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ENGINEERING AND INCORPORATING SUSTAINABILITY INTO SOFTWARE DEVELOPMENT: A DESIGN PATTERN APPROACH

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ABSTRACT

Context: Design patterns are solutions inside the software development life cycle that are used to solve concurrent problems software professionals encounter while developing new software. These patterns simplify their use with previously tested cases and examples. Design patterns have been used widely among software developers but problems related to Sustainability have not been widely considered among design patterns and if considered only related to power consumption. Hence the need to incorporate sustainability with its several dimensions into software development with the tools of design patterns and in that way proposing solutions to sustainability problems. This research explores the different methods of HCI design patterns and incorporation of sustainability strategies used within the software community The Goal of this research is to develop design patterns and tools that could help ICT community to create solutions incorporating the different sustainability dimensions. The results are design patterns that have sustainability incorporated within. These new set of design patterns will help ICT community and software developers to include sustainability into their products, therefore, making a helpful guide to create more sustainable goods and services.

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"Todas las teorías son legítimas y ninguna tiene importancia. Lo que importa es lo que se hace con ellas." Borges

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LIST OF SYMBOLS AND ABBREVIATIONS

GDC   General Design Cycle

HCI   Human Computer Interaction

ICT   Information and Communications Technologies

IT   Information Technology

SID   Sustainable Interaction Design

UI   User Interfaces

VSD   Value Sensitive Design

1 INTRODUCTION

In this chapter, the contents are discussed from the beginning of design patterns to the explanation of design patterns that have been created during the elaboration of this thesis, also with the basis and focus on other environmental factors related to the everyday use of IT.

The research questions are exposed to establish a base of research alongside the methodology that has been used to research the different aspects of the present work. To culminate the chapter the structure of the thesis is displayed to establish the layout it will follow during the document.

1.1 Background

This thesis aims to purpose the use of design patterns within the IT community, these patterns one way or another will include sustainability problems related to the use of IT with software or hardware.

The study to use design patterns began with design and architecture [3] (Figure 1) and since then it has been applied to every aspect where design is involved since the design is human solution human to solve humans problems.
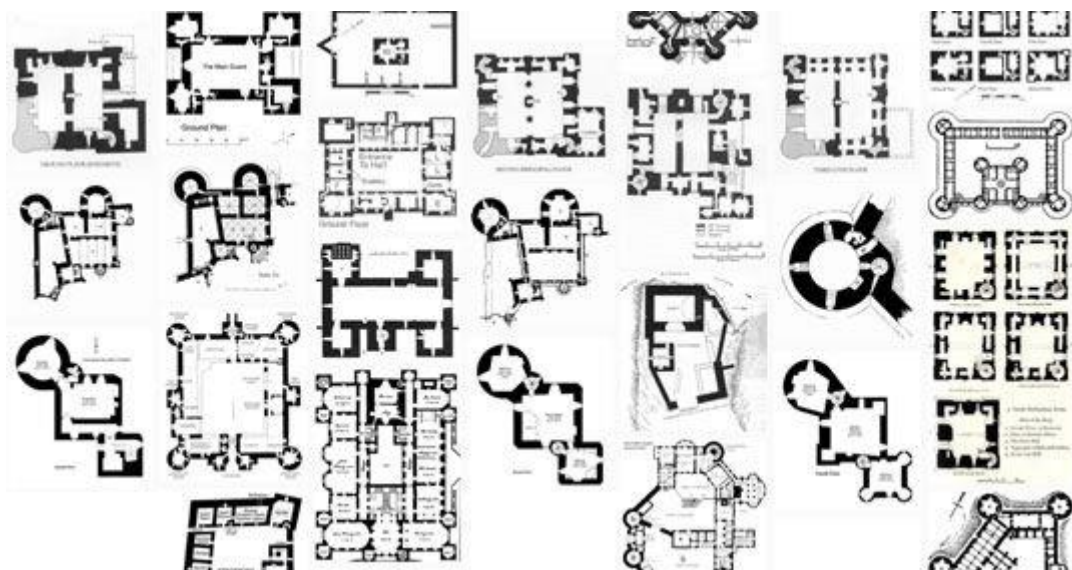
Figure 1 Design Patterns by (Alexander C)

A design pattern has three basic elements according to [3] which are (Figure 2):

- Context: describe the situation where the pattern can be used
- Problem: the forces that are occasioning the problem that is happening in the context to which the pattern should be applied
- Solution: a rule to be applied to solve the problem.
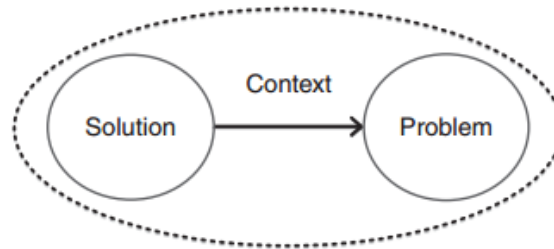
Figure 2 Elements of design pattern [3]

Design Patterns are a group of solutions one definition is "An invariant solution to address a recurrent design problem within a specific context" [4].

By using patterns in design, these solutions are simplified and cataloged, as the book [5] says that design patterns are concrete and abstract at the same time "… They are concrete enough to provide sound solutions to design problems, which can put immediately into practice. On the other hand, they are abstract enough to be applied to different situations".

A situation where patterns started to be applied is software development, because design patterns present solutions that have been previously used, and helps the developers to tackle de problems with the best practices and knowledge previously tested.

Design patterns have been used in a variety of areas and more specifically in design, they have been used since the decade of 1980 in IT as well, and there are several distinctions of design patterns in software development, although the ability of design patterns to be multi-cross disciplines has presented several advantages, such as diversity in studies in fields related to not just with software development but also with behavioral patterns, areas where human psychology and software engineering have been crossed to develop solutions.

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Design patterns are artifacts used for different disciplines for example programming patterns for software engineering they originally were adopted by [6] and they are classified into three different categories: Behavioral, structural and creational; as shown in Figure 3.
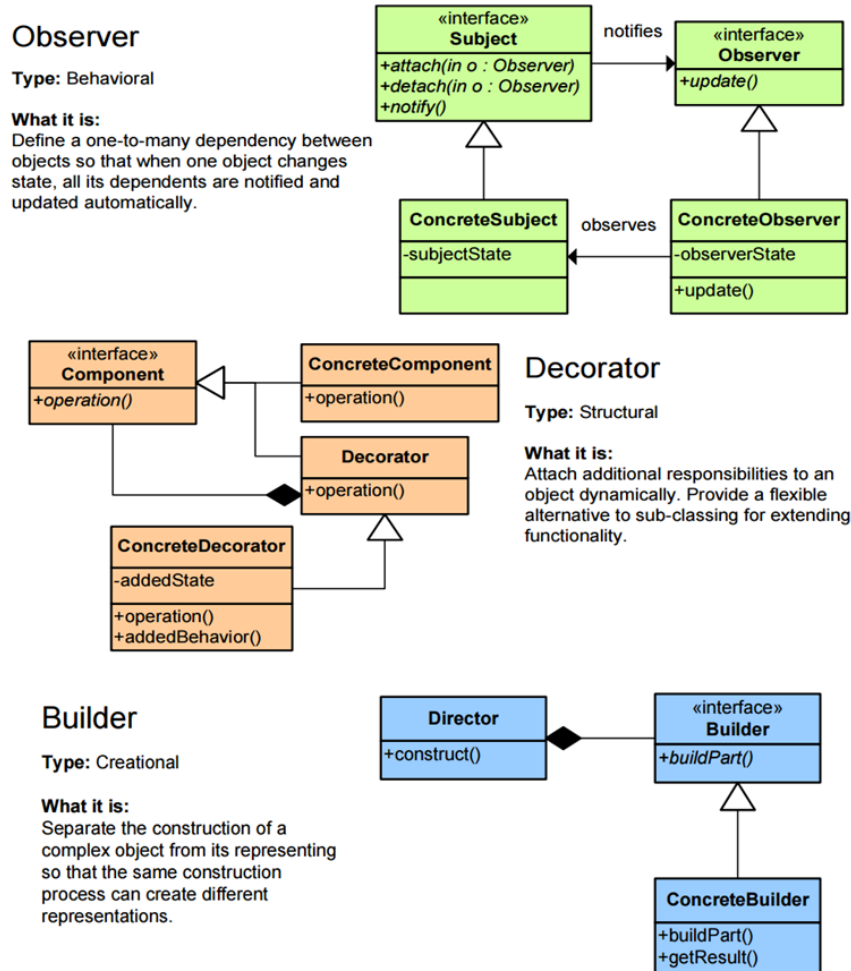
Figure 3 Software Design Patterns examples

One important distinction is the HCI Design patterns, which are tools that are exchanged in the knowledge in the HCI domain, which is centered in the interface design, can also be called UI pattern, and it was first introduced by Coram et al [7].

Design patterns exist in a higher level of abstraction and are not connected to any kind of source code. They are written in a general way [8] given the HCI designers the possibility to choose how the different artifacts should be used. An example of a UI pattern is shown in the following Figure 4

Pattern_Name: Convenient Toolbar Pattern	
type:	Navigation Support Pattern
Context_Use	**User:**Expert **Task:** Assist user to reach the most useful and frequently visited pages at any time through the Web site.
Workplace:	Web applications
Usability_Problem:	The user can easily find most commonly used pages regardless of the current state of the artifact. The user can reach these convenient pages promptly.
Usability_Factor:	**Factor:**Efficiency, Safety **Criteria:** Consistency, Minimal Action, Minimal Memory, User Guidance, Helpfulness
Example:	
Design_Solution:	Group the most convenient action links, such as home, site map, help and etc. Use meaningful metaphors and accurate phrases as lables Place it consistently throughout the Web site
Other Language Attributes:	Design_Principle Related Usability_Patterns Reading

Figure 4 Example UI design Pattern [5]

Design patterns can be stored in categorized catalogs [9] which cover different domains and are easy to navigate for the users to implement them in designs. The design patterns have several forms [8], the main forms are:

- Alexandrian Form
- UI Pattern Form
- Tidwell Form

1.2   Rationale

In the last years', efforts have been made to help software consume less energy, different kinds of patterns have been analyzed to define their levels of energy consumption, in through way these studies have been trying to help the environment by reducing energy consumption from ICT applications.

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Studies have been done in Design Patterns Energy Usage [10] that show the different impacts on programming patterns when designing software, further studies are focused on improving the energy consumption of design patterns [11] certainly, these are important ways to achieve common goals, but the problem is that most studies are focused on energy performance [12], the main issue with that approach is that other pillars of sustainability are not being considered in these studies. And that is generalized in the ICT industry.

When bearing in mind other aspects of sustainability, a different way to solve sustainability issues have to be used, and that is when a Design Pattern approach should be considered. With pattern language and format that has been used in HCI, it can be shown that design patterns are another alternative to solve to existing sustainability problems.

1.3   Research Questions:

The main objective of the current work is to incorporate sustainability with the approach of design patterns by answering the following questions:

- Which day to day sustainability problems are caused directly or indirectly by ICT.
- How to create sustainable design patterns that could help solve sustainability problems.
- How to create a new library of sustainable design patterns for the ICT community.

Making software that includes different sustainability pillars through design is a task that still needs to be fully implemented, along with the specifications to be included in the design of new ICT solutions such as any kind of software application. In previous works, sustainability has been suggested that can as a quality attribute sustainability could be included[13] increasing the quality attributes of software, and what this thesis aims to create a way in which ICT developers could implement sustainability as a quality attribute in their products by the creation of sustainable design patterns.

The main aim of this research is to develop design patterns that could be implemented by developers, and encourage their use within the ICT community alongside with the public, thus helping include sustainability as a quality attribute of software development as part of their products.

As this thesis will focus on finding HCI design patterns to incorporate sustainability, it will not measure the impact of sustainable implementations, whereas further work is recommended to define metrics to properly measure the impact and the sustainability when ecological measures are implemented. Therefore, the contributions of this work is to create artifacts that become the basis of future research.

1.4   Thesis Structure

Chapter 1: Introduction, presents the basic information about the research topic at hand giving a background on patterns, sustainability, the goals and delimitations of current work, alongside with the methodology used in this research to achieve results.

Chapter 2: Literature review, where the different research related to the design patterns is proposed, analyzed and described to find out what has been done in the field of sustainability and IT, and consequently to establish a background for the patterns here proposed.

Chapter 3: Design Patterns, in which design patterns are proposed that attempt to solve problems generated by the use of ICT and software, which can help the ICT community include sustainability.

Chapter 4: Online Patterns Catalog, where web application characteristics are shown in order to display to the ICT community and obtain feedback and ratings of the patterns presented in chapter 3.

Chapter 5: Discussion and conclusions, the achieved results are shown along with future line of work related to this thesis.

The thesis ends with References used for the thesis work.

2   RESEARCH METHODOLOGY

For the proper elaboration of this thesis it is important to stablish a proper research methodology that goes in accordance to the topic. In favor of developing a coherent work this chapter focuses on explaining the why? A research approach has been chosen, and for this work to be developed according to that methodology.

The research methodology here explained has been chosen carefully from the literature in research methodology for information systems and which ones are used in current research in the field.

2.1   Design Science Research

This thesis research has been done under the design science research methodology in order to develop design patterns that are applicable in the ICT field of software development and include sustainability into the development process through those created patterns. In this section, the research method that is used is presented and encapsulates the thesis research through design science research.

Due to the nature of the topic that is related to design patterns and because design patterns are artifacts that present different solutions to known problems. Design science research provide the framework to tackle the research, because the creation of artifacts is part of the framework of design science research method, as presented in the Table 1.

Table 1 Characteristics of Design Science Research Method [14]

Characteristics	Design Science Research
Objectives	Develop artifacts
	Satisfactory solutions to practical problems
	Design and recommend
Main Activities	Define de problem
	Suggest
	Develop

	Evaluate Conclude
Results	Artifacts
Type of Knowledge	How things should be
Researches role	Builder or evaluator of artifact
Empirical basics	Not mandatory
Collaboration	Not mandatory
Implementation	Not mandatory
Evaluation of results	Applications, Simulations, Experiences

To further explain the Table 1 each part is here explained:

- *Objectives.* - The main objectives of design science research is to develop artifacts that create solutions to practical problems, part of this development is to design and recommend these solutions, that fits properly with designing sustainable patterns that aim environmental problems created by the daily use of ICT, and by designing patterns with recommendations the objectives are in accordance with the research methodology.

- *Main Activities.* - Firstly, the problem has to be defined, then solutions have to be suggested and developed, for them to be evaluated and conclude into their use, this work a problem has been defined the solutions are the patterns with their development, and for their evaluation their incorporation in a pattern library aims to evaluate them, and a conclusion can be drawn.

- *Results.* - The results are artifacts, and the sustainable design patterns are artifacts thus they are the results.

- *Type of knowledge.* - is the knowledge of how things should be inside the artifacts.

- *Researches role.* - In this case is to be the builder of the artifacts and artifact library

- *Empirical basis, collaboration and implementation.* - are not mandatory fields but they have been considered, like collaboration with the ICT community and implementation of a design pattern catalog.

- *Evaluation of Results.* - Applications, simulations and experiences of the design patterns proposed in this thesis work.

In information systems design science research, has been recognized and implemented as an important part of Information Systems research, looking to improve its impact and to solve problems through design in [15] mentions "...design science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways.", and in this thesis some of the unsolved problems caused by the daily use of IT helped to create a way in through ICT community could include other pillars of sustainability into their daily use of IT using more sustainable design patterns.

2.2 General Design Cycle

The GDC has been proposed by Hevner et al. , and others authors like Alturki et al. [16] is referred as the design science research cycle, in this work this research cycle is used to describe the process in which this research has been developed, and its outputs in the different steps of the cycle. The modification of the cycle is summarized in the Table 2

Table 2. Adapted General Design Cycle [15]

Process Steps	Outputs
Awareness of problem	The lack of Design Patterns that help software developers include sustainability into the process of developing ICT solutions such as software
Suggestion	Tentative patterns are proposed to try to tackle the problem
Development	Artifacts such as definitive design patterns are proposed to solve problems related to sustainability including other aspects.
Evaluation	The patterns are evaluated by exposing them to the ICT community and recollecting suggestions and comments.
Conclusion	The patterns are reformed according to the recommendations and proposed as an improved version.

Within the development of the thesis a catalog of patterns will be created, and because design patterns are considered artifacts within the design science research, the process related to the creation of such artifacts is expanded within the different parts of this thesis.

3 LITERATURE REVIEW

The literature used in this work is closely related to the patterns proposed in this thesis, mostly with topics to be used in design patterns, although those topics are not related to energy consumption which is where most of the current research in design patterns is focused.

By reviewing different studies related to IT and environment, and in order to propose design patterns that could help solve sustainability problems through IT, the possibilities are incremented and related with other topics not yet associated with design sustainable patterns, which is the aim of the thesis.

This research used a systematic literature review, firstly identifying the research questions and using different keywords to identify related work in the different libraries online, the different documents were downloaded and categorized and depending on their importance to the work they were used or discarded. For the search of the different papers and books the following search words have been used throughout the literature review:

- Green software patterns, design patterns, HCI design patterns, sustainable HCI design, sustainability software development, green IT, green patterns, behavioral design patterns, sustainable behaviors, changing human behavior patterns, sustainable practices in the work place, sustainable printing, green printing software, electronic waste impact.

The keywords were mainly used in ScienceDirect, ACM, IEEE, Taylor & Francis libraries supported by google scholar searches. From the material obtained during the literature review process, the idea was created from the patterns in conjunction with the different topics in this chapter.

The following subsections were chosen to capture ideas of topics that could help create the sustainable design patterns, to properly start first there has to be a definition of sustainability in IT, secondly showing that several researchers have developed design patterns with

ecological focus but just considering the energy consumption, also to understand other consequences of everyday use of IT equipment such as printing, and its lifecycle with literature related to electronic waste. Finally, to tackle solutions through human behavior and for the design patterns to have a human aspect, papers related with human behavior in sustainability issues were targeted.

Not just for the creation of the patterns the following literature was studied, also to help answering the research questions, by looking at other studies related to sustainability problems and their different use of design patterns, also by observing other problems related with environmental sustainability.

3.1 Sustainability in Software Development

Nevertheless, to address sustainability problems within ICT community, a definition for sustainability has been worked during the years [17] were Penzenstadler mentions it's context in the relationship of software engineering. There are three distinctions where sustainability has a relation with Green IT mentioned by [18] Figure 5. But then again for sustainability to be included into software development definition and as an activity, it has four aspects to be considered [17].The four aspects are taken from Penzenstadler and resumed in Table 3
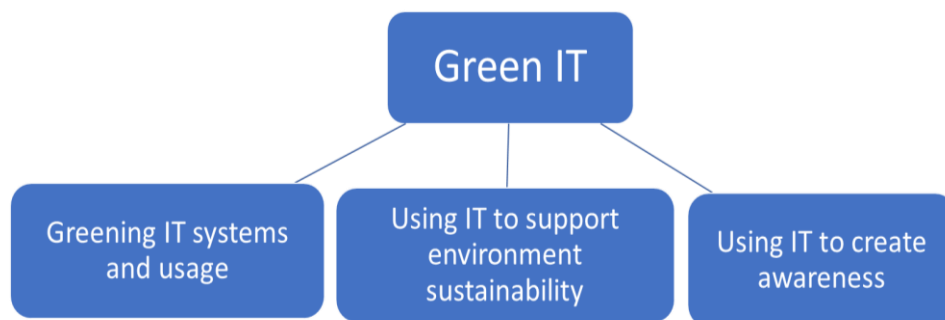
Figure 5 Green IT dimensions [18]

Table 3 Aspects of sustainability in Software Engineering from [17]

	System	Function	Time
Development Process	A software development company	Minimize impact on software development, economical with a good balance in working conditions.	The planning period for the company for the long-term software and business goals
Maintenance Process	Software development companies maintenance department.	Software maintenance with minimal environmental impact, balanced economics, and a good knowledge.	The lifetime systems planning
System Production	The companies that develop and supplies for the assembly of a specific product	Environmental impact in producing a system and enough economic balance	With the production forecast
System Usage	The system under analysis with operational environment and its business context	Minimized environmental impact with maintenance and evolution. Social responsibility with economic balance	Systems estimated lifetime, depending on the complexity

In the paper [19] from Chitchyan et al. the researchers investigated the current state of sustainability in design Requirements engineering and the concepts companies have of sustainability, trying to include the human, economic and environmental pillars of sustainability in design, most of the studies related to defining sustainability within software have been previously resumed by Shola et al. [13]

As continuing the work from Shola et al. [13] where sustainability is defined as a quality attribute for software development, this work focuses on incorporating sustainability and defining metrics alongside with a method to include it as a quality attribute.

The purpose of the current work is to continue forward with the work mentioned, but this time the discussion is how to incorporate sustainability with design patterns, therefore having a set of patterns, that will help developers to consider, when using IT in every daily activity and their tools they are using, and not just the developers, but also the institutions that are use IT as part of their operations and the different elements that conform the society.

3.2   Incorporating Sustainability into Printing

Since most of the efforts put into sustainability in software development have been concentrated in energy consumption thus the CO2 emission associated with that consumption [20], this effort has resulted in methodologies to reduce software energy consumption and metrics to evaluate energy consumption from software.

Sustainability in software development has been also focused on defining sustainability, methodologies frameworks, requirements, and metrics that include the other pillars and not just the environmental pillar but also the social and economic [21]. And for including other pillars in software development, a daily activity that ICT is related in every workplace and household is printing, by printing different resources are used at the same time, therefore, more pillars could be included such as the social and economic impact of printing from its resources to their impact.

However, printing is an activity which concerns the ecosystem from the exploitation of forest to obtain pulp for the paper to the use of inks that hinders and pollutes the environment. Billions of tons of paper are used across the world [22] and have increased due to the availability and reduced prices of printers and paper across the world. Also, the amount of recycled paper in the manufacturing of new paper has increased which is a trend that is growing but still the main source for paper is wood.

For making the change in the way people use printing on the daily basis, suggestions have been made [23] were as for how the change should be considered. First, there has to be an educational process in order to be able to make the case for going green in printing inside an organization or home, there has to be a full knowledge of the life cycle of printing, and how to be aware of the brands of paper that use more sustainable methods in their manufacturing. The persons must be able to calculate the impact of printing and set small goals at first to gradually reduce the effect. For making a case in the organization there must be like-minded people, that could help convince others into printing less, always using right evidence to stand the point and encourage the change within and organization/society, for example in Figure 6 which shows a poster used to generate an improved behavior.

Figure 6 Poster for incentivizing double side printing [23]

For instance, change must start personally first, before printing anything there should reflect whether printing is necessary or not, also another option is to find out if someone else has already printing to avoid unnecessary copies, and try to use paper that has been used already on one side.

Meanwhile, there are several areas where green printing affects, another consideration is to have environmentally friendly printers which use less ink and ink that it has a vegetable origin, combined with recycled paper or paper with sustainable origins. While designing the document to be printed, smaller margins, smaller type, and much less color should be considered. In that way, a green printing can be achieved.

Not only these solutions and engagement are proposed for greening printing but also the use of new to software to change the way of printing has been previously introduced [9], by using SID (Sustainable Interaction Design), researchers developed a plugging for Firefox that allows printing and making it more sustainable, the characteristics they include in their software development are the following:

Minimalist User Interface. - because it is an extension for printing for web pages it is only one click away, this app selected by default portions of the page and optimized the printing area.

Lightweight Document Image Processing. - the solution was to divide the web pages into rectangular spaces and evaluate the importance of the text from the HTML document.

Print Data Visualizations. - to create a sustainable impact, the authors decided to create a sharing mechanism of the printing data and make the effort of the user's rewarding points and with the use of the system, create critical behavior within the community of users.

In addition, this research concludes is that the use of their sharing tool created consciousness among users that could see their performance in real time. Now the task is to create a design pattern that will make future ICT professionals include into their products such as software development process and make printing of any kind of documents in a more sustainable way, by reducing the amount of printed material, thus generating a positive impact in nature.

3.3   Electronic Waste (e-waste)

It is noticeable that with the increase of technology and with the increase of living standards all around the world the use of electronics in every daily routine has become part of the life of most humans in the developed and developing the world, these consumer electronics become part of E-waste (Figure 7)

Figure 7 E-waste Types taken from (*Holden*)

There are studies that have been done [25][26][27] where they show the impact on the environment and the health of people, and how it has increased and will continue to increase during the following years. Figure 8
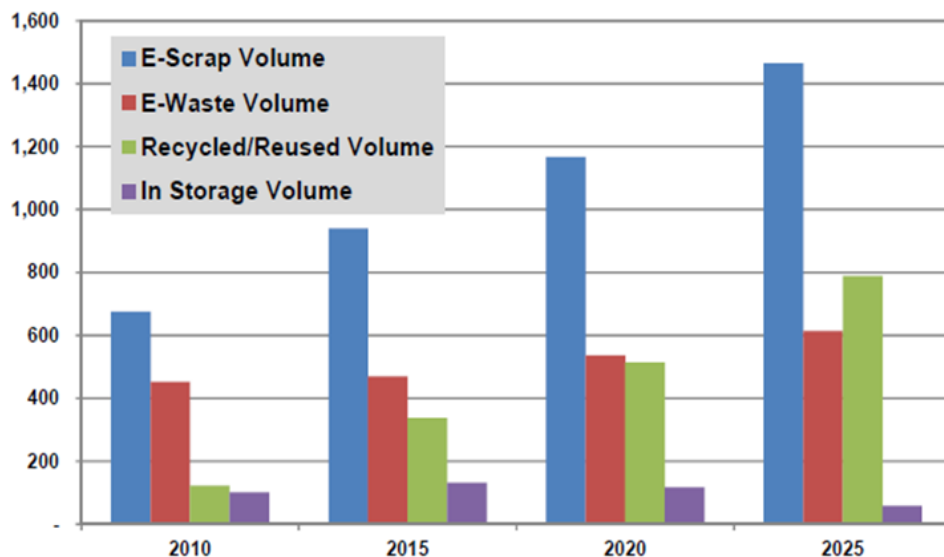

Figure 8 Growth of E-Waste (*Environmental Problems*)

Some countries around the world have approved legislation to manage the waste in more efficient ways and reduce the impact on the environment and human health, but measures

must be applied in every aspect of the product's lifecycle since their conception to their disposal making the electronic equipment easier to be recycled.

Moreover, even though efforts have been made all studies make emphasis that it is not enough to solve the problem globally, there is still a lot of e-waste trafficking from developed countries to developing countries, developing countries increasing their consumption and e-waste and lack of legislation in most parts of the world, [26] suggest that unless there is a global paradigm shift or technology comes up with a sustainable solution, the situation is not going to change.

Solutions have been proposed such as [29] where it clearly shows that when a good design and idea is applied it can help people change the behavior of waste and reduce the impact on the environment, this kind of solutions along with bigger solutions such as legislations and global agreements, could help reduce and hopefully one day completely eliminate the problem.

3.4 Behavioral Patterns

In terms of behavioral patterns, current research is focused [30] on changing human behavior for achieving sustainability, they have been used in different contexts and with different results across different spectrums of applications, but also a lot of these studies have been made to change energy consumption on users through behavioral changes, through individual and collective approaches [31], [32].

The research from [11] where they continue the work from [10], did improvements in the programming design patterns where they observed that had a bigger energy use as it shows in Figure 9.
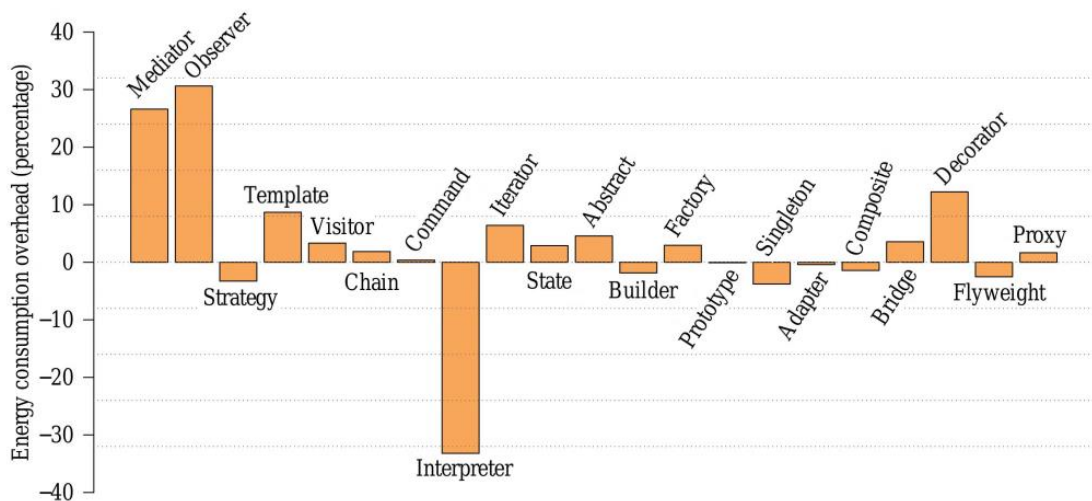
Figure 9 **Energy overhead of design patterns from** [11]

Knowles et al. [33] address the way technology and patterns are used to persuade people to make them more environmentally conscious and reflects on how previous studies have been made concerning the approach to sustainability, this paper focused on the research of values or VSD (Value Sensitive Design). The paper remarks on certain types of values and why these values are more important to achieve better results for achieving sustainability in long-term.

A suggestion that Self-Transcendence values are better than Self-Enhancement values because Self-Transcendence values approach to Universalism and Benevolence which are more powerful change makers than Self-enhancement that relate to power and personal achievement. Therefore, this paper is focused on persuasive technologies that will generate lasting sustainable changes. They propose a set of 5 sustainable patterns discussed in Table 4.

Table 4 Set of sustainable patterns proposed by Knowles et al.

Name of the Pattern	Problem	Discussion	Antipattern	Pattern
Broad Self-Transcendence	The need to ST values to be greater than SE	ST activate more	Narrow Self-Transcendence: tendency to help	Activate universalism values, just as

	to enhance better environmental behavior.	beneficial values related	environment alone	peace equality, justice, when people feel better for helping others
Consistency	Difficult to design for people with different values	Research has concluded that offering mixed motivations generate better results	Mixing motivations: the problem is that in the long term there is no change inflicted	Promote long term and lifestyle change behaviors.
Designing to the value	Behavior is strongly influenced by values	Most of the changes are focused on SE other than ST values	Designing to the barrier: most work has been done to this design.	How to get people care about sustainability and why
Facilitate Reflection	Difficult to inspire concern	Giving people information sometimes will not make them change behavior,	Provide Information: By presenting reasons the designer thinks the user might protect the environment	Facilitate the opportunities for the user to reflect what is important to them to help the environment
Measuring impact ripples	Means to evaluate their success	How to measure small changes that make big changes	Measuring target behavior change: information missed such as rebound effects	Widening definition and encourage alternatives design solutions

However, [34] classifies the different studies made with sustainable HCI and divides it into different topics, differences between papers, and issues generated in the different studies, they gathered papers before 2010 and helped shape the landscape of the research until then done in sustainable HCI.

The genres they could classify in the papers are the following:
- Persuasive technology.
- Ambient Awareness.
- Sustainable interaction design.
- Formative user studies.
- Pervasive and participatory sensing.

Some genres did not enter their analysis because there was not enough material to associate with other studies. They wanted to expose the difference of commitment in the different works, by stating how the different problems are proposed, the differences they found are the following:
- "Sustainability as research focus vs application area.
- Individual consumers' vs other users, groups or scales.
- Users as the problem vs solving users' problems.
- Improving vs fundamentally changing lifestyles.
- Technology as an adequate vs inadequate solution.
- HCI as usual vs HCI must be rethought.
- Political differences are relevant vs irrelevant" [34].

Throughout the analysis, they come to reflect on different issues raised by the HCI studies with sustainability and those are the following:
- Knowns and Unknowns: repetition of topics and ways to address problems
- Open Areas, Potential connections: there is loss in connections with HCI
- Foresting Debate: no debate occurring in important topics such as ethics involved.

This paper illustrates a clear image of the research and the approach it should be given in the current work and trying to not repeat studies done before and propose solutions that are different to ones offered in previous reports.

3.5   Changing Human Behaviors

For human behavior the research [30] analyses different works related to changing human behavior with persuasion through different ways, and how they relate to HCI and propose other paths to cause persuasion. They studied how the research has been realizing different proposals to persuade people to change the resource management with their behavior, either by indirectly changing individual's behavior, sensing and reporting information sensed and how the different studies evaluate if any change was generated.

It establishes a relationship between modernism and persuasive sustainability and how being as a form of modernist approach narrows the approach to achieve a global sustainability focusing just on individual behaviors which the authors consider it minimizes the problem without considering other factors.

Some problems that this paper found in the different research papers are that for example, the definition of sustainability used by some authors is too narrow to have measurable metrics, other problems are focused just on individual behaviors and neglects the political relationships and social norms that involve more citizens and not just individuals. Another problem encountered is when information is given to the actors for generating a reaction, this approach doesn't take into consideration that not all humans will change with the information given and once again this approach falls into focusing on individual behavior and dealing with changes over time.

These problems have consequences for HCI because it limits the way of change just to individuals, and grants expertise to the designers when most of the cases they aren't and so for they constraint of HCI by setting different bounds into the design.

The authors came to 3 specific suggestions to improve persuasion in persuasive HCI, firstly by increasing the understanding of persuasion, and creating new types of design like that

reinforce sustainable values, secondly is include different kinds of users in the design process, by doing this the design is closer to the final day to day life of the user and the designs become more effective, and final suggesting to expand the application from individuals to social groups of people, such as different organizations public or private, and if it is considered in a community the impact could be much broader.

There is also a demand to have a shift in attitude from prescription to reflection, from behaviors to practices, and consequently, they suggest a new type of studies should be made in order to achieve more comprehensive solutions.

The following researches[31], [32] show that a superior way to incentive people to changing behaviors, and reducing even their ecological impact was to share the results of their daily activities, Delmas et al. [31] show how by making their users compare their statistics with groups of people, they change the behavior in the usage of electrical devices that consumed energy, and created a challenge for the users for having a better reputation among their peers, they compared with two other groups where there was one control group which was not engaged in to change behavior and a group where the information about their consumption was shared in a private way.

As shown in Figure 10, people who public profile was exposed change their behavior in more strategies that the one where the information was private.
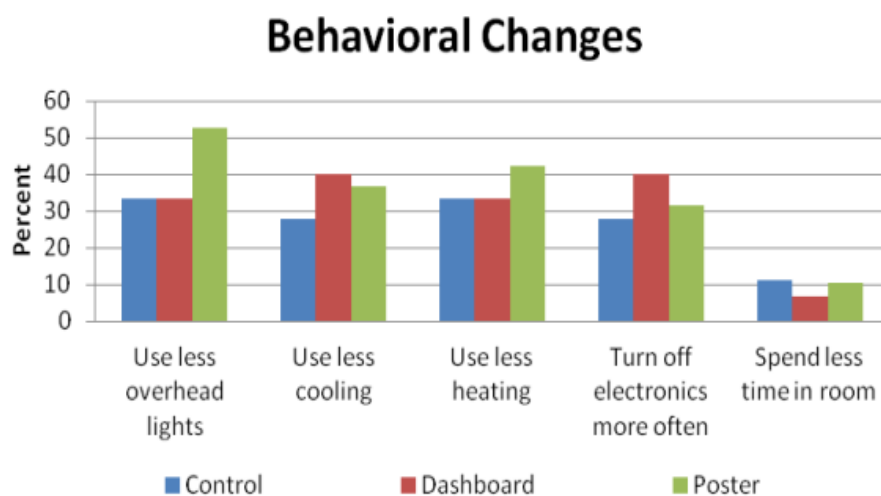

Figure 10 Behavioral change from (Delmas)

But for helping the domestic consumption whereas most of the data is not visible for the users the study from Sarah Darby[35] helps to prove the idea that a feedback is always needed in order to start generating conscious behavior, considering that such information has to be presented in a user-friendly way.

Barclay [36] showed in a human behavior research that people contribute and help when their reputation is considered to be altruistic, and by being the most altruistic in a group their contribution is the highest, other research from Carpenter et al. [37] showed that monetary rewards do not increase the participation of people, but keeping the reputation was more important for their participation.

While in the research from Ma et al. [32] the culture from where the groups are, their origins from which the people are, had an incidence on how they respond to eco-feedback and how the behavioral changed depended on the type of culture they were into, showing that what may work for one cultural group work less for other cultures.

4 DESIGN PATTERNS

In this chapter, the different design patterns are explained and exposed, which they have been proposed to be improved and later on cataloged into a set of sustainable patterns but before implementing those steps, an explanation of sustainability and design patterns have to be addressed to continue with the study.

The basic characteristics have been previously defined for design patterns, and the basic elements that conform the design patterns, but how these elements could be joined with sustainability, are further explained in Figure 11, which is a modification from Seffah et al. [5], whereas the relationships between the different components of the patterns are explained further along with their environmental description.
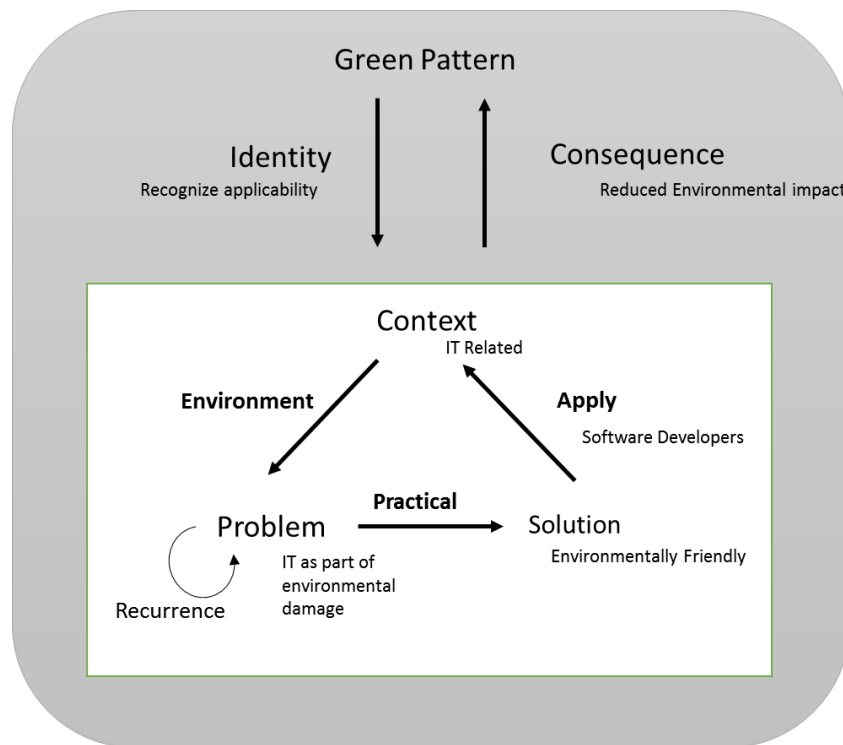

Figure 11 Green Patterns Adapted from Patterns Ingredients

Having discussed the current problems IT generates, directly or indirectly, and the currently existing solutions for those problems. In this thesis design patterns are proposed; an overview is shown in Figure 12. Each pattern is described in pattern language for its

abstraction and easy implementation, also design patterns come with an example of their possible application, by HCI designers or daily users
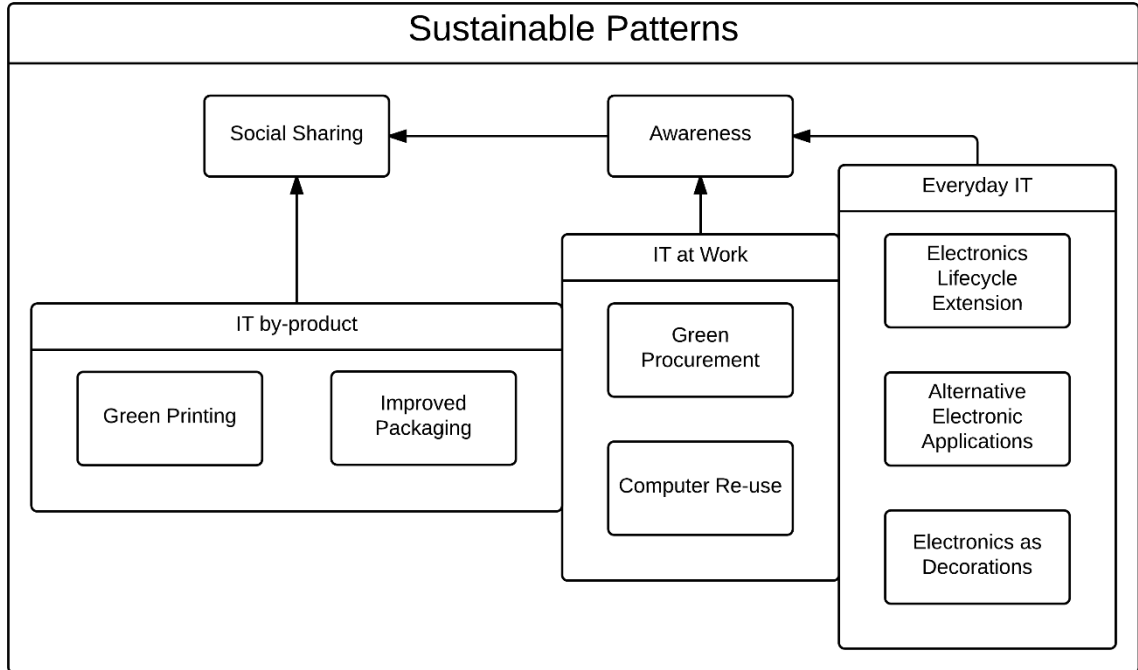

Figure 12 Design Patterns and their Relationship

It is worth mentioning that all the examples here presented were created with the application [38], hence 9 mockups were created to showcase the use of the different design patterns.

4.1 Green Printing

Printing is a task closely related with IT, since the beginning of printing era people has been used to print in hard the information provided in screens, and the task for ICT developers has been to enable printing as an easy way to back up in paper, but the concerns of wasting paper and resources were not considered, the prices for printing decreased and the speed in which information could be printed increased.[39]

Therefore this pattern has been thought as the way in which HCI developers and ICT Engineers could help reduce the amount of printing material, also this pattern is open to improvements and discussion for part of the community.

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Pattern Name:	GREEN PRINTING
Context/Intent	This pattern is to reduce/stop printing unless necessary
Problem	Large sums of documents are printed unnecessarily generating a huge waste of resources (paper and ink) and hindering the environment
Forces	The document size is large and is widely used, and almost every person in the organization wants to print. The document is in colors, 1 face, spaces between lines and margins are wide Oversized images that take much space
Solution	Disable by defect the print button If user really needs to print go to special site and display warning Advice the user why he should not print Show leaderboard/point reward system Finally print but with print, settings changed
Consequences	Users print less Less resources are consumed.
Related Patterns	SOCIAL SHARING

The pattern shows the problem of printing in great quantities, a matter that happens in any kind of institution and homes and people that print on a daily basis, the solution is proposed as a process which could difficult, and make the users realize their impact of the document they are printing.

As shown in Figure 13 below an example of the application of the pattern, certainly it must be analyzed if it improves and reduces consumption within an institution.
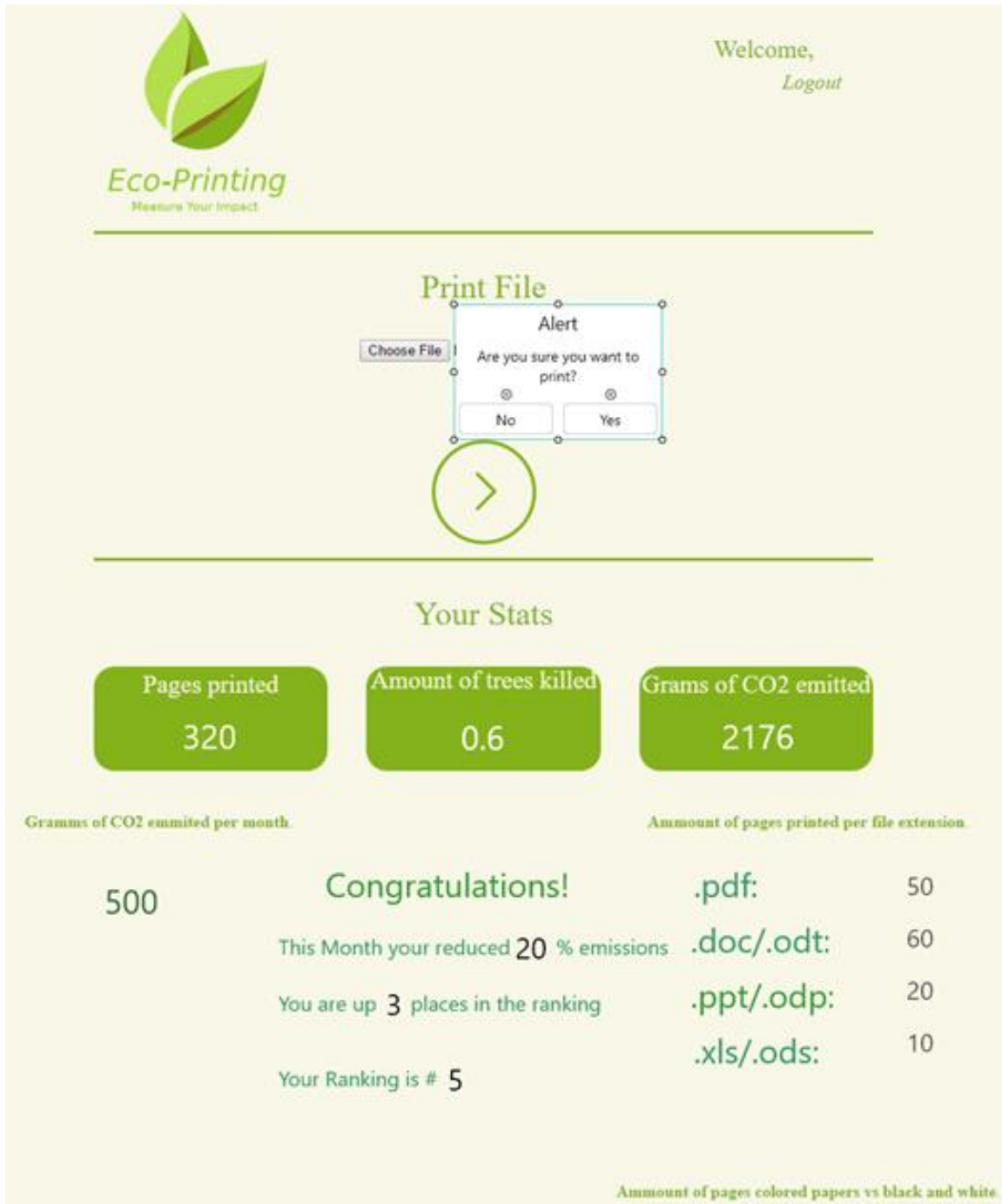
Figure 13 Green Printing Example

4.2   Improved Packaging

In the supply chain to the final customer materials such as special foams, cardboards and plastic are used to pack the items, even the smallest items are packed individually, the amount of packaging used has become a problem. The logistics have improved thanks to

technology, improving efficiency in delivery [40], and a way to continue improving is to create awareness and for IT engineers to be part of the solution by the use of the following pattern

Pattern Name:	IMPROVED PACKAGING
Context/Intent	This pattern showcases how to reduce the unnecessary extra packing when ordering items online.
Problem	Due to the easiness of online shopping more and more people are buying items online, which increase the amount of packaging used for shipping those items.
Forces	Any item bought online has their own packing plus the packaging for shipping. People tend to buy items separately. Materials (plastic) are not biodegradable. Packaging is disposed of.
Solutions	When purchasing the item show the types of packaging available for shipping, pre-select less packaging thus cheaper option. Attach instructions to conserve the packaging and reuse them as gift boxes. Encourage recycling. Encourage devolution of packages for further use in other shipping.
Consequences	The Less useless package is used when sending items. More packaging is reused within online shopping. Customers reuse packaging for other uses. Packages are reused.
Related Patterns	SOCIAL SHARING

Nowadays create an online store has become an easy task, hence becoming a force to the problem in the pattern, but if the solutions presented in the pattern above, are implemented on the online store, wasteful packaging could be reduced, not just that, when presenting an

option to the users they can choose to decrease their waste. An example is shown in Figure 14.
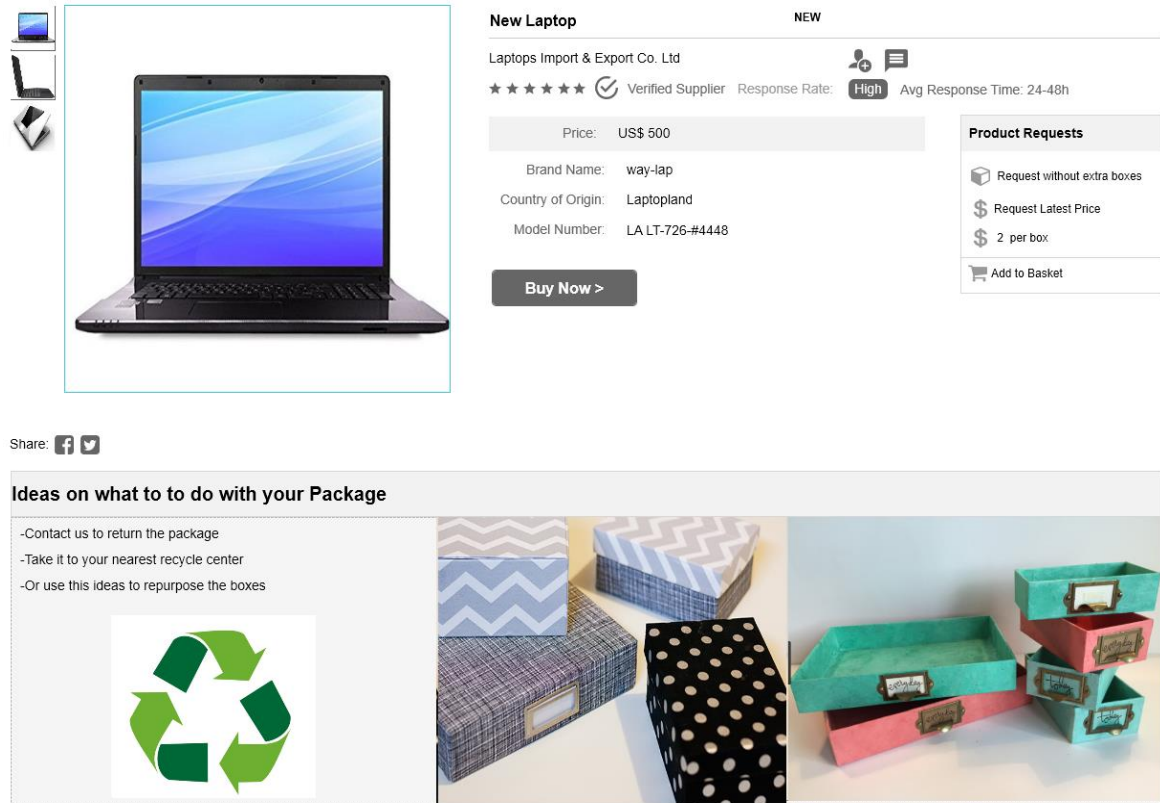

Figure 14 Improved Packaging Example

4.3   Electronics life cycle extension

When talking about any electronic, most people change them in the first two years of use, for any reason that may be [41], whether their plans force them, or just feel the need to have some new phone with a new design and better characteristics.

Certainly improvements have been done across several countries where regulations have been introduced [42] also with the help of academia [43], and the recycling of electronics has increased in the last years, in order to encapsulate those efforts and help to continue this trend and incorporating into IT lifecycle for electronics users, the next pattern is proposed

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Pattern Name:	ELECTRONICS LIFECYCLE EXTENSION
Context/Intent	This pattern will showcase components (screen, battery, memory, processor) life and avoid disposal of still usable electronics and if disposed of reuse for a person in need recommended.
Problem	Electronics are disposed of even when components (screens, chips, metals, plastics) are still working or available to be repaired.
Forces	Relatively new electronics such as cell phones are replaced by new ones in a lapse from 6 months to 2 years.
	Electronics components have long life expectancy.
	Materials are not biodegradable and hard to extract.
Solutions	Show life expectancy of components.
	If some component suggests repair/replacement.
	Provide guides to repair the own cell phone.
	Provide sources where to find parts.
	Encourage repair with motivational phrases.
	Provide solutions if repair is not effective.
Consequences	Fewer electronics are disposed into the environment.
	Life expectancy of electronics increased.
	Users become more aware of their environmental impact.
Related Patterns	SOCIAL SHARING, ALTERNATIVE ELECTRONICS APPLICATIONS, ELECTRONICS AS DECORATION

The pattern displays the current problem and its forces, it proposes several kinds of solutions that could be incorporated into the software development for electronics, such as apps that display the life expectancy of the different components, and if any needs replace, has replacement guides according to with the model encouraging repair [44], and not only that provides where is possible to get the parts.

By repairing their own electronics users consume less electronic products, increasing life expectancy of the products, some examples are shown in the figure below, repair information was taken from [45], and was used to mockup the follow example in Figure 15.
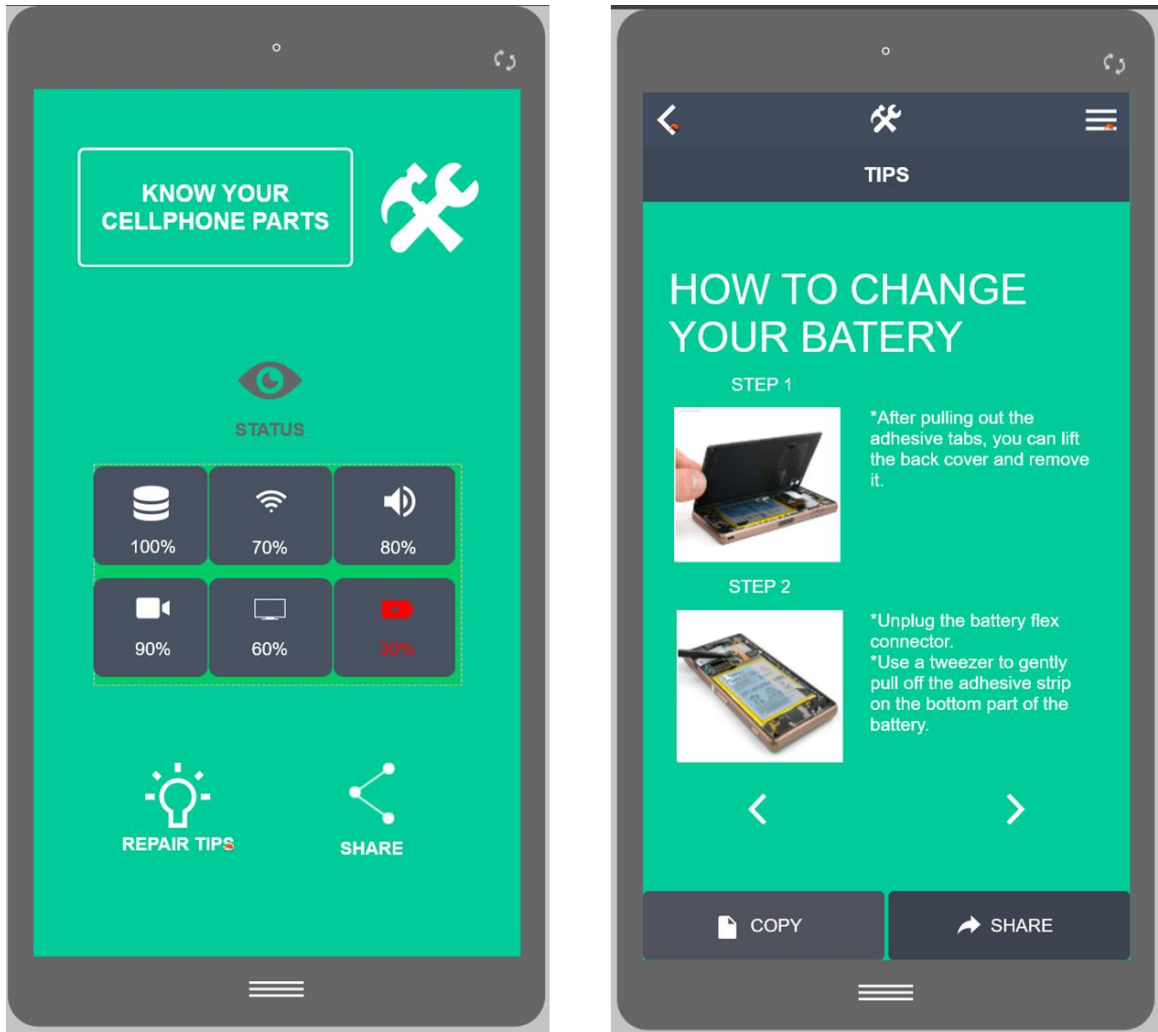
Figure 15 Electronics Lifecycle Extension Example

4.4 Alternative Electronic Applications

In the case the electronics objects are still functional, they could have other electronic applications to what they were originally intended to, giving them more life.

Pattern Name:	ALTERNATIVE ELECTRONIC APPLICATIONS
Context/Intent	This pattern showcases when at the end of an electronic equipment life-cycle alternatives for reusing its electrical components.
Problem	When electronic devices are at the end of their lifecycle all parts are discarded even if they are functional, devices have useful components such as sensors, screens, fans which can be used to other It purposes
Forces	People dispose of all devices components when just a part fails Old equipment accumulates in landfills They are sent to development countries hindering the environment and the people.
Solutions	Sensors can be reused for IoT applications Screens can be used for displaying IoT devices Old cell phones can be used as remote controls Cameras can be used as security cameras. As Fixed GPS for the car
Consequences	Fewer devices are thrown in the garbage. Electronic waste is reduced hence less chemical are exposed in the environment Development countries have less waste from first world countries Other applications increase comfort.
Related Patterns	OTHER IT APPLICATIONS, SOCIAL SHARING.

Online there are a lot of ways where electronic devices can be given other purposes once they are discarded, a platform where all these ideas are shared along with guides step by step that shows how to repurpose electronics or even an app that can help to directly convert the mobile to another use as shown in Figure 16.

Figure 16 Alternative Electronics Applications Example

4.5   Electronics as Decoration

People have shown creativity when reusing elements consider as garbage and giving them a second life but for a completely different use, in this way, the harmful elements are not sent to the landfills and avoid damaging the environment.

The following pattern proposes this alternative and will help software developers/IT workers connect with people outside the industry that can help increase the number of ideas and sharing materials.

Pattern Name:	ELECTRONICS AS DECORATION
Context/Intent	This pattern showcases when at the end of an electronic equipment life-cycle alternatives for avoiding sending to landfills.
Problem	When electronic devices are at the end of their lifecycle they are sent to landfills and most of the components not recycled.
Forces	People throw to garbage damaged or old equipment Old equipment accumulates in landfills They are sent to development countries hindering the environment and the people.
Solutions	Components like motherboards graphic cards can be reused as decoration items, such as lamps or art items. Smaller components, such as transistors, resistors, microchips, can be used to make handicrafts. The platform was different components are shared among people interested. Guides on how to create different decorative elements as DIY
Consequences	Fewer devices are thrown in the garbage. Electronic waste is reduced hence fewer chemicals are exposed to the environment. Development countries have less waste from first world countries.
Related Patterns	ALTERNATIVE IT APPLICATIONS, SOCIAL SHARING

The main purpose of this pattern to solve the problem with its forces is to include in websites space where people could share electronics before disposal, with a network of people that use this electronics as elements for decoration, clothing, jewelry etc.

This pattern has received critics concerning its relation to ICT daily use, but this pattern comes as an informational tool and forecast an alternative to throwing electronics into the garbage and creating more E-waste, thus the mockup idea in Figure 17 its to show that such informational tools could help people get ideas and waste less.
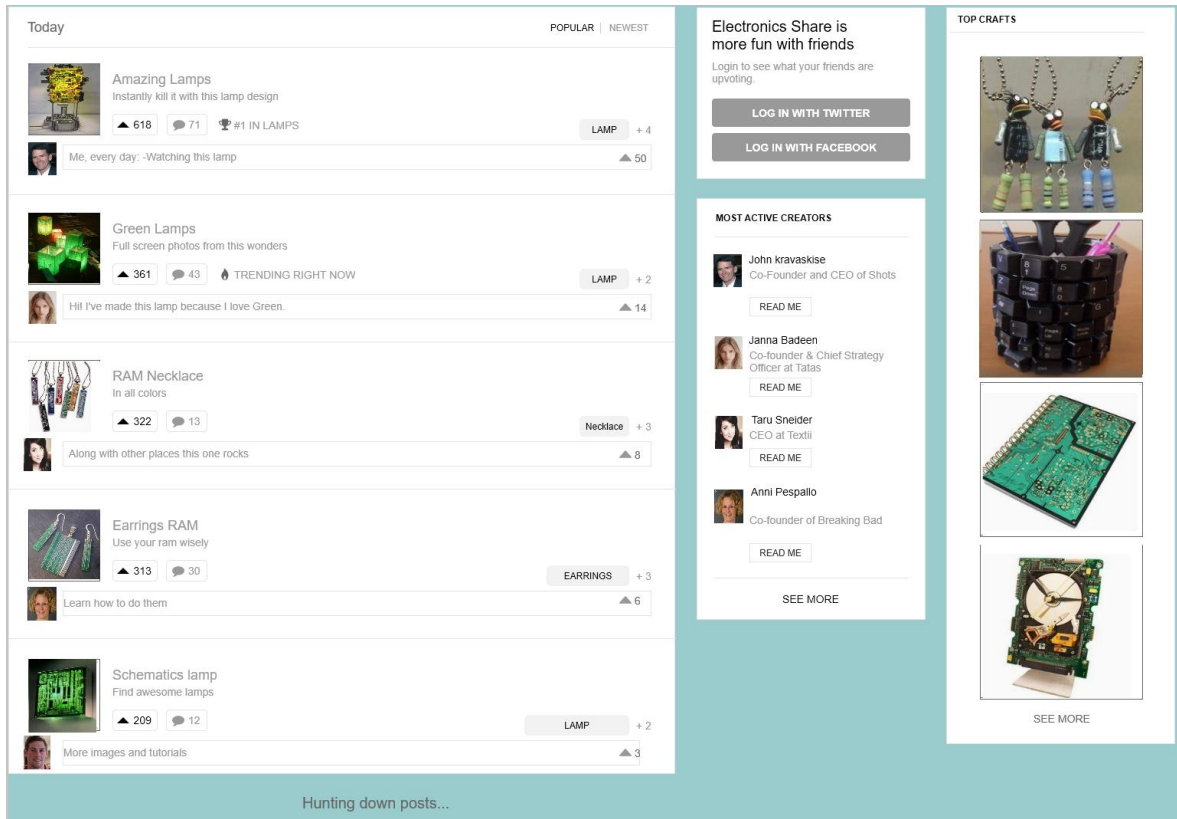
Figure 17 Electronics as Decoration Example

4.6 Computer Reuse

Computers inside any institution have a considerable low lifespan, and they are being replaced with new ones, making the still usable ones obsolete. Also, the process for cleaning up a machine takes time and human resources, and if the computer is going to be replaced it could be donated to charity institutions.

The IT department is in charge of distributing the computers among the workers inside an institution, therefore the IT department could develop software to include the following pattern.

Pattern Name:	COMPUTER REUSE
Context/Intent	This pattern will showcase possibilities for extending the use of computers inside a company.
Problem	After 2-3 computers are being replaced in despite that they are still useful, also cleaning data and configuration takes time.
Forces	Policies inside companies force changes after 2-3 years of use People demand changes due to mismanagement Cleaning computer takes time.
Solutions	Reward employees who keep for longer time their tools If computer returns computer employee is in charge of cleaning before handling The hard drive from the previous computer could be used in new one, so the hard drives are not destroyed and information stays with the user. When the computer is replaced, a donation to schools and libraries to avoid destruction.
Consequences	Increase time of use in computers inside an organization Fewer computers parts are wasted in replacement with new computers Users learn to be responsible with their office's tools
Related Patterns	GREEN PROCUREMENT, SOCIAL SHARING

To implement the solutions presented in the pattern above, software like timers of use could be applied in association with the employee ID, keeping track of the use and the components inside, along with regulations established inside the institution which could help users to increase the time of use of the computers.

In order to show the employee an idea like in Figure 18 could be used or expanded to further create conscience and encourage human behavioral change.
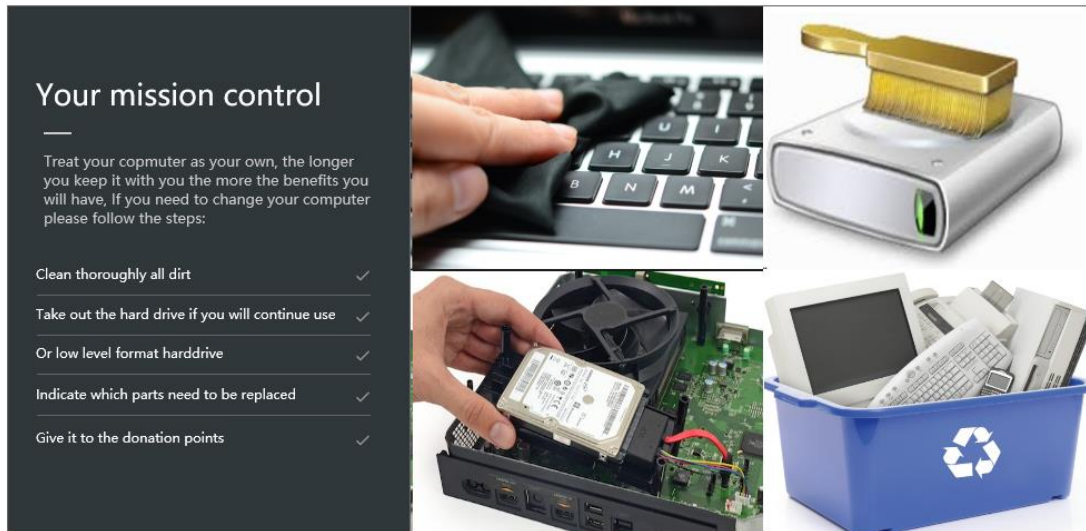
Figure 18 Computer Reuse Example

4.7   Green Procurement

The creation of this pattern is for the cases when different working tools are not being shared among other teams inside an institution, creating an excess of tools that later are not used by other departments.

The idea is to facilitate sharing tools bought by the institution, reducing the wasteful buying and even generating savings.

Pattern Name:	GREEN PROCUREMENT
Context/Intent	This pattern showcases when new software/hardware is bought, members across an organization can share these resources.
Problem	When tools are not shared across departments inside organizations, there exists an overspending and not sharing across departments.
Forces	Equipment such as printers, scanners, measurement equipment, projectors, laptops, specialized software that has expensive licenses installed on single computers.

Solutions	List of tools available for use for other departments
	When new equipment/software is bought for a department, other departments are also aware
Consequences	Less equipment is bought
	Unused equipment is shared in other places
	Life use is increased
Related Patterns	COMPUTER RE-USE, SOCIAL SHARING

The problem and the forces are easily solved by an automated list that displays the inventory database and availability of other user equipment in the institution, such impletation could like in Figure 19.

Figure 19 Green Procurement Example

4.8   Awareness

With the help of shocking images and videos show the result of the human activities in the environment and in the people, that are affected by those activities, presenting the users the solutions previously proposed by the different patterns.

Make ICT professionals include images of awareness in their daily activities, alongside with the creation of new projects which include not just the problems but the solutions on how to alleviate the problems.

Pattern Name:	AWARENESS
Context/Intent	This pattern showcases current environmental problems that shock and create consciousness.
Problem	Lack of knowledge of how electronic waste is handled doesn't provoke any change in people and how they dispose of electronic tools.
Forces	Information about current situation handling of electronic in the countries is not spread enough.
Solutions	Show information, pictures, videos related to e-waste that displays how the management of is being done. Present patterns to help alleviate the problem of e-waste.
Consequences	People will be more conscious when disposing of electronics in the garbage, generating less waste thus reducing pollution.
Related Patterns	IT FOR DECO, ALTERNATIVE IT APPLICATIONS, COMPUTER RE-USE INSIDE COMPANY, GREEN PROCUREMENT, ELECTRONICS LIFECYCLE EXTENSION.

For creating consciousness about electronic waste, crude images have to be shown to people for them to realize what is happening the current situation, hence the next example where documentaries such as The E waste Hell from BCC [46].In the Following example in Figure 20 images have been taken from the following sources: [46]–[48].

Figure 20 Awareness Example

4.9 Social Sharing

After all, humans are social beings and what a better way to incorporate social elements in the patterns previously mentioned, the objective of this pattern is to make the developers realize that all the patterns could incorporate a social approach.

Pattern Name:	SOCIAL SHARING
Context/Intent	This pattern shares ecological reputation using different environmental protecting activities.
Problem	Lack of commitment and engagement to incorporate actions to reduce environmental impact.
Forces	People not engaging in changing hindering behaviors. The passiveness of people with environmental problems.

Solutions	Establish a reputation system that shows daily ecological action
	Compensate with points ecological activity
	Share with members of our community the points
	Have an awarding system for the more engaged.
	Help others reach high points by educating
	Also, keep confidentiality if required
Consequences	Establish a community passionate about environmental protection
	Community improves self-esteem
	Reduce environmental impact
Related Patterns	ELECTRONICS AS DECORATION, ALTERNATIVE ELECTRONIC APPLICATIONS, COMPUTER RE-USE, GREEN PROCUREMENT, IMPROVED PACKAGING, ELECTRONICS LIFECYCLE EXTENSION, AWARENESS

Since this problem is focused on human behavior, all the other patterns mentioned before could help to change the behavior, by incorporating a point system to each of the sustainable activities. For instance, if you work in an institution where there exist better printing, procuring and sharing practices and those are implemented on a daily basis, a certain amount of points should be distributed among their workers, in another case for example if someone is using for longer period any electronic, or repurpose the electronic in any way or reuse packaging, award points according to their actions, points that are shared among other people to show the progress and the commitment, with those points there should be some kind of benefits whether by some company, local government etc.

To increase the impact the bigger the group and the communities it should be applied the more people will engage the better commitment to change, until reaching a point where people engage in everyday life and becomes part of human behavior like in Figure 21.

Figure 21 Social Sharing Example

5   ONLINE PATTERNS CATALOG

Once the patterns have been expressed and collected, a good way to catalog them is to create a site where they could be refined, improved and even more patterns suggested to increase the size of the catalog. The patterns here created need to be shared in the world and through this website where users can comment and rate the different sustainable design patterns after seeing the sustainable design pattern itself and an example of its application, there is also the possibility to send a private message to the creators if users want to maintain privacy.

The reason for the creation of a catalog is for the free sharing of information and tools such a design patterns among the HCI and ICT professionals, and the main objective is to showcase ideas and solutions to existing problems, and a catalog gathers all of the design patterns into an unique "database".

Nowadays several design patterns catalogs exist online related UI design [49], Interaction Design [50] and a more comprehensive database were several types of design patterns from different authors and different areas of software development and IT [51].Given the circumstances, posting this web application online increases the availability of designs patterns and introduce the patterns here discussed in the world.

5.1   Frameworks, Technologies, and Architecture

The languages used for the web application were PUG(Jade) that render the HTML5 page content, CSS3 for the design. These are one the most used tools for web development in the current year [52][53][54]. The frameworks Bootstrap, and Nodejs, that use JavaScript programing language, to create the different transitions from the bootstrap template. For Local testing, Express was used to start a local server connection, for the database the library mongoose was used to connect to the MongoDB database.

The web application was developed with the following frameworks and technologies in Figure 22:

Figure 22 Technologies Used

The idea of using Heroku is using a free hosting service which uses Amazon cloud, along with database as a service provided by mongo DB Atlas, which also uses Amazon cloud as their infrastructure. When a user access the site it displays a menu of the different patterns which can be accessed and shown, The comments are stored in a NoSQL database [55] that is mongo DB, due to the nature of the app, in that way comments are retrieved from the database in a fast way every time the user access to each of the patterns, also the comments and ratings are displayed immediately after the user activates sends a comment. Also, a google form was introduced in case some user wants to send a private commentary that doesn't want to display on the pattern page.
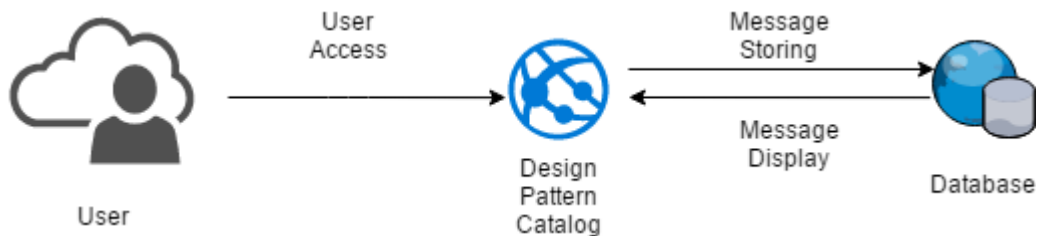
Figure 23 App Architecture

5.2   Web Catalog Implementation

For the purpose of the catalog creation the framework used is Nodejs whereas the file structure created is used in several files, those files are connected and configured through the main app.js, and all the routes to the different files are called through the file index.js. Each web page is rendered via the files. pug, a page was created for each pattern in HTML and render through. pug files. The CSS files and the JavaScript for the different animation, and elements from the site are in their own folders.

The database schema is defined in the file coment.js, where the commands post and get will use this fall to save the different commentaries posted in the catalog.

Figure 24 File Structure

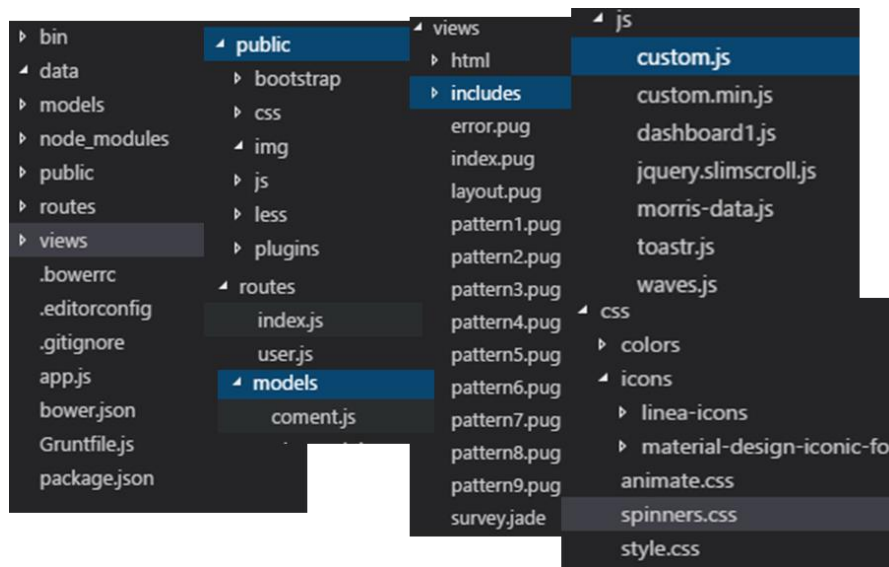In the file, app.js is where the main functionality of the application is declared, and where the routes for all the files and connections are defined for the use of the web application as seen part of the code in Figure 25.

```
app = express();

var env = process.env.NODE_ENV || 'development';

var mongoose = require('mongoose');
//mongoose.connect('falcmongo://node:patmongo@ds149501.mlab.com:49501/patterns');
mongoose.connect('mongodb://node:patmongo@cluster0-shard-00-00-ivki8.mongodb.net:27017,cluster0-shard-00-01-ivki8.mongodb

var db = mongoose.connection;

db.on('error', function () {
    throw new Error('unable to connect to database');
});
```

Figure 25 Connection to the database app.js

All the patterns for the catalog are written in HTML, and to save code they were split in header and footer and they were rendered through the .pug file as shown in Figure 26, due to the nature of the variables they could not be processed in the HTML file, thus the rating system is declared in the .pug file

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```
include ./includes/header.html
include ./html/Pattern1header.html

each _id in all_comments
        br
        h4 Name: #{_id.namecoment}
        h5 Commentary:
        p #{_id.coment}
        //- td Rating:#{_id.lastrating}
        h5 Rating:
        - for (var i = 0; i < _id.lastrating; ++i) {
         fieldset#pattern.rating(name='pattern')
                    labelcol.full
        - }
        br

include ./html/Pattern1footer.html
include ./includes/footer.html
```

Figure 26 Pattern .pug

The most important part of the live rating and commenting system is declared In the index.js and coment.js files, where the plugin mongoose helps providing and easy access schema to the database, meanwhile in the index.js the saving and displaying procedure for the database is done.

```
router.get('/pattern1', function (req, res) {
  var query = {"patternid": 1};
 Comment.where(query).then(function(comments){
    console.log(comments);
    res.render('pattern1', { title: 'Express', all_comments: comments });
  });
});


router.post('/pattern1', function (req, res) {
  var comment_data = {
                "lastrating"   : req.body.rating,
                "patternid"    : req.body.patternid,
                "namecoment"   : req.body.commenter,
                "coment"       : req.body.commentBody,
                "email"        : req.body.email
            };
 console.log(comment_data);
 var comment_object = new Comment(comment_data);
 comment_object.save(
        function(err){
          if(err)
            console.log(err);
          else
            console.log('Comment for pattern1 added to database!');
        });
 res.redirect('/pattern1');
});
```

```
var mongoose = require('mongoose'),

    Schema = mongoose.Schema;

var CommentSchema = new Schema({

    lastrating  : { type: Number },
    patternid   : { type: String, required: true },
    namecoment  : { type: String},
    coment :    { type: String },
    email   :   { type: String }
});

module.exports = mongoose.model('Coment', CommentSchema);
```

Figure 27 database connection

5.3 Working Pattern Design Catalog

This part describes the use of the pattern catalog that has been developed as a web application, with the tools previously explained.
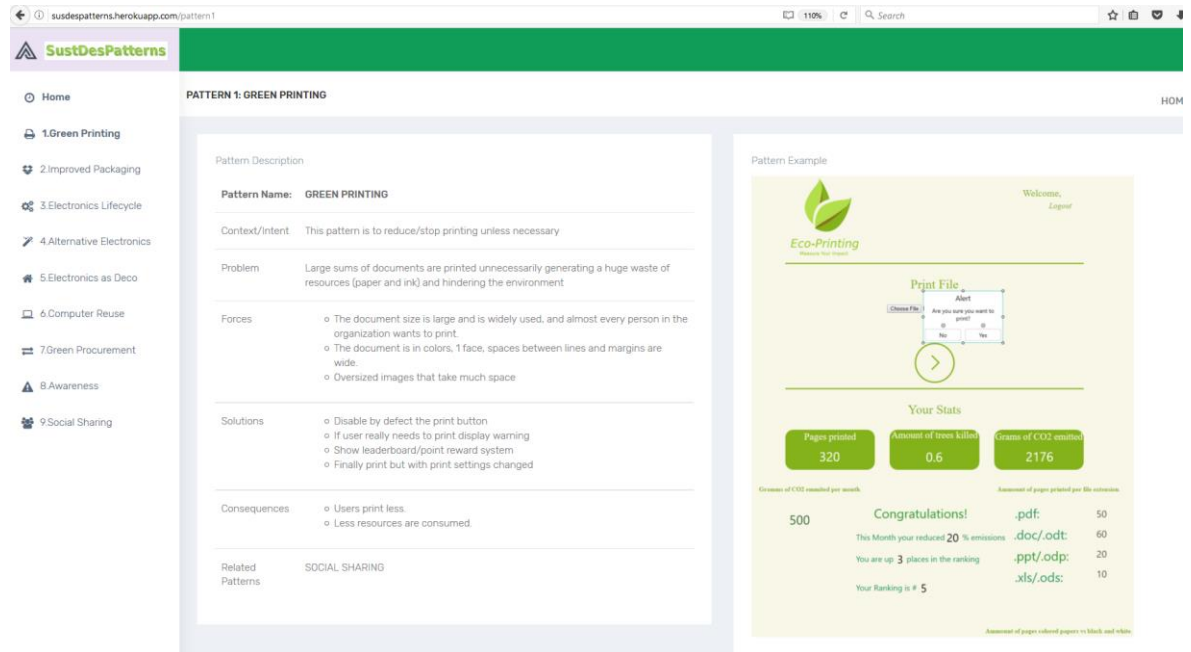

Figure 28 Pattern Catalog web site

The patterns are in the sidebar listed by their names, in each one there is the description of the pattern alongside with the example as shown in Figure 28, to access the site the link to follow is http://susdespatterns.herokuapp.com/, next to each pattern the live commenting system is implemented in order to improve, and rate the different patterns and know the opinion of the community as seen in Figure 29.

The following application will be included in http://hci-cps.lut.fi/ as a part of future research for GALAPAGOS : A Gamified Language of Patterns for Global sustainability, for further explanation in the reference [56].

Figure 29 Commenting System

As mentioned before not just the commenting system in Figure 29 but also a google form system to reach directly to the author of the patterns is implemented for the users as shown in Figure 30

Figure 30 Private Message system

6 DISCUSSION AND CONCLUSIONS

The main focus with the creation of the design patterns for this thesis was to diverge from the focus on energy consumption and focus on a broader idea of sustainability, where other activities of everyday life are intertwined with IT. Such activities and their impact alongside with the current solutions are explained in the literature review. All the problems are focused on making the users of IT and the IT community to change behaviors, by expressing and collecting that idea in the format of design patterns.

Through the mean of observation, the different problems were defined, in that way a design pattern could be created, suggesting them and then creating an example of that pattern, showing that their application is feasible within the different constraints it may have, in that way suggesting different solutions that address sustainability problems.

A pattern catalog or library was created with the inclusion of all the design patterns, for the creation of this online catalog, several up to date web technologies were used making the development faster, showing that the creation of an own pattern catalog is possible. This catalog has a comment and rating system, which its purpose is to evaluate continuously the quality and usability of the patterns, as the evaluation of different patterns is a continuous process until the patterns are established and recognized it goes beyond the time constraint of this thesis project.

By addressing different problems related to sustainability, such as in focusing on the social impact with the social sharing pattern, whereas if implemented in a real system the impact would be in the social and environmental pillars of sustainability, also with the use of this pattern that encapsulates all the other, thus the others could be applied as well. Their impact evokes the 3 main pillars of sustainability, environmental by reducing resources use, social by increasing awareness and economical by reducing costs.

All the examples here sketched are focused on software development, as these examples could be considered to include into the development of new software as part of ICT solution,

and with the inclusion of new sustainability metrics, they could be even considered as extra qualities for new software.

As future work is recommended firstly to include more solutions and improve and optimize the patterns here proposed, secondly to consider the   creation of different metrics that could measure the impact of the different patterns here proposed, for that new standards should be defined and more studies in the subject have to be done, the basis is established.

This thesis project was developed as part of a first stage from a bigger project where the second stage is the redesign of a new tool that captures and manages design patterns for all kinds of areas, called Galapagos. The link for the Galapagos project is http://hci-cps.lut.fi/index.php/galapagos/.

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