurance of parameters.

The focus of this project is, more than developing new procedures or algorithms to solving problems, putting these innovations on the hand of the user, with a clear purpose: that these innovative tools should be guided to assist people.

3.1 Data Fusion

The process of data fusion is handled by local central nodes, where data is submitted to data fusion process according to the number of overlapping and complementing sensors. In this regard, there are a number of strategies that can be followed according to context. The first one mentioned is a weighted average of values for the same type of sensors in the same context to get an overview of an attribute with multiple sensors to reduce measurement errors. The weights are defined manually by the local administrator. More sophisticated fusion is employed with complementary sensors which according to some logic defined into the system measure an attribute by joining efforts such as user presence with both RFID readers and wireless connection of personal devices such as smartphones. In this case, the system knows the user is present whenever one or both of the sensors are triggered. In this last example there is the use of heterogeneous data to create attributes with some level of knowledge expertise. Other examples can be found in is the assessment of thermal comfort using default indicator expressed as mathematical formulae such as the PMV index [2] or the more recent physiological estimated temperature (PET) [4]. Other application is the definition of sustainable indicators according to custom mathematical formulae in the platform that shall process some attributes in the system to make their calculation. The PHESS project, in its contextual inference uses convergent data fusion techniques and heterogeneous data sources as income of data. Context can take a form of averaged sensor readings to complex indicators that are directly or indirectly assessed. Operation over datasets are present to filter, group and randomize samples through slice, aggregate and sample operators. A generic visual representation of the time-sequence to represent the evolution of indicators over time is shown by figure 3.

Each time-sequence is based on action detection. The action sensors provide the granularity of the analysis as action recognition can be based on user movement (e.g. from one environment to other), activity detection (e.g. walking, driving, ex-

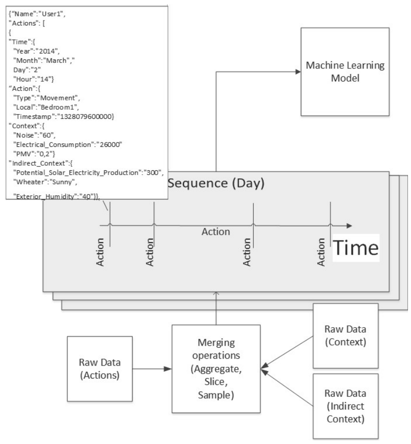

Fig. 1 Daily based time sequence contextual information based on user activity.

ercising, cooking). Physically, the PHESS platform perform a number of calls to sensor and context services in order to gather the information needed to build the time-sequence. Figure 2 details the list of calls to PHESS internal services to manage and display time-sequences to the user.

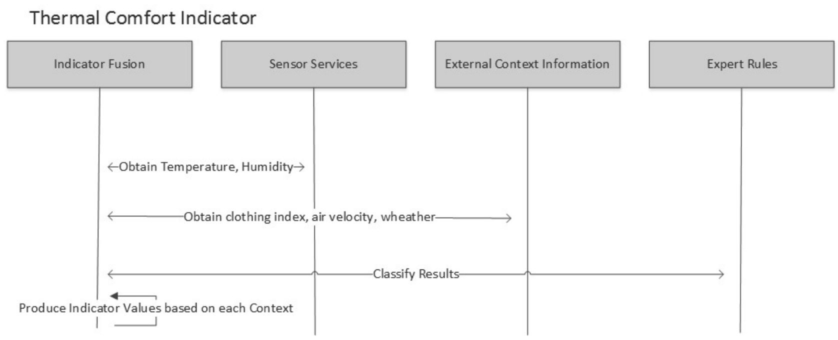

Fig. 2 Indicator Construction in PHESS workflow.

The configuration of data fusion steps, the selection of sensors and streams of data is made on the initial step of the system by the local administrator. This flexibility addresses the needs for the system to produce relevant information locally. Also, the historic of time-sequences allows for machine learning tasks and to anticipate user actions based on context or environment response to user behaviour depending on interest.

3.2 Expert Rules

A predictive system needs to find not only what is expected in the near future but also to guide results according to guidelines extracted from complementary sciences. These are called expert rules due to the fact that they are created from knowledge passed to the system. For instance it is expected that daytime is hooter than nigh time and peak activity occur during daytime while resting period is during night time. As mundane as these rules are, they provide a substantial clues to direct learning efforts, assess sustainable parameters based on living conditions and plan what is ahead.

Other rules such thermal comfort of temperature and humidity or ergonomic lightning conditions provide insight to how much optimization can occur before human comfort and sustainability is affected. A traditional example shall be reduce electrical costs by turning down all electronic equipment. Though, it yields mathematically sound results, the human side is completely forgotten and may enforce hard living condition for today's habits. PHESS platform takes it into consideration as it is belied that no computer centric can endure without taking in consideration usability and comfort.

Table 1 Expert rules dependent on activity

Attribute	Acceptable Range
Artificial Light	$[50lux, 2000lux]$
Temperature	$[18°C, 24°C]$
Relative Humidity	$[20\%, 60\%]$
Ambient noise	$[0db, 60db]$
Step Count	$[6000, 10000]$
Heart Rate	$[60bpm, 75bpm]$

Table 1 display a simplistic demonstration of expert rules that define acceptable intervals for attributes that can be monitored from environment or users. These showcase what is considered normal ranges in which human behaviour is not negatively effected. If sustainable solution would violate these conditions then it is likely that at least the social dimension of sustainability would be harmed as well. In the system, expert rules act as means to assess indicator results and give them human interpretable meaning.

4 Case Study

The PHESS platform was used to perform experiments validating the theory presented in this research paper. The cases selected were a household environment and a office environment. These environments were set up in the PHESS platform by their physical representation. In each case, fixed and mobile sensors where introduced as in the configuration.

The target was to control, environment comfort, physical condition and compound targets that combine expected contextual conditions with expert rules to design smart notifications to end users. To this end, the creation of time-sequence context was used to gather information about contextual information on each user. Notification were addressed each time

The fixed sensors used were: an electricity meter to monitor energy consumption, temperature and humidity to monitor environment state. Furthermore, mobile sensors linked to users inside of each space was demonstrated by the use of smartphones, RFID tags and smartwatches data.

The professional environment is composed by a large room inside a office building frequented by a variable number of users. Ergonomic rules are obtained by the required conditions of office work documented by ergonomic studies. On the other hand, the house hold environment is composed of a number of room in which localization determines only weather the user is present in the environment. The sensor reading are also relative to the as generic data about the total building. Expert rules for each case are determined by expert rules as detailed in section 3.2. These rules are transmitted to the PHESS platform which will manage contextual information to extract the maximum benefit for optimization and saving measures while preserving sustainable parameters.

Table 2 User time-sequence results

	Household Environment	Office Environment	
	User 1	User 1	User 2
Actions Detected	53	104	96
Indicators Monitored	4	4	4
User Notifications	2	4	5

These experiments occurred over in distinct time-frames but they had the duration of a full week of analysis. In table 2, preliminary result, indicate the number of actions detected and indicators and notifications towards the end user. Indicator design was generated in the PHESS platform and included attributes to monitor sustainable indicators according to the dimensions of sustainability. The indicators are related to the thermal comfort according to the PMV indicator, noise levels, electrical lightning consumptions and number of active steps executed by a user. Notifications are generated according to the compliance of ergonomic rules during the day taking in consideration the last two hours and a proportionate expectation for each indicator. For instance in the case of thermal comfort it is not expected to by violated during the day, but the number of steps is divided by the number of active hours during the day. Electrical optimization is made detecting the need for artificial lightning with weather and solar exposition inputs and their relation to electrical consumption needs.

Table 3 Indicator predicament based on user context

Input	Output	Accuracy
Time & User & Environment	Thermal Comfort	83%
Time & Action User & Environment	Thermal Comfort	84%
Time User & Environment	Electrical Optimisation	72%
Time & Action User & Environment	Electrical Optimisation	68%
Time User & Environment	Noise Comfort	75%
Time & Action User & Environment	Noise Comfort	86%
Time User & Environment	Steps	71%
Time & Action User & Environment	Steps	88%

The context in strips of time-sequence actions, reveals behaviour according to actions and provides historic information to machine learning models. In this case predictive action are produced to derive Indicator values according to time or time and action as input. It is possible to see in this example that some routines have more impact on indicator values than other. For instance time and action provides a contextual information that improves the predicament of noise comfort and steps activity during the day. These indicator are clearly more dependent on the activities performed during the day while the other indicator seem to have similar results when only time is considered as input.

This assessment shall be used in the future to suggest activities that improve have impact on the monitored indicators. The strategy employed here might yield good results and also identify which activities have the most success to improve such indicator values according to each user habits.

5 Conclusion

Context based on action time-sequences provides context in which actions are made. It is possible to observe which actions are based on context or based on user routines independent of context. The novelty proposed by this work is the middleware and data processing for the creation of sustainable machine learning models based on user activity detection. Furthermore, these models shall support the development of sustainable applications that take advantage of such models and information.

Time-sequence creation from basic aggregate, slice and sample provides a simple work-flow which is powerful enough to deliver meaningful results which can be used to deduce conclusions about future behaviours.After modelling each time strip, contextual records are ready to be used by machine learning models. Results show that the composed values of indicator can be expressed either by time-sequences, but for some indicators, better results are yield when action is present. In fact, the improvement of the prediction of activities seems to indicate that some activities have more impact on indicator values and thus more prone to be used in suggestion systems.

As future work, there is the need to exploit other models for user context modelling, as well as, the design of better activity detection sensors, based on improved data fusion techniques and heterogeneous devices. The objective is to exploit more sources of data to interpret activity engagement by users. Assessment of time-sequence strips and categorization of sustainable indicators values can be used to fuel both environment actuators and leave notification design system as a fall-back when no actuator can mitigate the impact on indicators.

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3.2.3 Assessing Road Traffic Expression

Scope of the International Journal of Interactive Multimedia and Artificial Intelligence

The International Journal of Interactive Multimedia and Artificial Intelligence (IJIMAI) provides an interdisciplinary forum in which scientists and professionals can share their research results and report new advances on AI tools or tools that use AI with interactive multimedia techniques.

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Assessing Road Traffic Expression

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Department of Informatics, University of Minho

***Abstract* —** Road traffic is a problem which is increasing in cities with large population. Unrelated to this fact the number of portable and wearable devices has also been increasing throughout the population of most countries. With this advent, the capacity to monitor and register data about people habits and locations as well as more complex data such as intensity and strength of movements has created an opportunity to contribute to the general wealth and comfort within these environments. Ambient Intelligence and Intelligent Decision Making processes can benefit from the knowledge gathered by these devices to improve decisions on everyday tasks such as deciding navigation routes by car, bicycle or other means of transportation and avoiding route perils. The concept of computational sustainability may also be applied to this problem. Current applications in this area demonstrate the usefulness of real time system that inform the user of certain conditions in the surrounding area. On the other hand, the approach presented in this work aims to describe models and approaches to automatically identify current states of traffic inside cities and use methods from computer science to improve overall comfort and the sustainability of road traffic both with the user and the environment in mind. Such objective is delivered by analyzing real time contributions from those mobile ubiquitous devices to identifying problematic situations and areas under a defined criteria that have significant influence towards a sustainable use of the road transport infrastructure.

***Keywords*— Traffic Expression, Smart Cities, Computational Sustainability**

I. Introduction

Current trends such as smart cities and the internet of things has focused attention towards the quality of living and well-being inside big cities . It is also believed that most people will be living inside cities until 2050. If true, such statement would predict the increase of road traffic in cities that were not neither originally designed nor prepared to handle such influxes of traffic. Ambient Intelligence (AmI) is a multi-disciplinary subject that is equipped with procedures that may help solving such problems taking advantage of fields such sensing systems, pervasive devices, context awareness and recognition, communications and machine learning. It is currently applied in a number of applications and concepts in fields like home, office, transport, tourism, recommender and safety systems, among others [1] .

Road traffic analysis is an expensive and time consuming task which traditionally involves direct evaluation and field studies to assess and evaluate the impact of the flux of traffic in certain cities. An alternative to this is simulation experiments provide possible scenarios under which some assessment can be made. However, the downside of simulation lies in the use simplified models that are thought to mimic reality when in fact they may differ to some degree. Ubiquitous sensorization may be used to assess current traffic conditions, avoiding the use of costly field studies. Example of ubiquitous sensitization can already be found in certain areas such as traffic cameras and smart pressure detectors to assess traffic flow in specific points. This sensing is limited to the area it is implemented and does not provide information outside its operating range [2], [3]. More complex studies can be made with portable ubiquitous devices that follow drivers either because there a sensing device in the vehicle or the person driving carries a portable sensing device able to capture data related to driving. The nature of mobile ubiquitous devices also enable the possibility of direct analysis of driver behavior and community habits (points of congestion, high speed hazardous corners, aggressive sites) assessed trough the statistical treatment of driving records and offer safer alternatives for navigation with such information. These models have a direct impact diagnosing the current state of traffic and traffic behaviors to each route that may be used in modern GPS navigation systems, as an additional parameters.

Other approaches for the use of ubiquitous sensing devices involve real-time safety assessment, in [4] and [5] where a set of indicators is used to assess driving safety. Such indicators take into consideration the time of reaction, vehicle breaking time and whether or not there is a collision course. Yet, the analysis is still limited to the visible surrounding area and activities such as identification of other vehicles within the nearby space with the help of video interfaces disregarding sources of information outside that scope. In transport applications inside an area also known as Smart Cars, the AmI system must be aware not only of the car itself and its

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surroundings, but also of the driver's physical and physiological conditions and of the best way to deal with them [6]. The driver's behavior is important with several authors proposing machine learning and dynamic models to recognize different behaviors in drivers [7]. There are also examples of applications integrating AmI and ubiquitous principles in driving and traffic analysis. In [8], it is described a monitoring and driving behavior analysis system for emerging hybrid vehicles. The system is fully automated, non-intrusive with multi-modal sensing, based on smartphones. The application runs while driving and it will present personalized quantitative information of the driver's specific driving behavior. The quality of the devices used to perform such monitoring have a direct relationship to the quality of the measurement, thus, in this case, it is the main source of measurement error which needs to be controlled and contained to known error values order to make this study effective to production use. Other advantages include the possibility to increase information quality and create new routing styles in existing navigation systems taking into consideration aspects such as driver's driving style or accident or hazardous events rate during the routing planning phase.

Other approaches to analysis of driving behavior can be found in [9] a mobile application assesses driving behavior, based on the identification of critical driving events, giving feedback to the driver. The I-VAITS project [6] is yet another example that pretends to assist the driver appropriately and unobtrusively, analyzing real-time data from the environment, from the car and from the driver itself, by the way the driver uses the different elements of the car, their movements or image processing of their face expressions. In [10], in the context of a car safety support system, an ambient agent-based model for a car driver behavior assessment is presented. The system uses sensors to periodically obtain information about the driver's steering operation and the focus of the driver's gaze. In the case of abnormal steering operation and unfocused gaze, the system launches proceedings in order to slow down, stop the car and lock the ignition.

An alternative approach to the use ubiquitous sensing is to gather information about the condition of the environment the driver is in, mapping it to further use. In the Nericell system [11], from Microsoft Research, monitors road and traffic conditions using the driver's smartphone and corresponding incorporated sensors, but it can also detect honking levels, road condition and potholes as an example.

In what refers to devices used, there are today a wide range of options that can be used. The most effective should be portable devices that are always present and can perform complex tasks while not requiring user's direct attention. In such list, there are devices like smartphones, smartwatches, and intelligent wristbands. Those offer the advantage of accompanying user from one situation to another, however there are devices that can be used that are more specialized such as the internal computer of a car. In this last case the object itself becomes part of the car which might increase its production cost while on the other hand multi-purpose portable devices might suffice to the work described.

The work described in this paper tries to enhance ubiquitous sensing for driving applications with the objective to support the concept known as sustainable driving. It requires the gathering of information about traffic condition but also, consciousness about sustainability dimensions such as environment, economic and social. With this in mind optimization should consider more than just economic aspects of driving, but also consider fuel emissions and social aspects such as driver's status, attention and driving style. Such work should complement existing other works and act as a platform for smart city traffic assessments. Moreover, the information generated by such system may be useful to third party systems which may use the knowledge base in their management applications and management systems.

II. Computational Sustainability

A. Computational Problem

The term computational sustainability is used by researcher such as Carla Gomes [12] to define the research field where sustainability problems are addressed by computer science programs and models in order to balance the dimensions of sustainability. It is accepted that the world ecosystem is a complex sustainability problem that is affected by human and non-human actions. In order to tackle these problems complex management systems should be put in practice in order to predict a number of attributes related to the sustainable problem at hand. Nevertheless, the pairing between computer science and the study of sustainability is as old as the awareness of sustainability and the availability computing systems. It is a fact that, as computational power capacity increased over time so did the complexity and length of the models used to study sustainability. The advent and general availability of modern techniques from artificial intelligence and machine learning allowed better approaches to the study of sustainability in a wide range of domains such as smart cities and transport systems.

Classical computational sustainability problems are not only found in smart grids, pollution, and distribution of energy but also city traffic. Considering the definition of sustainability and the topic of traffic expression, the use of computational methods to monitor and assess and optimize the transport efficiency are already used in systems today [2], [13], [14]. Nevertheless, the efficiency problem need to consider all dimensions of sustainability in order to become complete. The systems need to concern the optimization of not only traffic flow, economy and emission but also emissions, safety, and driver awareness.

In order to proceed to the collection of data and information required for the assessment of transport and traffic sustainability there are a number of topics under computer science that may be used. Perhaps, the most obvious would be the traditional methods of information acquisition through the sensorization of the environment and users, ambient intelligence, ubiquitous computing and information and data fusion. Less obvious techniques, concern the dynamic modelling of the environment and simulation of real world states when subjected to the conditions under study. The computational problem is therefore created by the means used to acquire this information and the resolution of the problem under the computational sustainability which include resource constraint optimizations, the satisfaction of dynamic models and preservation of statistical behaviors and actions.

B. Sustainable Driving

Traffic assessment is directly related to trending topics such as ubiquitous and pervasive methods that allow the balancing of economic, environmental and social factors needed for sustainable development. A new emerging and interdisciplinary area, known as Computational Sustainability, attempts to solve problems which are essentially related to decision and optimization problems in correlation to welfare and well-being. Due to its importance, some researchers have discussed and proposed quantification methods, and modelling process for sustainability [15], [16].

Often, decision and assessment are based on measurements and information about historical records. Indicator design provides an explanation on why such decisions are being made and it often uses information fusion to create and update its values. From a technological point of view, indicator analysis uses different and sometimes nonstandard data which sounds feasible by technological data gathering software that collect, store and combine data records from different sources. In the case of transportation systems, the assessment of the impact of a given driving pattern is made over sustainability indicators, like fuel consumption, greenhouse gas emissions, dangerous behavior or driving stress in each driver's profile.

Applications and systems that deal with this information acquisition and reasoning are already present in the literature. A system to estimate a driver profile using smartphone sensors, able to detect risky driving patterns, is proposed in [17]. It was verified whether the driver behavior is safe or unsafe, using Bayesian classification. It is claimed that the system will lead to fuel efficient and better driving habits. In [18], and in addition to car sensory data, physiological data was continuously collected and analyzed (heart rate, skin conductance, and respiration) to evaluate a driver's relative stress. The CarMa, Car Mobile Assistant, is a smartphone-based system that provides high-level abstractions for sensing and tuning car parameters, where by developers can easily write smartphone applications. The personalized tuning can result in over 10% gains in fuel efficiency [19]. The MIROAD system, Mobile-Sensor-Platform for Intelligent Recognition Of Aggressive Driving [20], is a mobile system capable of detecting and recognizing driving events and driving patterns, intending to increase awareness and to promote safety driving, and, thus, possibly achieving a reduction in the social and economic costs of car crashes.

In [21], an android application is depicted which makes use of internal vehicle sensors to assess driving efficient patterns. With information about throttle, breaking and consumption the application is able to provide driving hints in real time according to a set of predefined rule matrixes. In this case the application is focused on fuel efficiency. A more compressive study for the use of driving and traffic data can be found in [22]. This analysis considers the availability of data internal vehicle sensors, traffic data through internet services and historic driving patterns records to help the creation of more efficient navigation plans.

From the systems reviewed, there is clear focus on the lower level problem towards sustainable driving. The interest for the consideration of the sustainable problem across all of its dimensions is not the primary target of these systems but rather themes like safety, efficiency and driving profile through event detection. These applications do however fit in the category of computational sustainability as computational tool that may be used on a subset of the driving sustainability problem.

Our interpretation of the application of computational sustainability in sustainable driving is represented in figure 1, where sustainable driving is obtained through 3 types of problems that can be applied to each dimension of the classical definition of sustainability separately or in conjunction. Those 3 problems consider constraints optimization and reasoning problems, acquiring and storing information through sensorization statistics and machine learning procedure and building dynamic models that can express the state of the environment and its participants so that the impact of decisions may be assessed.

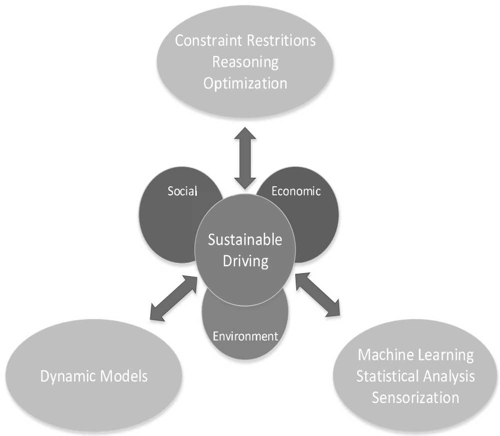

Fig. 1. Sustainable Driving Approach

In this work, the theme of sustainable driving will be addressed using a ubiquitous system for data acquisition integrated in a sustainability framework for the building of dynamic models that express the behavior of traffic and its conditions.

III. Driving Evaluation

A. PHESS Driving System

The People Help Energy Savings and Sustainability (PHESS) project is being developed to help drive awareness towards the need for sustainable and energy efficient behaviors [23]. The framework is based on distributed system of multi-devices that generate data towards the creation and maintenance of indicators in the platform [24]. In order to drive awareness, specialized modules were developed that target user attention, mood and engagement. Through a set of usage real world scenarios the platform is being demonstrated across different applications [25].

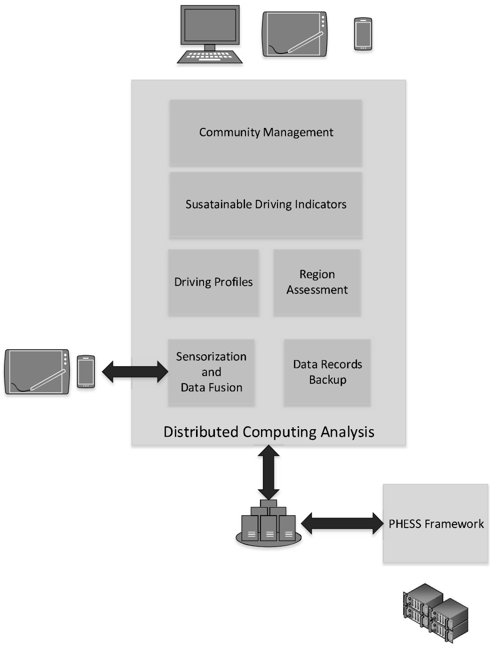

Fig. 2. PHESS Driving Architecture

In regards to the work presented in this paper, the driving scenario is being targeted. Figure 2, illustrates the system designed to monitor, assess efficiency and sustainability in driving actions. As a building blocks to assess sustainable driving the system uses both driving profiles from the data gathered while driving, event detection from the analysis of such data and indicators defined in the PHESS platform. The indicator definition is made with application both in the driving profile definition and the analysis of regions in cities. That procedure reduces complexity while it does not lose much of the information in the aggregation of data records and information and becomes more meaningful.

B. Indicator Development

In order to produce information about traffic flow and route safety it is necessary to gather information about relevant information about driving patterns. The focus of our analysis was derived from indicators accepted in related studies in the literature review. Towards this effect it was considered the following indicators:

- Average velocity;
- Average fuel consumption;
- Intensity of acceleration and breaking;
- Number of breaking and accelerating events per time unit;
- Standard deviation of velocity, intensity of breaking and acceleration and number of breaking and accelerations;
- Number of turn events based on curvature detection;
- Intensity of force exerted in the vehicle during turns;

All of the indicators defined and built upon ubiquitous mobile sensorization, thus limited to their sensing abilities. Even so, some of the indicator defined are obtained through simple statistical procedures over the recorded data like average speed, number of breaks and standard deviations. The intensity of acceleration and breaking events is a more challenging task. Due to the usage of mobile smartphones, sensor access is not easily controllable. Efficiency measures make data reading uneven in time meaning sometimes there is oversampling where others there is under sampling. In order to mitigate such problem the assessment is made using the linear slope from the line connecting an initial and final velocity over a period of time as presented in equation 1. Such slope provides a mean to assess intensity that is independent of the size of the time interval.

$$Slope = \frac{v_f - v_i}{t_f - t_i} \quad (1)$$

Number of breaking and accelerating events are measured in time windows, referenced as per unit of time. Defining an event window is helpful because only accelerations and breaking inside such window are considered and can be analyzed and compared between time windows.

Average fuel consumption is obtained from the fusion of user input data and the distance travelled. As an initial setup the user is required to configure the smartphone with a number of initial variables such as vehicle model and vehicle average consumptions. The aggregation of different vehicles in a large scale analysis makes this indicator more relevant for analysis.

Curve and turn detection is a special event due to characteristic and driving difficulty. Due to car handling, driving inside curvatures can present a risky task specially if driven at too much speed or under high breaking or accelerating intensity. As a consequence, for this analysis, a special strategy is employed which monitor the degree of curvature trough smartphone sensors.

$$Direction = \tanh(\sin(\delta_2 - \delta_1) * \cos(\varphi_2), \cos(\varphi_2) * \sin(\varphi_2)) - \sin(\varphi_2) * \cos(\varphi_2) * \cos(-(\varphi_2 - \varphi_2)) \quad (2)$$

Equation 2 demonstrates the formula used to track angle difference in the direction between two points. As the curvature becomes more intense the road curvature is identified as potentially more dangerous than others. The intensity of forces while driving inside curvatures is monitored using the intensity of the accelerometer vector, equation 3.

$$Intensity = \sqrt{Acc_x^2 + Acc_y^2 + Acc_z^2} \quad (3)$$

The indicator analysis uses a three level classification scheme based on the statistical occurrence of the indicator value being accessed. For the classification definition, quartiles are used as a mean to identify outlier data in each indicator and classify it differently. Consequently the procedure adopted was to order the sample data records and classify data between the 80-95% quartile as yellow events, the data above the 95% quartile as red events and the rest as green events. This leads to the assumption that most drivers will have an adequate driving style for the most of their trips. In table 1 it is presented, the classification for each indicator represented in this paper.

C. Driving Profile

The usage of roads can be affected by driver's driving patterns. It is accepted that some drivers have a predisposition to drive more aggressively than others and there are significant deviations in their behaviors. Our approach uses this thought to gather the driving records from a community of users to classify different driving patterns to different people and link that data geographically in later analysis. The driving profile is based on the indicator defined in this papers plus attributes that respect directly to the person's driving profile. Thus the list of driving attributes considers the indicator plus the list of attributes:

- Time of day;
- Trip average duration;
- Standard deviation of trip duration;
- Average maximum and minimum velocity per trip;
- Number of cars driven.

With those measures, a complete profile can be designed and executed in applications that monitor current driver's performance. In [26], [27] other parameters were used to collect data from ordinary drivers in real traffic situations, such as wheel rotation, engine speed, ambient temperature, use of breaks and fuel consumption. In these studies, GPS data was also monitored, where each driving pattern was attributed to street type, street function, street width, traffic flow and codes for location in the city (central, semi-central, peripheral). It was concluded that the street type had the most influence on the driving pattern. The analysis of the 62 primary calculated parameters, resulted in 16 independent driving pattern factors, each describing a certain dimension of the driving pattern. When investigating the effect of the independent driving pattern factors on exhaust emissions, and on fuel consumption, it was found that there already studies with a common number of factors amongst the literature. Due to the decision to implement a pervasive system over mobile sensorization the work here described will account the attributes that are able to be collected by smartphone applications.

While these attributes characterize driving in a long term analysis, such strategy might miss spontaneous events that occur sporadically. An example of such is a sudden break with high intensity. In order to deal with these one-off events, other attributes are of relevance:

- Force exerted in the car;
- Slope of the line connecting initial to final velocity during breaking and accelerating events;
- Degree of the curvature of the road and force exacted in the car.

It is important to stress that these attributes are already accounted in the driving profile because they are also defined as indicators in the PHESS platform.

D. City Analysis

The usage of roads can be affected by driver's driving patterns. It is accepted that, if the majority of drivers have a predisposition to drive more aggressively in certain areas than others, then those areas are more dangerous. Our approach uses this thought to gather the driving records from a community of users and use them to calculate potential hazardous spots inside cities. Most evaluations are made using standard driving attributes, matured in the literature over a number of studies across different authors and projects. This kind of analysis is only possible with a dedicated user community that constantly updates and makes use of the platform supporting these models.

There is information that is dependent on external conditions of traffic and not related with driving itself. The platform developed will try to assess external condition using context estimation from the data gathered. The strategy employed uses indicator data linked with geographical data to define such context information. The indicator data is aggregated over a squares of geographical regions and their average value is computed. The granularity of the assessment is dependent on the size of the squared region. Nevertheless, such approach with an appropriate level of granularity is able to assess regions with high congestions rates or with high average speed, as an example. In this case, the velocity recorded by users is aggregated inside each square of terrain. The same analysis is available for other indicators in this systems and displayed in the same manner. Value added information produced in the system is published using a range of public web services. These web services provide public information about current traffic and driving conditions as well as, modelling analysis based on the historical data available in the platform.

Aside from driving study, other analysis can be made with the help of context conditions. Such conditions include weather, traffic congestion and time of day, for instance. Each example can have significant influence on the safety and on the assessment of attributes related to driving. Aggressiveness and dangerous behavior has different meanings in any of these conditions and while some concepts are broad enough to be used by all, others are situation specific meaning that what is dangerous in one situation might not be in another. Usually, driving patterns are defined and associated to the speed profile of the driver, but it can be expanded to other variables, as gear changing, and big changes on the acceleration [27]. Experiments with communities are often used to provide real time analysis of geographic conditions and events, with examples of such in the Waze platform [14]. However, they are the lacking features of historic analysis and historical supported suggestions.

The aim of this work is to focus on intangible and soft attributes which we define as attributes that are not directly observed by data records but rather computed with techniques from static analysis and machine learning processes. Such attributes should be used to find hidden patterns of road usage that might be missed in standard traffic flow simulations. Examples of such errors in simulation include driving aggravation due to unforeseen events even with normal traffic conditions.

IV. ANALYSIS AND DISCUSSION OF STUDY RESULTS

Although this work is not using the internal data from vehicle sensor system as in past research [26], the approach followed in this work uses smartphone data for ubiquitous and pervasive monitoring. Data gathering is made through sensors, which is pre-processed internally with data fusion methodologies to enrich data and provide richer information. The number of variables used to assess driving patterns is based on the indicators and driving profiles defined.

Using indicator assessment over normal car trips in the system it is possible to take note on each point detected by the GPS sensor the indicator classification. An example of such mechanism is present in figure 3.

Each view can be personalized taking into account all indicators or a subset of them according to their interest to the analysis. Using the indicator classification it is also possible to assess whether or not there are dangerous systematic behavior in each driver's driving profile. Such task may be accomplished by assessing each indicator present in the profile. Other approach would be to directly compare driver's inside the community by their driving profile attributes.

Fig. 3. Event Detection Based on Indictor Analysis

The model described in this article was tested as a complimentary module to a sustainability framework PHESS. Its aims are to produce and generate knowledge that can be used to perform decisions and suggestions that have a direct impact on sustainability and the sustainability of user's actions. More than a responsibility framework, it is intended to increase awareness to sustainable problems that arise from user's own actions and road usage by drivers.

Taking into consideration a test city with a community of 10 users, it is possible to assess the sample metrics and indicators defined. Using the strategy described in the section city analysis a demonstrative example of the region grid classification of indicator is made in figure 4. In order to analyze the classification and demonstrate that the scale has been appropriated to detect a small but significant set of yellow and red events. Such detection mechanisms can be improved with more technical data about dangerous events or even adjust the quartiles used for classification, nevertheless the proposed approach provides satisfactory results.

Each event is characterized in the map, and for the user it is possible to see the information relevant to that assessment. On the other hand, figure 4 does not provide event level explanation but rather a set of filters with each indicator defined that may alter the map zone classifications according to whether or not they are selected.

The map covered by the identification of low and high average speed squares is within the expected range but varies according the time of day, however the location of squares is preserved although with different averages. Our approach, identifies such metrics on daily basis but the identified spots are within 10% to 15% of the visible map.

As with the analysis on figure 3, the analysis present in figure 4 may only include a subset of indicators in its representation thus simplifying the analysis of the map.

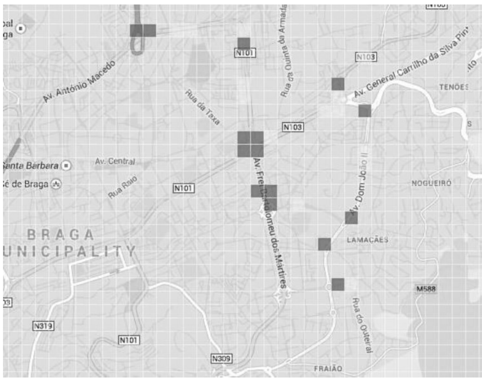

Fig. 4. Region Analysis

The results provided are based on web services which take information from the central distributed system to deliver information to graphical tools that display the information. In this case standard webpages were used.

While the results are satisfactory, future development should improve the social dimension of sustainable driving defining indicator directly associated with driver actions and emotions.

V. CONCLUSION

The use of pervasive devices already adopted by communities of users possess enough information and computing ability to build collaborative systems to tackle complex tasks. City traffic evaluation is one of such problems that are costly to audit and diagnose structural problem but can be simplified with crowd computing. Results are seem as satisfactory are reliable with the possibility to adjust according to specifics needs or needed improvement. The use of mobile sensors does constitute an additional effort to mitigate external influences such user involuntary movement, measurement and coverage errors. Nevertheless, the outputs generated in this platform were also found of relevance to the study of sustainability, where the intangible metrics and the structures employed to the indicator analysis pave the way to building sustainability assessing indicators able to join general purpose sustainability assessment frameworks such as the platform PHESS in discussion in this work.

In future iterations there are plan to update from grid analysis to road detection and road analysis becoming more accurate. Also, the validation of experiments on other cities are planned in order to prove both resilience and adaptation of the system. Integration of metrics found by this platform in common navigation systems are planned on the long term project, thus influencing routing options of people and acting as a true pervasive and ubiquitous object directing people away from dangerous situations into more comfortable and safe environments

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3.3 Summary

The experience compiled for the structure presented in this archetype is based on the compilation of previous experiments both in the course of this doctoral programme and through the collaboration of master students which participated in the elaboration of testing scenarios for the PHESS platform. Although, a robust approach, it can still be extended with new features and case scenarios which was the main justification for a modular approach when building this archetype.

The current approach relies on the existence of intelligent environments with sensors configured in the environment to create a distributed system that acts both locally and centrally. The local nodes employ basic functions such as data collection, local data fusion and communicate with the central nodes for community management, user profiling and notifications. Mobile applications and webpages are used to interact with users. Mobile applications are also used as sensory devices where their internal sensors are used to the benefit of the platform. The notification system employed is based on web applications and mobile application, both of which can receive and show users the recommendations of the archetype platform.

Add-on modules reinforce the strategy of adaptation and incorporation of strategies to promote overall sustainability and sustainable efficient behaviours while keeping in mind user and environment needs. For this analysis, these modules target subjects such as indicator design and modelling an simulation. Specifically, the affective computing modules detail an alternative approach for the management of user reactions towards an environment in a way that results in the anticipation of discomfort. On the other hand, gamification elements are used to foster the development of user awareness and user competition. Combined with suggestive algorithms, it is possible to see users compete while guiding them with proposals for sustainable behaviours.

The major contribution is the adaptation of the archetype to different case scenarios where the PHESS archetype platform can be used. The case studies presented consisted of environment applications, urban transport areas and assessment of well-being. Results of these case scenarios are not only in form of laboratory experiments and field experiments but also computer simulation from models acquired and stored in the PHESS platform.

Chapter 4

Conclusions and Future Work

4.1 Discussion of Results and Conclusions

The use of computational sustainability in intelligent systems enforces the idea of sustainable behaviour and the sustainable use of resources. This benefits and contributes to the betterment of society. By means of computer science, autonomous procedures can be developed to create and maintain sustainable parameters. The developments found trough the use of these platforms can be integrated into new concepts such as IoT and Smart City design as an additional layer for its efficient management.

The experiments detailed in this thesis go beyond the study of computational sustainability as a research field. They consider intangible dimensions such as comfort and behaviour promotion and modification. The contribution to the state of the art offer an integrated view of the application of methodologies, not only to assess sustainable parameters, but also their acceptance by users and means to motivate behaviour change.

A conceptualization of an archetype platform was developed to answer the research hypothesis defined in section 1.1.2. The development of this archetype was supported by experimentation to answer the research questions which are also validated by the elaboration of demonstrations of the application of the archetype platform. From computational sustainability and sustainability assessment to user affective computing and gamification for behavioural change, the work in this doctoral program evidenced the use of ambient intelligence, machine learning, context awareness, social behaviour analysis as tools to answer the research hypothesis.

In this doctoral work the research questions were addressed by the archetype where the application of knowledge gathered by literature review and previous experimentation phase helps justify research activities.

The first and second research questions regarding the approach by multi-agent systems and the indicators assessment, are addressed by the core module of the PHESS archetype. In here, the use of software agents enables the management of data sources either by software interfaces or software services. For instance, software interfaces are applied with connectors to hardware such as sensors and actuators which allow environment and user sensorization while software services are applied to the search of information through broker services such as IoT and other information available in the internet. Data fusion processes fuel the creation of sustainable indicators and their update in the platform. With dedicated agents it is possible to manage data flow from the acquisition of the necessary attributes to the management of fusion processes. The process is generic and adaptable to different definitions for sustainable indicators. Accountability is defined based on global strategies such location of users and environments compared to the indicators they refer to. It is possible to achieve room by room or user by user precision depending on the implementation and availability of data.

The third research question regarding the application of affective computing is addressed in the creation of the affective module in the PHESS archetype. It enriches the platform with affective considerations such as mood estimation according to premisses taken from literature review. Mood was chosen because is a stable manifestation of the user affective interpretation of environment variables. Therefore, a representation of beliefs, personalities and weights to each belief are composed into an affective engine that estimates the probable mood state each specific user is likely to have in the environment. Nevertheless, its assessment detail user response under normal circumstances where other external factors are not considered. This limitation can be limited by increasing the attributes used to estimate mood states, more accuracy in the interpretation of user personality and tuning the engine according to specific populations of users. Experiments on this field, demonstrated the affective evaluations follow norms of user comfort with the attribution of negative feelings to discomfort states and vice-versa.

The fourth research question regarding user awareness, user suggestion and behavioural modification was addressed by the elaboration of user and environment profiles to raise user-awareness and competition through gamification modules in the PHESS archetype. This shows and identifies both good and bad sustainability indicators to each assessment. From these, suggestive models were demonstrated both based on expert knowledge and through the use of community knowledge. Suggestion can be produced either by deductive reasoning inside PHESS or taking into account the experience of community of users as it was demonstrated with the application of case-based reasoning. Gamification implementation use awareness and suggestions in competitive environments to support and motivate the need to behavioural change either by self-realization or suggestion made within the platform. These use cases, were validated on the implementation of the PHESS platform as shown in chapter 3.

The application of the platform in case studies documented in science forums demonstrates the validity of results achieved. From environment to urban transports the archetype was successfully migrated across fields of application taking the insight of computational sustainability alongside. Strategies to assure user comfort and user engagement are delivered by add-ons structure which results from the definition of the archetype. These add-ons, mood estimation and gamification, provide means to manage users locally and integrated into communities.

From these developments, there are possible routes for further improvement and validity of the experiments taken. The modular approach to the archetype enables these future development while keeping knowledge already acquired.

4.2 Prototypes and Case Studies

From the work elaborated in the context of this thesis, one visible result are sample applications and case studies which take the form of prototypes and case studies. In this section, a brief explanation of the relevant application is conducted.

4.2.1 People Help Energy Savings and Sustainability

During the research activities conducted during the doctoral program, the PHESS platform was specified embedding the results being portrayed. This application in particular, is the implementation of the archetype for home and professional environments. This platform, encompasses modules for data acquisition, information retrieval and automated modelling and suggestion based on the components available.

Although it is poised for energy efficiency, this framework requires a set-up phase where administrator set their objectives, their indicators, control attributes, devices used and a representation of the environment being sensed. It is the flexibility in indicator representation and communication channels that allows this framework to support the works done in the context of doctoral program.

Aside from performing and conducting reports based on user and environment sensors, the platform acts also as an open data system which can receive and provide data to external applications. This useful feature was embraced by master students which took interest in experimenting with the platform and its data for their own applications.

4.2.2 People Help Energy Savings and Sustainability - Driving

This prototype portrayed the use of the PHESS platform for new environments and sustainability scenarios. In this case road sustainability requires the perception and treatment of data across a large environment, the road and transports system. Though complex the systematic approach using indicator analysis proves useful and meaningful.

This approach was used to demonstrate the flexibility of the PHESS platform and the robustness of the solution found.

This project actively collects data from ubiquitous devices using the PHESS platform and maintains driving indicators both local to the user and to a community of users. It also features intelligent user notifications and gamification to influence the community of users towards sustainable behaviours.

Among its strong points, this application is able to quickly demonstrate problematic behaviours to the users by mean of driving indicators defined based on literary review. The aggregation of these indicators transforms user data into community knowledge managed by the platform. The community indicators are used shown to the user as overlays in map data.

4.2.3 Gamification Platforms

As part of the demonstration of the PHESS framework, gamification platforms were developed taking advantage of the gamification module created. In this sense, two platforms were developed taking advantage of the main study cases developed: intelligent environments sustainability assessment and urban transportation, the original PHESS implementation and the PHESS Driving implementation.

Both follow the same structure, as they are derived from the same module, but the customization allows the creation of specific rules, levels and achievements targeting each use case scenario. Both integrations are able to deal with community management and promote sharing of information through users to motivate competition. A platform administrator is responsible for setting objectives and leading user by promoting the acquisition of new behaviour through game rewards such as points and achievements.

The application of gamification to each scenario was developed taking in consideration the indicators created in each scenario. Therefore, the visual aspect of each implementation differs slightly to accommodate each implementation specificity. If in the same case environment and its division are taken into consideration, in the second implementation user driving trips take that role.

4.2.4 Ambient Sensorization

Developed as a home sensorization environment with self-learning, this project was realized in collaboration with master students also using the the PHESS platform as a stand point. It acts as a data collector and classification platform relying on the PHESS platform to deliver its classification and predictive services.

The main driver behind the use of this application was to classify an environment according to its safety and comfort. For such, a two-step based indicator classification was used. Firstly, security indicators were designed which take into consideration sensors which may detect hazardous situations for human living such high temperatures or toxic gases. After safety parameters, then comfort values are assessed.

The sensors were also built recurring to arduino boards equipped with communication through usb connection and bluetooth connection. This implementation was also adapted to connect to the PHESS platform to register data.

Finally, a prediction of comfort and security was available based on the historical records present in the platform. This was supported by machine learning and context variables such time, epoch and immediate sensor values prior the estimation. The prediction was notified to the user both through mobile device and email whenever a possible discomfort or unsafe situation was predicted or sensed.

4.2.5 Emotion Recognition from Environment Attributes

The search for affective indicators lead the development of mood and emotion recognition. This prototype produces an approach to estimate emotions based on the perception of user personalities with the use of questionnaires, and the perception of environment attributes such as temperature, humidity and luminosity. Expert rules dictate the mood variance according to each user predominant mood based on their personality assessment.

This application was based on a simple implementation of the PHESS platform where the affective module was used. Contrary to most use cases, this application was developed as a desktop application which connected to the PHESS platform and was able to insert software agent to communicate inside with the PHESS multi-agent platform.

Later implementation of the application were integrated into websites and used in scientific research which resulted in the publication of scientific articles.

4.3 Research Directions

The quest for sustainable systems is determined by scientific development. These system are constrained by the current knowledge available that undermines sustainable solutions. Therefore, as scientific discovery increases so do sustainable solutions and, as a consequence, optimal solutions need to re-calculated. Time is a cornerstone of sustainability, and solutions regarded as optimal tend to lose their status as time increases leading to the necessity of adjustments. New research directions need to take this view into account, and drive the development of these systems as scientific and industrial behaviour shifts, improves or diminishes.

Aside from time, external factors may impair sustainability beyond what is actually foreseeable. Catastrophes and crimes, can impair sustainable solutions to the point where significant and extensive modification need to impair perception such as security, comfort or well-being. Thus, reclassification of these fundamental definitions may drive sustainable solutions to areas that actually harm traditional human behaviour. A study to classify such risk would also serve as a warning towards the current user base and actually increase user-awareness.

Automatic response from ambient actuators to changing condition being them predictable or unpredictable are a natural response for the points discussed above. Nevertheless, automatic actions drive responsibility to the system making them. Severe restriction and the liberty to make decisions have impact on the possibilities such systems. These conclusions are extracted from robotic studies but can be applied in the case of computational sustainability. A software agent need to take into consideration restrictions based on different perspectives with different weight and consequences associated with them. Current IoT protocols and management system are rather mechanical, in a sense that they do not consider impact of actions and only follow commands to the best of their ability. Extending IoT to account for deliberative platform and restriction based on compounded indicators could improve the development of computational sustainability projects.

Computational sustainability faces hurdles to which solution in not directly assessable by mathematical means. Group decision, specially on aspects as intimate as comfort and well-being may lead to disputes and divergent opinions. Solutions to these problem require mediation which can be manual, assisted or fully automatic. Mathematical solutions based on logic induction or statistics are possible, but the stochastic nature of human behaviour needs special attention. Assumptions such as individual preferences that remain unchanged over time, are unrealistic and simply not true.

4.4 Dissemination of Results

As it was described in section 1.1.4 Research Plan, the work developed along the path taken throughout this PhD project was planned to have a high level of scientific dissemination through journals, conferences and prototyping of solutions.

Also, the participation in scientific meetings and the organization of scientific events were possible allowing knowledge consolidation that, otherwise, would not be possible. In addition, the experience gained in the supervision and monitoring of master students was an asset, that leveraged the PhD work.

Thus, in order to demonstrate the outcomes of the work developed, this section will encompass a review of the results achieved. For the publication of results, it was a privilege to spread the work through international events, both at conferences and in journals in the fields of Computer Science and Artificial Intelligence, and, also, in scientific meetings.

4.4.1 Publications

The work described in this manuscript was disseminated through the participation in scientific meetings in the fields of Computer Science and through the publication in international journals and conference proceedings.

4.4.1.1 International Journals

The work detailed in this thesis has been documented in international scientific journals. The folowing list presents the journal articles published:

- Silva, F., Analide, C., Rosa, L., Felgueiras, G., & Pimenta, C. (2013). Gamification, Social Networks and Sustainable Environments. International Journal of Interactive Multimedia and Artificial Intelligence, 2(4), 52. (ISSN: 1989-1660)

- Silva, F., Analide, C., & Novais, P. (2014). Assessing Road Traffic Expression. International Journal of Artificial Intelligence and Interactive Multimedia, 3(Regular Issue), 20–27. (ISSN: 1989-1660).

Further article proposals were submitted for publication and are currently under review are also presented:

- Silva, F. & Analide, C. Ubiquitous Driving and Community Knowledge. Submitted for publication in: International Journal of Interactive Multimedia and Artificial Intelligence (ISSN: 1868-5137).

- Silva, F. & Analide, C. Tracking Context-Aware Well-Being through Intelligent Environments. Submitted for publication in: Advances in Distributed Computing and Artificial Intelligence Journal (ISSN: 2255-2863).

4.4.1.2 Book Chapters

Along the dissemination by means of international journals, it was possible to spread work through the publication of scientific proposals and results in book chapters:

- Silva, F., Cuevas, D., Analide, C., Neves, J., & Marques, J. (2012). Sensorization and Intelligent Systems in Energetic Sustainable Environments. In G. Fortino, C. Badica, M. Malgeri, & R. Unland (Eds.), Intelligent Distributed Computing VI (Vol. 446, pp. 199–204). Springer Berlin / Heidelberg.

- Silva, F., Analide, C., Rosa, L., Felgueiras, G., & Pimenta, C. (2013). Social Networks Gamification for Sustainability Recommendation Systems. In A. Berlo, K. Hallenborg, J. Rodríguez, D. Tapia & P. Novais (Eds.), Distributed Computing and Artificial Intelligence (Vol. 217, pp. 307-315). Springer.

- Silva, F., Analide, C., Rosa, L., Felgueiras, G., & Pimenta, C. (2013). Ambient Sensorization for the Furtherance of Sustainability. In J. Pan, M. Polycarpou, M. Woźniak, A. Carvalho, H. Quintián & E. Corchado (Eds.), Ambient Intelligence - Software and Applications (Vol. 219, pp. 179–186). Springer.

- Silva, F., Analide, C. & Novais, P. (2013). Information Fusion for Context Awareness in Intelligent Environments. In J. Pan, M. Polycarpou, M. Woźniak, A. Carvalho, H. Quintián & E. Corchado (Eds.) Hybrid Artificial Intelligent Systems (Vol. 8073, pp 252-261). Springer Berlin / Heidelberg.

- Silva, F., Olivares, T., Royo, F., Vergara, M. & Analide, C. (2013). Experimental Study of the Stress Level at Workplace Using an Smart Testbed of Wireless Sensor Networks and Ambient Intelligence Techniques. In J. Vicente, J. Sánchez, F. López, F. Moreo (Eds.), Natural and Artificial Computation in Engineering and Medical Aplications (Vol. 7931, pp 200-209). Springer.

- Gomes, M., Oliveira, T., Silva, F., Carneiro, D. & Novais, P. (2014). Establishing the Relationship between Personality Traits and Stress in an Intelligent Environment. In Moonis Ali, Jeng-Shyang Pan, Shyi-Ming Chen, Mong-Fong Horng (Eds), Modern Advances in Applied Intelligence (Vol. 8482, pp. 378–387). Springer.

- Silva, F., Analide, C., Gonçalves, C. & Sarmento, J. (2014). Ubiquitous Sensorization for Multimodal Assessment of Driving Patterns. In Ramos, C., Novais, P., Nihan, C. E., Corchado Rodríguez, Juan M. (Eds.), Ambient Intelligence - Software and Applications (Vol. 291, pp. 143–150). Springer.

- Silva, F., & Analide, C. (2015). Ambient intelligence: Experiments on sustainability awareness. In F. Pereira, P. Machado, E. Costa, A. Cardoso (Eds), Lecture Notes in Computer Science (Vol. 9273, pp. 33–38). Springer.

- Silva, F., & Analide, C. (2016). Intelligent Distributed Computing IX: Proceedings of the 9th International Symposium on Intelligent Distributed Computing IDC'2015, Guimarães, Portugal, October 2015. In P. Novais, D. Camacho, C. Analide, A. El

Fallah Seghrouchni, & C. Badica (Eds.), (pp. 309–318). Springer International Publishing.

- Quintas, A., Martins, J., Magalhaes, M., Silva, F., & Analide, C. (2016). Intelligible data metrics for ambient sensorization and gamification. In Studies in Computational Intelligence (Vol. 616, pp. 333–342), Springer International Publishing.

- Silva, F. & Analide. (2016) Sensorization to Promote the Well-Being of People and the Betterment of Health Organizations. In Applying Business Intelligence to Clinical and Healthcare Organizations, IGI Global .

4.4.1.3 Conference Proceedings

Participation and publication in conferences was, also, a matter of concern always present throughout the PhD work. Over this section a list of conference proceedings published during the research activities during the doctoral programme is presented:

- Silva, F., Analide, C. & Novais, P. (2015) Traffic Expression through Ubiquitous and Pervasive Sensorization - Smart Cities and Assessment of Driving Behaviour, PECCS 2015 - Proceedings of the 5th International Conference on Pervasive and Embedded Computing and Communication Systems, ESEO, Angers, Loire Valley, France, SciTePress.

- Silva, F., Costa, A., Novais, P., & Analide, C. (2015). Ubiquitous community driven traffic analysis. In 2015 International Symposium on Innovations in Intelligent Sys-Tems and Applications (INISTA), (pp. 1–8). IEEE.

4.4.2 Participation in Events

Participation in scientific events was made throughout the doctoral programme as a means to exchange ideas and provide further training and experience. The list of relevance events is:

Survey Design Foundations of Survey Research, the participation in the summer school of the summer course survey design foundations of survey research which took place in Utrecht Netherlands. This course focused on the study, planning and implementation of surveys as a research method.

Logic of Dynamical Systems the participation in the spring school of the spring school of logic of dynamical systems course. This course was coordinated by Prof. André Platzer from Carnegie Mellon University and explores the theory, practice, and applications of the family of differential dynamic logics, which includes logics for hybrid systems and extensions to distributed hybrid systems and hybrid games.

Innovation and Creativity for Complex Engineering Systems (ICCES) the participation in the intensive course at Bosch facilities in Braga, Portugal in a intesive erasmus programme. During the ICCES programme Ph.D. students were confronted with real engineering problems owned by the industrial partner acting as the local host of the delivery of the Innovation and Creativity for Complex Engineering Systems (ICCES) Programme. The students, organised in multi-disciplinary teams, were expected to propose a research plan that adequately tackles a given problem, with both a scientific perspective and a business/market one. The plan should include issues like intellectual property rights, patents, industrial innovation, funding for innovation projects, market needs, research collaborations, publication of industrial case studies and demonstration cases.

Executive Training on Foundations of Governance Information Leadership the participation in electronic governance by the United Nations University. The aim of the training is to build awareness and capacity among policy-makers, decision-makers, public managers and CIOs from government, business and intergovernmental organizations in establishing, managing and sustaining policy-driven IT and EGOV initiatives.

4.4.3 Invited Presentations

Other than the publication of scientific articles, research was also disseminated through invited talks and tutorial demonstrations. In this aspect, the following list details the oral presentations produced:

- Sustainability & Energy Efficiency - presentation to the PhD student of the Doctoral Program on Informatics of the University of Minho based on the research conducted during the research programme;

- Master on Informatics Engineering - presentation to master students on the contexts of machine learning, multi-agent systems and intelligent environments. In specific, presentation were made in:

  - PHESS & Sensor Datasource API - presentation to master students on autonomous systems and the use of PHESS platform for generating autonomous systems in the field of intelligent environments using multi-agent system platform;
  - Machine Learning Projects and Applications - presentation to master student on machine learning tools and frameworks, providing tutorials on how to integrate these into custom made applications;
  - Computational Sustainability - presentation to master students in the field of intelligent systems introducing computational sustainability and application use cases.

- Jasper & Java API for Prolog - presentation to students of the Degree on Informatics Engineering of representation of knowledge and learning on the integration of logic programming with object oriented programming languages.

- Doctoral Program on Informatics - multiple presentations to Informatics Msc students in the field of intelligent systems at the University of Minho in the concept of computational sustainability and its application to intelligent environments and ambient assisted living;

4.4.4 Organization of Events

The dissemination of scientific knowledge in the fields of computational sustainability has proportionate the organization of science events such special sessions and workshop inside renowned scientific conferences.

The participation as an organizing committee member in the special session energetic sustainable ambient intelligence of the 9th international symposium on intelligent distributed computing has led to development of international venue for exchange of research ideas on the field of this doctoral programme. In the Special Session ESAmI[1] it was created a multi-disciplinary discussion forum that brought together researchers from the different fields addressed discussing issues in Artificial Intelligence topics included in the Ambient Intelligence and Energetic Sustainability. Researchers were welcome to present both theoretical and practical works as well as the lessons learned with their application in the varied range of domains. Emphasis was placed on the presentation of concrete systems, discussion of implementation and development challenges and sharing of conclusions achieved and relevant results.

Recently, the International Workshop on Computational Sustainability, Technologies and Applications CoSTA[2] workshop proposal was accepted to be included in the 12th International Conference on Intelligent Environments. Currently, it is ongoing the phase for paper submission. This workshop addreses topics of special relevance in this thesis, and allow the organizing committee, from which I take in, and the target audience to exchange scientific research on the fields such as Computational Sustainability, Smart-Cities and Ubiquitous Computing.

4.4.5 Research Stay

In the context of the research work performed during the doctoral programme, the candidate spent a research period in the University of Castilla-La Mancha. During this stay he was under the supervision of Prof. Dr. Teresa Olivares. The purpose of this partnership was to develop a link between the Universities of Minho and Castilla-La Mancha in the form of knowledge exchange and collaboration on current and future projects.

From this research stay, capture and analysis of data from a testbed based in the University of Castilla-La Mancha was used as a source of data for research on computational sustainability, comfort and energy efficiency assessment. Among the outcomes of this collaboration there is the article entitled Experimental Study of the Stress Level at Workplace Using an Smart Testbed of Wireless Sensor Networks and Ambient Intelligence Techniques.

4.4.6 Supervision of Students

The candidate has successfully co-supervised master students that developed their work in the context of this PhD thesis. The list of students will be presented along with a summary

[1] The special session webpage with additional information about the event can be found at: http://islab.di.uminho.pt/ESAmI2015/

[2] The workshop webpage with the cal for papers, topics and information about the event can be reached at: http://islab.di.uminho.pt/CoSTA2016/

of each work plan in this section.

4.4.6.1 Cedric Fernandes Pimenta

A gamification implementation for energy efficiency was implemented by Cedrics works having the intial PHESS platform as data source. This project proposes to act on the habits of those users, applying the concept of Gamification as to, not only foster a higher engagement between the user and the system developed, but also incentive a healthy competition between the system's users, with the goal of improving non-sustainable behaviours or promoting the sustainable ones.

In co-supervision with professor Cesar Analide

Year of conclusion: 2013.

4.4.6.2 Gilberto Martins Felgueiras

In his work, Gilberto presents information on the relationship of psychology, sustainability, affective computing and how these fields can be interconnected. It was developed a platform using virtual agent technology to collect information about the environment and should proceed to the calculation of an emotional state. The results obtained from the work were encouraging, and show that this type of simulation can be an advantage for a system to support the sustainability based on ambient intelligence.

In co-supervision with professor Cesar Analide

Year of conclusion: 2013.

4.4.6.3 Luís Miguel Ferreira Rosa

The work of Luís focuses on the integration of Information and Communication Technologies (ICT) in the environment with sustainability strategies within the social, environmental and economic dimensions. ICT associated with physical elements, such as buildings, can reduce energy consumption and environmental impact, in that it can efficiently manage resource consumption and help to reduce waste. The work here detailed is one of the first extensions of the PHESS platform with processes from sensor and information fusion and the creation and monitoring of new indicators that can promote social, economic and environmental sustainability

In co-supervision with professor Cesar Analide

Year of conclusion: 2013.

4.4.6.4 João Duarte Machado Sarmento

In this work João, focused on gathering data from mobile devices, as smartphones and tablets, to obtain useful information to create driving pattern profiles, classify the road quality and explore mean to share aggregated information.Communication and data acquisition is based on the PHESS platform.

In co-supervision with professor Cesar Analide.

Year of conclusion: 2014.

4.4.6.5 Jorge Daniel Nogueira Martins

While performing this work, Jorge developed and experimented gamification methodologies over a community of users based on the PHESS platform. The main objectives were to analyse data of trips made by users, evaluating them through the use of gamification elements, according to a criteria that aims to promote sustainability. It is through these elements that it will be possible to organize users based on their performance. Together with point classifications, there will be more gamification elements such as levels and achievements that will have the objective of rewarding users for goals achieved. Allied to this, the research project will explore areas dedicated to feedback in order to foster a sense of community among users of the system.

In co-supervision with professor Cesar Analide.

Year of conclusion: 2015

4.4.6.6 Marcos Leonardo Lopes Magalhães

In this work, Marcos is developed a systems to the optimization of ambient variables and attributes, the improvement of users behaviour,the reduction in global energy consumption and an increase in sustainability of the environment based on electronic sensory boards such as arduino. Data acquisition is made through the use of sensory networks composed by environmental and energy sensors directly integrated into the system. It is based on the underlying PHESS platform described in this thesis. The objective is to both assess the current state of the environment in terms of security and comfort, and to predict those values with machine learning algorithms based on the history. The development of this work encompassed both hardware and software implementations.

In co-supervision with professor Cesar Analide.

Year of conclusion: 2015.

4.4.6.7 Artur Filipe Freitas Quintas

Tasked with developing methods to improve sensorization from ubiquitous devices in the application of PHESS to urban transportation systems, in this work, Artur developed means to process data collected from existing mobile devices and create metrics of quality. Furthermore, there was interest in ameliorate the current process to extract better information from the current data fusion processes. The work plan includes the correction of sensor values through map-matching algorithms, addition of contextual information from map data and correlation of existing assessments against new contextual information taking data quality into consideration

In co-supervision with professor Cesar Analide.

Year of conclusion: Currently ongoing.

Appendix A

PHESS

In this appendix information abou the official site for the PHESS project can be found after a short description of the projet itself.

A.1 Description

Energetic sustainability concerns the making of the necessary conditions to the sustainable use of energy. Informatics is the science that deals with the automatic treatment of information, related with the use of computing devices (computers, sensors and actuators). People and the act of helping people, must be always a goal to achieve by whom intends to commit itself for and by the society.

With this project it is intended to, by helping people, make them intervene in the society, in the context and with the purpose of contributing for the energetic sustainability of their world. Informatics, computer science and computing systems are the right means to achieve this goal. The body of knowledge represented in the research team gathered for this project in the areas of Intelligent Systems, Computer Communications and Production Systems are the know-how allowing informatics and computers to be the natural mean to provide people with the ability to take part in the environment and its energetic sustainability.

Actually, the energetic sustainability issue is gaining importance and stirring society. There is perception and desire, in the society and in people, to discuss this matter. However, it is noticed some lack of ability to act by the people, due to some unavailability to drive changes or to some lack of knowledge about what to do. The help to people will be held in this way: endowing the environment with mechanisms and providing people with the tools of information about the environment, advising them about what to do, what actions to take, enabling people to interfere and intercede in the environment, always with a strong emphasis on the sustainable use of energy. Each action should make a difference with respect to some energy saving criteria.

A.2 Project Home and Documentation

Project website	`http://islab.di.uminho.pt:/phess`
Project documentaton	Included
State	Onlines
QR Code	

Appendix B

PHESS - Driving

The PHESS Driving project is an initiative to track driving behaviour in cities through a community of users and pervasive sensorization. This document describes the rest API used to get user information, profiles and trip metadata actually used by the project.

B.1 Data Overview

The PHESS Driving project is responsible for gathering data about driving behaviour using pervasive devices. Currently, the approach uses smartphones as sensors and is able to track trajectories, velocities, gravitational forces and accelerometer data during each trip. The values of this system resides on the data processing at the server node, where statistics and trip events are catalogued and indexed in a trip by trip analysis and user by user analysis.

In a bottom-up approach, first, there is data stored about the user, its vehicle and sensor devices (smartphone). This information is available as context information. Raw information is made available by the actual sensor records for each trip recording and ordered by timestamps. Trip statistics are also available as processed data summarizing trips. Trips events detected are stored as new contextual information. They are available, as well as a justification for its identification being a descriptive analysis or the records that originated the detection of that event.

Each trip updates drivers' profiles. These profiles express the behaviour of drivers in their daily trips and detail what is considered their normal behaviour.

B.2 Project Home and Documentation

Project website	`http://islab.di.uminho.pt:10001/Phess_Driving/`
Project documentaton	Included
State	Online
QR Code	

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