Computer-Aided Design 59 (2015) 214–228

Contents lists available at ScienceDirect

Computer-Aided Design

journal homepage: www.elsevier.com/locate/cad

Ubiquitous conceptual design of a ubiquitous application: A textile SME case study for real time manufacturing monitoring

Ricardo Mejía-Gutiérrez, Gilberto Osorio-Gómez*, David Ríos-Zapata, Daniel Zuluaga-Holguín

Design Engineering Research Group (GRID), Universidad EAFIT, Colombia

HIGHLIGHTS

- An index to evaluate the ubiquitous level of product-service systems was proposed.
- A framework integrating methods and tools supported the conceptual design stage.
- Hardware–Software were integrated through a Ubiquitous Design Support Environment.
- An industrial implementation allowed the evaluation of a Ubiquitous service.

ARTICLE INFO

Keywords:
Ubiquitous technologies
Ubiquitous conceptual design
Artifact and service combination
Ubiquitous design support environment
Fuzzy inference system

ABSTRACT

Advances in Information and Communication Technologies (ICT), computing, networking, mechanics and electronics are changing the people's way of life. Several research efforts are leading the design and development of Artifact and Service Combination (ASC) with the implementation of Ubiquitous Technologies (UTs) in multidisciplinary sectors. However, the design process of such systems often ends in the implementation of conventional approaches and tools. A Ubiquitous Design Support Environment (UDSE) comprising an application intended to guide the different activities, tools and resources applied at the conceptual design stage is presented. After needs analysis, multidisciplinary collaborations are also required in order to generate innovative conceptual solutions, focusing this approach in the conceptual design stage of traditional design methods. Some activities from the conceptual design stage are enhanced through the use of the UDSE as well as through the use of a novel ubiquity assessment tool for concept selection and validation of Ubiquitous Products and Services. Finally, a case study on a Small and Medium Enterprise (SME) from textile sector, in a developing country, is presented to analyze and validate the presented concepts.

1. Introduction

Advances in Ubiquitous Technologies (UTs) have led practitioners and researchers to find novel applications, in order to exploit the potential benefits that a proper combination of these technologies can offer to a specific industrial or scientific field. Together with this, UTs have demonstrated to be a complete path to the evolution of applications in order to meet the globalized needs of today [1]. This is making UTs a more interesting field for emerging markets, in order to make their economies more competitive in a globalized environment.

This trend also implies the development of better design practices and tools for this kind of products and services taking advantage of the same technologies, that is, a Ubiquitous Design Support Environment (UDSE) or work platform supported by a Ubiquitous Conceptual Design approach with a supported process and evaluation tools.

According to Horváth et al. [2] a UDSE should not only consider aggregation, processing and preservation of information, but also supply alternative ways of completing design activities and allow designers to take advantages in four contexts: inspiration, communication, visualization and validation. Their work pays special attention to the on-demand information management in the Need identification stage of the design process.

* Corresponding author. Tel.: +57 42619500.
E-mail addresses: rmejiag@eafit.edu.co (R. Mejía-Gutiérrez), gosoriog@eafit.edu.co (G. Osorio-Gómez), drioszap@eafit.edu.co (D. Ríos-Zapata), dzulua19@eafit.edu.co (D. Zuluaga-Holguín).

http://dx.doi.org/10.1016/j.cad.2014.01.008
0010-4485/

Considering a design process divided in three stages, stated as need identification, conceptual design and detailed design. In the first two stages are contained most of the activities where different actors should interact and work on the same topics in an important collaborative manner whereas the detailed design stage considers activities of modeling, analysis and simulation which are often developed in an independent way by domain-specific actors. Proceeding along this way, efforts have been conducted to the development of a UDSE for the conceptual design stage, where different disciplines are involved and innovative solutions at the leading edge require collaborative, generation and decision-making activities, can be carried out using different methods and tools in a workflow which guides the designer throughout the design process.

The conceptual design stage for complex products starts from the synthesis of the problem and finishes with the selection and evolution of a conceptual solution represented by a general architecture where main components and their interactions are identified and located in the physical space [3]. Such process guarantees the analysis of functional and technical aspects of the solution along with the aesthetics, ergonomics and human-centered issues aiming to the development of innovative products.

For this stage, the proposed UDSE includes tools and methods oriented to enhance and facilitate the design process underpinning a systematic approach in order to guarantee the quality of the result. In the specific case of design of a ubiquitous product and service combination, the support environment contains a new tool which provides the designer the service to evaluate the ubiquity level of the solution during the whole process in order to take decisions about the different characteristics to be implemented.

The first effort has been conducted to the development of a standalone in-place collaborative work platform considering specific tools for conceptualization integrated with data management software and organized according to a defined design process. In hardware, this platform considers a workstation connected to a multi-touch screen where several people can work interacting simultaneously, different input–output devices and connectivity through different communication technologies. In software, the activities for recording and generating ideas are supported through writing, drawing, diagramming or using some specific computational tools oriented to creativity enhancement. Besides, a computational framework supporting the Ubiquitous Conceptual Design approach presents these tools in an intuitive way in order to suggest a specific design process.

The UDSE has been validated by redesigning a previously implemented solution for a textile industry. Understanding Artifact and Service Combination (ASC) as the combination in which a physical system is intended to provide a background service to the user. In this textile solution, UTs had been implemented in order to measure productivity and manage information in real time. The Ubiquitous level of the previous solution was evaluated and then some specific important aspects to enhance its ubiquity level were reviewed.

In Section 2, the document presents the state of the art of ubiquitous products and services, as well as of the ubiquitous design. In the following, Section 3 is dedicated to the ubiquitous conceptual design methodology including stages of alternatives generation, concept selection and concept validation. The UDSE is considered in Section 4, and finally, is validated through a case study in a Small and Medium Enterprise (SME) from textile sector in Section 5.

2. State of the art

2.1. Ubiquitous products and services

Ubiquitous technologies in their basic definition are related to solutions available anywhere and anytime [4]. Usually, this type of technologies is not available as a product or service itself. Otherwise, they are applied in a ASC way [5], as the combination between product and service is almost synergistic for this type of technologies. Gerritsen and Horváth [6] defined five functional clusters for UTs in order to illustrate the relationships of functionally similar technologies to humans, artifacts and environments. These clusters are: exploration, conversion, networking, transmission and sensing.

Currently there are distributed, multidisciplinary and unattended ASC but not all of them can be considered as ubiquitous applications. It is because of this, that current ASC should be evaluated in order to determine if they are meeting the ubiquity features. In order to develop this evaluation, different approaches have been created. As a reference, the Ubiquitous computing (UbiCom) concept started in the late 80's and rapidly expanded in the 90's with the aim to support humans in their daily life activities in a personal, unattended and remote manner through the integration of computer power in devices and environments [6]. In ubiquitous computing applications, security and context awareness are crucial aspects which should be evaluated in order to decide when an application will fulfil the ubiquity concept. An approach to evaluate ubiquitous computing applications is the Proof-of-Concept (PoC) defined by Weiser [7] as "The construction of working prototypes of the necessary infrastructure in sufficient quality to debug the viability of the system in daily use". Taking this definition, sometimes the development of a complete PoC for a ubiquitous device could be expensive in time and resources. In this way, it would be useful to know beforehand if the proposed application will fulfil the desired ubiquitous behavior. Kwon and Kim [8] defined a methodology to evaluate the ubiquitous level of ubiquitous services. Their methodology is based on three keywords and twenty seven items related to evaluate the ubiquitous level. Under this approach [4] presented an organization of the key properties of a UbiCom. Five core properties were defined as: Distributed systems, Implicit Human–Device interaction (iHCI), Context-aware, Autonomous and Individual Intelligent Systems. Each of these core properties are defined in terms of over 70 sub properties.

Ubiquitous computing is closely related to ubiquitous technologies since it is able to empower technological products and services into most everyday life objects, thus, improving the user experience with them, through the use of Information and Communication Technologies (ICTs) . This must be one of the fundamental challenges of implementing ubiquitous technologies in the development of ASC [9]. Associated with this responsibility, ASC appearing on different areas of knowledge should become more transparent and invisible to the users. All these areas have in common the relationship between UTs and improving user experience [10].

2.2. Ubiquitous design

As ICTs are evolving, there are new opportunities to support concept generation, product and process modeling, virtual simulation, communication, collaboration, data management and operative research in product design processes [11]. Besides, this evolution encourages collaborative work and their pervasive use has driven the development of support environments based on UTs with a service oriented perspective [12] and advances in networking that allow human-knowledge interaction thus enhancing human–human interplay and cooperation as well [13].

The concept of design and manufacture supported by ubiquitous computing technology is known as UbiDM (Ubiquitous Design and Manufacture) [14]. With this frame it is very important to collect all the information created during the design processes, via ubiquitous computing technology, in order to support the design activities.

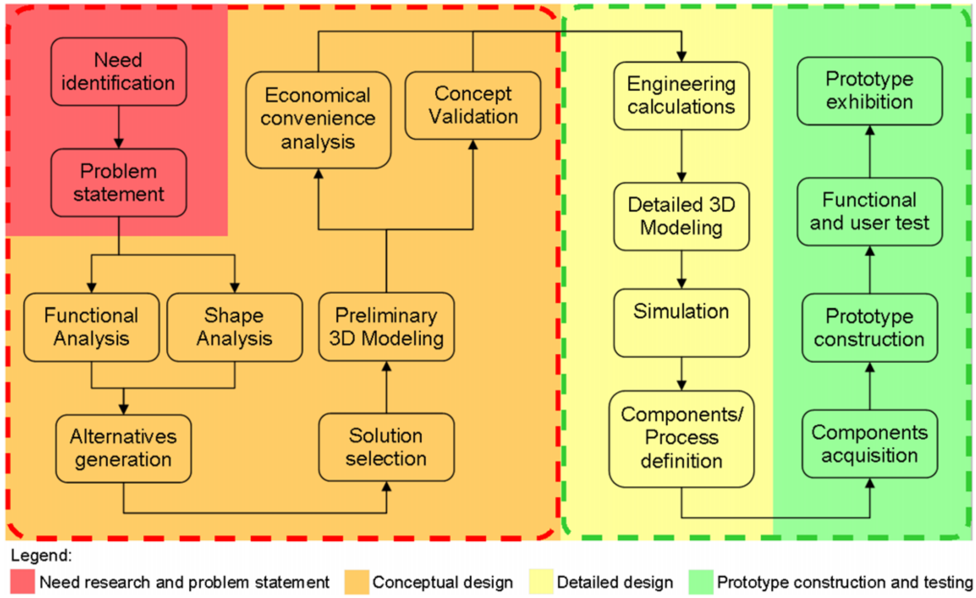

Fig. 1. Integrated product design methodology [3].

In another context, ubiquitous design is defined as a design support process, through the integration of a network of transmission, processing and communication that functions as a complex system of services with special attention to the application of information management [2].

These definitions locate ubiquitous design tools that help collecting information of the results obtained in different design stages, in a ubiquitous manner. Nevertheless, ubiquitous design is not yet conceived as a design performed on a ubiquitous manner, in other words, as a design guided in a transparent way.

In line with this research evidence, a Ubiquitous Conceptual Design approach for conceptual design stage is presented herein, considering the three key clusters defined next.

3. Ubiquitous conceptual design (UCD) methodology

There is a need to enhance regular design processes which are evolving towards distributed, collaborative and ubiquitous approaches. That is why a methodology to support the conceptual design phase in a ubiquitous manner is proposed, more specifically, a Ubiquitous Conceptual Design Methodology. This approach has been oriented to the design of Ubiquitous ASC since there are recent trends on developing artifacts enriched with UTs .

Conceptual design activities analyzed in this section are based on the methodology for integrated product design presented by Osorio-Gómez et al. [3] and depicted in Fig. 1.

From this methodology, some of the activities were adapted to the Ubiquitous Conceptual Design context integrating infrastructure and supporting tools. Also, Need research and problem statement are complemented with context mapping techniques [15]; these techniques empowers the designers to understand the latent needs of the users [16]. These interventions are described in the following subsections.

3.1. Alternatives generation

In the conceptual design stage the generation of ideas is supported by searching abilities in local or remote databases, creativity enhancement, graphical representation and collaboration. In order to support the Ubiquitous Conceptual Design approach, the UDSE explained in Section 4.1, is used.

3.2. Concept selection

Considering some related research and theoretically established parameters on ubiquity level it is observed that different fields or clusters have been stated in order to define major and general characteristics that a system should present to be considered ubiquitous. Anyway, each cluster has a finite number of aspects interpreted in different ways by each author and evaluations are conducted in a subjective manner according to that.

According to the three core requirements for Ubiquitous Computing presented by Weiser [7] concerning computer networking, hidden human–computer interaction and context awareness, the authors, in order to evaluate, validate and select a conceptual solution fulfilling ubiquity requirements in the best of its ability, state that the three main clusters of features are arranged in the following terms:

1. User/Context/System Interaction (see Table 1).
2. Data Transfer (see Table 2).
3. Data Processing (see Table 3).

These clusters are the three main pillars of Ubiquitous applications and its aspects were defined in a way that ambiguity is reduced. In order to evaluate the Ubiquitous Level of the designed application, based on classifications such as the one from [8,4].

Then, each feature is evaluated individually for all the alternatives of concept by professionals involved directly in the design process. From now on these professionals are named "experts". This evaluation is made based on the following scale from 1 to 5:

1. the application definitely does not fulfill the feature(s) intention;
2. the application does not seem to fulfill the feature(s) intention;
3. it is hard to decide if the application fulfills the feature(s) intention;
4. the application seems to fulfill the feature(s) intention;
5. the application definitely fulfills the feature(s) intention.

The proposed approach mixes, the evaluation of each feature (within each cluster) and a fuzzy evaluation to convert subjective inputs (inevitables in the conceptual design stage) into a numerical value of an application's "Ubiquitous Level" as seen in Fig. 2. This index will enable designers to give preferences while deciding on

Table 1
User/Context/System Interaction.

Features	Description
Environment/context-aware, localized, situated, adaptive	In a dynamic environment, the application actively adapts to context changes rather than just present context changes to the user. The system can discover the situation or context such as: location, time and user activity. Physical context-awareness includes more than spatial and temporal awareness, such as environmental information (e.g. Temperature, Humidity, etc.)
User-aware, personalized, tailored	The application is aware of presence of the user, user ID, user characteristics. This may trigger system adaptation and the HCI is tailored to an individual user or type of user, based on personal details or characteristics that a user provides or is gathered about a user
Hidden, invisible	The application is invisible to the user. It is integrated into the general ecology of the context
Ease of use, tangible, natural, non-intrusive	Interaction is via natural user interfaces and physical/virtual artifact interaction that can involve gestures, touch, voice control, eye gaze control, etc. and can be used intuitively and non-intrusively by users
Reactive, reflex	Environment events are sensed. Events then trigger action selection that may lead to actuators changing their environments

Table 2
Data transfer.

Features	Description
Generic	Able to operate across different software platforms, seamless integration of devices and environments
Networked, transparent, virtual	Devices are interlinked using a network which is often wireless
Synchronized, coordinated, response time	Multiple entity interaction can be coordinated synchronously or asynchronously over time and space interactions. It guarantees an adequate response time
Mobile, nomadic	Users, services, data, code and devices may be mobile
Security	Data is only accessible to authorized persons/entities

Table 3
Data processing.

Features	Description
Model-based, rule-based logic, reasoning, intelligence, inferences	Systems use a model of how itself operates and the how the world works. There are many types of model representation such as rule-based, different types of logic-based, agent-based, artificial intelligence, etc.
Autonomic, self-managing, self-star	Able to support various properties such as self-configuring, self-healing, self-optimizing and self-protecting behavior
Recursive, interactive	System interacts with shared knowledge (e.g. access public databases or search for information in the web)
Anticipatory, speculative, proactive	Improving performance and user experience through anticipated actions and user goals in relation to current context, past user context and group context. This overlaps with user context-awareness
Distributed processing	Tasks can be divided and processed independently. It may be distributed to guarantee fault-tolerance

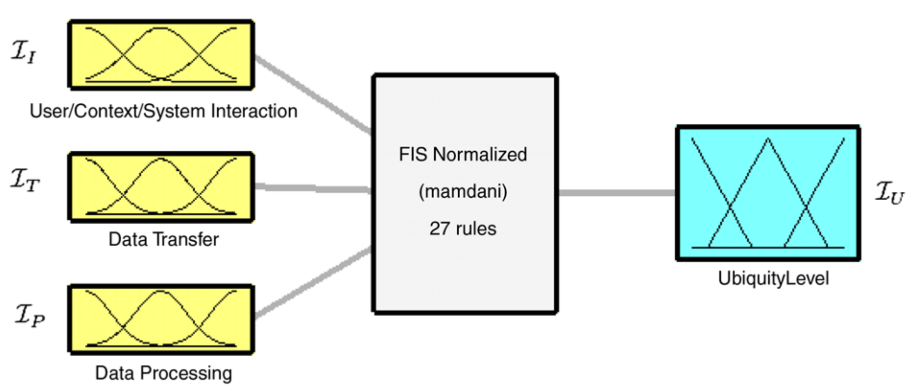

Fig. 2. Fuzzy inference system (FIS).

which concept may reach a better level of Ubiquity. The Ubiquitous Level index ($\mathcal{I}_U$) is obtained using a Fuzzy Inference System (FIS) based on the Mamdani model [17]. The system is composed of 3 inputs ($\mathcal{I}_I$, $\mathcal{I}_T$ and $\mathcal{I}_P$), 1 output ($\mathcal{I}_U$) and 27 rules, explained next.

The crisp inputs for the FIS are three normalized sub-indexes, defined according to clusters' features (described in Tables 1–3) and calculated according to the evaluation of the experts for a particular design concept. These inputs are:

- User/Context/System Interaction Index ($\mathcal{I}_I$).
- Data Transfer Index ($\mathcal{I}_T$).
- Data Processing Index ($\mathcal{I}_P$).

In this case, for m experts and n features, $\mathcal{I}_x$ is the index for each cluster, where x represents each of the three clusters ($\mathcal{I}$, $\mathcal{T}$, $\mathcal{P}$). The index is calculated by obtaining the average of expert's evaluation of each feature, as shown in Eq. (1), where f_i represents the evaluation of each expert:

$$\mathcal{I}_x = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{1}{n}\sum_{i=1}^{n} f_i\right)_j . \quad (1)$$

Three linguistic variables were defined for the different levels that the FIS's inputs (indexes) can take. Each variable has three different levels (fuzzy sets) named "Weak", "Acceptable" and

Table 4
Defined fuzzy rules.

	Fuzzy rules													
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}
I_I	w	w	w	w	w	w	w	w	w	a	a	a	a	a
I_T	w	w	w	a	a	a	s	s	s	w	w	w	a	a
I_P	w	a	s	w	a	s	w	a	s	w	a	s	w	a
I_U	w	w	w	w	a	a	a	a	s	w	w	a	a	a
	R_{15}	R_{16}	R_{17}	R_{18}	R_{19}	R_{20}	R_{21}	R_{22}	R_{23}	R_{24}	R_{25}	R_{26}	R_{27}	
I_I	a	a	a	a	s	s	s	s	s	s	s	s	s	
I_T	a	s	s	s	w	w	w	a	a	a	s	s	s	
I_P	s	w	a	s	w	a	s	w	a	s	w	a	s	
I_U	a	a	a	s	w	a	a	a	a	s	a	s	s	

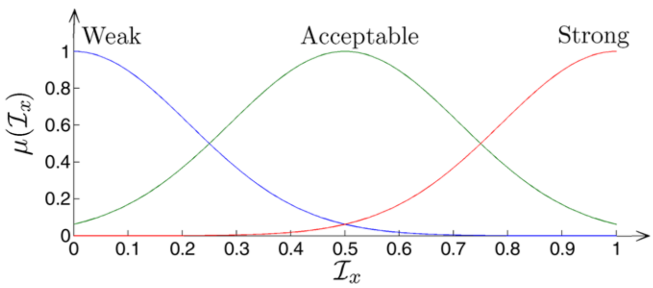

Fig. 3. Fuzzy sets for FIS's inputs.

"Strong", representing a membership function to map it into a normalized value $\mu(\mathcal{I}_x)$ [18]. Fig. 3.

Every index $\mathcal{I}_x$ is normalized, where $\mathcal{I}_x \in [0, 1]$ and can be described by the fuzzy sets "Weak" $= \tilde{W} = \mu_W(\mathcal{I}_x)$, "Acceptable" $= \tilde{A} = \mu_A(\mathcal{I}_x)$ and "Strong" $= \tilde{S} = \mu_S(\mathcal{I}_x)$ or any possible combination of these. The fuzzy sets used to represent each linguistic variable correspond to a certain ubiquitous level per cluster.

For making the FIS operational, 27 fuzzy rules were defined to cover all combinations from the three inputs (indexes) with all their three possible fuzzy sets ("Weak", "Acceptable" and "Strong"), which means $3^3 = 27$. These fuzzy rules are constructed with an IF — THEN structure and evaluated using conjunction ($\wedge$) as logic connector. This is the interpretation of authors about the weight of clusters in the ubiquitous level.

A typical rule can be viewed as:

IF ($\mathcal{I}_I$ is "*Weak*")
AND ($\mathcal{I}_T$ is "*Weak*")
AND ($\mathcal{I}_P$ is "*Weak*")
THEN ($\mathcal{I}_U$ is "*Weak*").

Representing the authors' perception about the most important features for a ubiquitous application; the fuzzy rules have been defined as seen in Table 4.

For the defuzzification stage the Centroid technique was used. The output of the systems is the normalized index $\mathcal{I}_U$ with values between 0 and 1 representing the ubiquitous level that a design concept may have. An example of one of the response surfaces ($\mathcal{I}_U = f(\mathcal{I}_T, \mathcal{I}_I)$) is shown in Fig. 4. This response surface is equivalent for any combination of the three input variables because the fuzzy sets used for its representation are symmetric (see Fig. 3).

3.3. Concept validation

In order to enhance the human–computer interaction of the UDSE and considering that Ubiquitous systems pretend to embed computing into the user's environment in an unobtrusive way, this Ubiquitous Conceptual Design approach includes Augmented

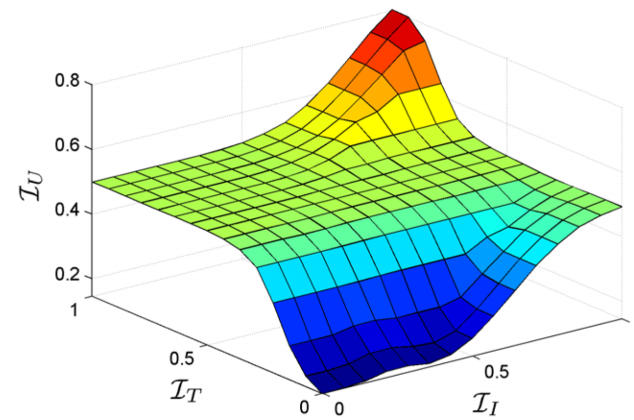

Fig. 4. FIS response surface $\mathcal{I}_U = f(\mathcal{I}_T, \mathcal{I}_I)$.

Reality (AR) as the best option to allow interaction with the real physical world adding relevant virtual information in order to evaluate the solution alternatives generated during the design process visually.

Such evaluation and validation of the conceptual solutions allow the designer to carry out tuning and prepare the information for the next stage of detailed design.

AR enhances user satisfaction and allows interaction of real spaces with concepts and information in a more intuitive way than 2D interfaces even if no stereoscopic vision has been implemented for this UDSE . Anyway, wearable computer interaction is attained with virtual reality glasses adapted with a camera located at eye level. Other advantages of AR have to do with cheap and commercial components implemented in the application and with its ease in configuration and flexibility in interchanging virtual models and information.

4. Ubiquitous design support environment (UDSE)

Every Ubiquitous system is composed of both, infrastructure and application elements, taking advantage of the affordances of multiple technologies [8] and fulfilling features of all the three main clusters previously defined in Section 3.2. Besides, the system should be composed of different kind of work locations or nodes (fixed, portable, wearable, embedded and/or transferable) with network connection to database and remote server containing both the information management system or Product Lifecycle Management (PLM) system and the intelligent framework able to guide the design process, as shown in Fig. 5.

In order to support a ubiquitous design process, a ubiquitous design platform worked as a fixed node (Fig. 5) and based on infrastructure and applications has been developed as the first step of the whole system construction. This node has been designed for collaborative process supported by a framework devoted to guide the design process and a standalone information management

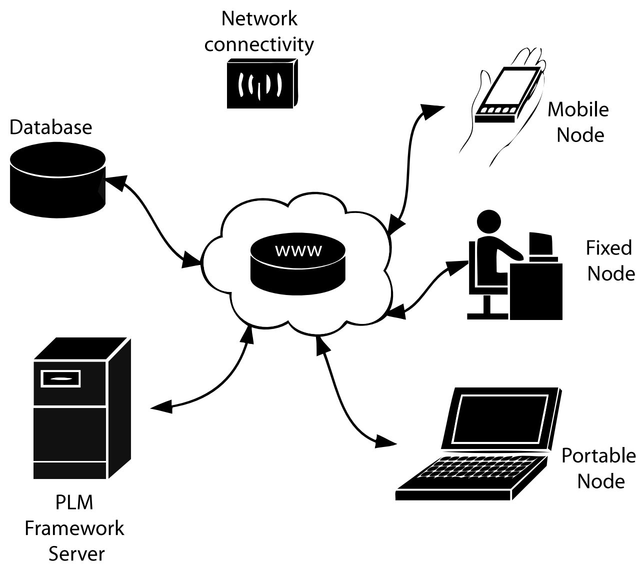

Fig. 5. General configuration of a UDSE.

system in order to evaluate the feasibility of the proposed solution for a ubiquitous design process. The framework is explained in detail in Section 4.1 and the system which evaluates the feasibility is the programmed FIS described in Section 3.2.

Regarding the three main clusters, the User/Context/System interaction is considered in the work platform by adopting different technologies devoted to enhance the interaction with the user and the context taking information from both of them in an intuitive way. The Data Transfer considers the capability of the infrastructure to guarantee either wired or wireless connectivity with a web-based network, between different fixed node locations or between the work platform and portable devices in order to centralize all the information into the fixed node. About Data Processing the computational framework or application implemented within the work platform provides designers with a suggested design process where different activities can be carried out using different intended applications and, according to the type of user, the presented information can be adapted and expertise-oriented according to the workflow of the process.

4.1. Collaborative platform

The UDSE is based on computer tools, both software and hardware, adopted in product design methodologies. Concerning suitable software according to its assertiveness in the product design processes, the computer tools implemented in the framework have been classified into functional tools, that are related to the tasks on different design stages, and collaborative-work support tools [19] connected to Prasad's concurrent engineering principles [20], and stated as communication, project management and information management tools.

Regarding the relationship between the fixed node and the usage of these collaborative-work support tools on the infrastructure, and based on Computer Supported Collaborative Work (CSCW) matrix [21], the platform can perform a role on all the four working contexts:

- face to face interactions: the working area in the infrastructure allows more than one person to interact with it. This empowers the infrastructure to support meetings and design tasks;
- continuous task: supporting this working context, the infrastructure is empowered with information and project management tools. For this purpose working strategy and tools for PLM have been implemented within the use of the infrastructure;
- remote interactions: if necessary, more platforms can work together in a distributed manner, therefore, the infrastructure is connected to the Internet and can support video conferencing with other platforms or other computers at any time;
- communication + coordination: on remote and asynchronous interactions PLM tool is used to empower the infrastructure to support this working conditions.

Summarizing, collaborative-work tools are adopted to support the whole design process in a collaborative manner. Nevertheless the whole ubiquitous design is supported by the blend of design methodologies and functional tools.

This blend was achieved through the programming of a computer framework designed to integrate principal product design methodologies (Pahl & Beitz [22], Ulrich & Eppinger [23] and Baxter [24]) and according to each design stage, it suggests tools to facilitate the accomplishment of each task. The methodology is explained in detail in Section 3.

Besides, the framework suggests the sequence of tasks to be performed during the design process. These suggestions were built by the identification of the different tasks and activities that happen within a design process. Then, a set of the available computer tools that can be used for solving those activities was determined.

Finally, each section of the framework was developed by making the clustering between the set of activities and tools at all design stages. For three sections, in the development of the framework, all the design tasks were identified, and for each task, the identification of the computer tools was also made: the entire process was made by defining the set of task-activity-tool to any product design stage.

Particularly on conceptual design stage, the set of design tasks was determined by following a systematic methodology, by so, reducing chances of mistakes. In other stages (need identification and detail design), the platform offers computer tools and suggests tasks to perform in a particular order, but the designer decides which tools and tasks to implement:

- on need identification, the platform can support the designers' interaction during meetings and the development of design sessions. All the information generated during these sessions is stored and processed in the platform, reducing the design time;
- in the detailed design stage, the platform includes different suitable computer tools to be selected according to the design task to be performed. Anyway, the platform suggests the tool to be used in each task, but it does not guide the detailed design process. The different tasks where the framework includes different computer tools are: drawing, modeling, simulation (ergonomics, manufacture, mathematical, motion, multi-physics, virtual reality), calculation, writing, environmental management and mechanical, electrical and mechatronics detailed design.

Emphasizing on the conceptual design module, the framework is structured on three blocks of tools related to:

- the design activities that can be performed during this design stage; (Upper row of tools in Fig. 6.)
- the computer tools that are available to perform certain design activities on conceptual design stage; (Second row of tools in Fig. 6.)
- a programmed routine that can guide the whole conceptual design process. (Third row of tools in Fig. 6.)

It is important to recall, that the ubiquitous assessment (containing the FIS rules) can be used directly in the platform when a design team is working on the platform. For this, design teams can evaluate the ubiquitous level of their designs using a graphical interface.

The interface of the conceptual design module is shown in Fig. 6.

From Fig. 6, the layout of the framework allows to differentiate the four blocks, even if the users of the platform do not realize it.

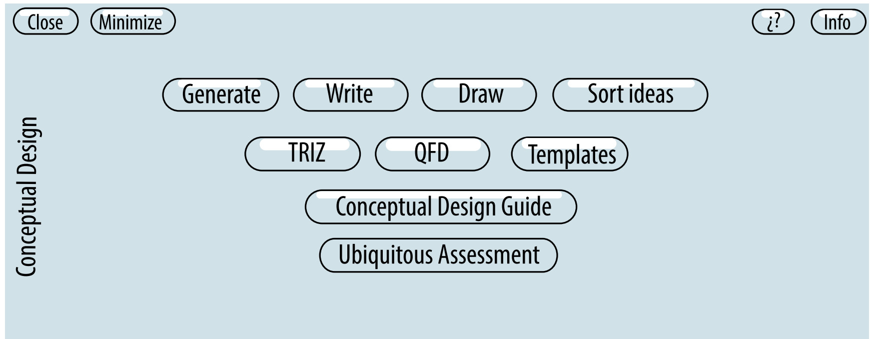

Fig. 6. Framework interface on conceptual design.

Table 5
Activities in conceptual design stages.

Activity	Description
Generation	Generating ideas is a key task within the design process and there is a module that can be described as a whiteboard where users can interact as they would be working on a regular environment, but on a virtual environment. The submodule offers the possibility of writing, drawing and using post-it during meetings and generative sessions.
Writing	This submodule contains different writing computer tools that can be used for writing reports. It is conceived in order to include most of the computer tools that will be used on design processes. This results in an integrated solution.
Drawing	Some activities on this design stage require drawing concepts of solution. This submodule offers tools to perform that.
Sorting ideas	This module offers an interface where design information, ideas and needs can be easily organized and synthesized. Since the platform is conceived to allow interaction of many users, the process can be performed in a collaborative way between the members of the design team.

This allows them to select how to perform the design and, even so, the framework will guide the user during the design process in a non-imperative, ergo and ubiquitous manner.

Regarding the activities that can be performed in the conceptual design stage, these can be categorized in: generation, writing, drawing and sorting ideas. These activities are explained in Table 5.

About the available computer tools, the framework allows working with computer tools to support specifications definition and creativity enhancement just like QFD (Quality Function Deployment), TRIZ[1] and PDS (Product Development Specifications).

Related to the programmed routine which guides the process, this was based on creating an automate framework based on a model that guides the conceptual design stage by guiding the process through the 9 steps established by Pahl & Beitz [22]: processing requirements list, abstract to identify the essential problems, establishing overall function and subfunctions, defining working principles that fulfill subfunctions, combine working principles into working structures, select suitable combinations, specify principle solutions variants, evaluate variants against technical and economic criteria and define the concept solution.

This routine has embedded the activities shown in Table 5. Each activity appears in the specific step where they are needed. This allows the designers to work under a frame that guides them through all the stages of the conceptual design.

Regarding the FIS the developed interface can be seen in Fig. 7. There, designs can be graded onto the different categories that are explained in Section 3.2. The interface facilitates the grading process because it provides the name to each category and a help interface if needed. After grading is done, the fuzzy evaluation is automatically performed by the framework.

In order to calculate the fuzzy, the FIS routine was written in Java using *jFuzzyLogic* package [25]. With the use of this package, the framework computes and normalizes the grades, e.g. if I_I grades were: 5, 3, 1, 2, 1, then, the average value will be 2.4, and the normalized value will be 0.52. Finally, the framework will calculate the ubiquitous level I_U and will offer the user the option to print the rules and the response surface.

Finally, regarding the interface implemented on the platform, a UUI (Ubicomp User Interface) is used instead of a regular GUI (Graphical User Interface). The UUI is a Surface Ubicomp Interface (SUI) defined as a class of user interface that relies on a self-illuminated projection coupled with a computational control onto the same physical surface [26]. In other words, SUI can be interpreted as a large multi-touch screen.

Additionally, the platform allows connectivity with other hardware that can be used in different design stages. In this connection the developed SUI has integration with VR/AR goggles, 3D mouse (for modeling) and drawing tablets. At last, Fig. 12 (in Section 5.3) shows a users group interacting and working with the platform during a design activity.

Further implementation is related to the network connection with remote terminals. Connectivity and processing capabilities have been considered as ubiquitous characteristics but they are not allowed during the first validation of the hardware. Besides, all the hardware and software required to guide and execute the design process have been installed locally in order to evaluate, in first instance, their acceptance and advantages and disadvantages for the Human–Computer Interaction.

4.2. Information management

As PLM strategy is growing in importance in distributed engineering design, the use of advanced information management support tools has become a key issue. Nowadays globalized trends are leading companies to adopt PLM tools that enable engineering teams to create, manage and share the set of information generated throughout the product lifecycle. These trends are directly linked to Ubiquitous Design Processes. This is a complete integration component in distributed/ubiquitous design teams that typically include centralized Databases to store the product

[1] TRIZ is a technique used to empower concept development through the use of a patent database; TRIZ is Russian acronym to Theory for Solving Inventive Problems.

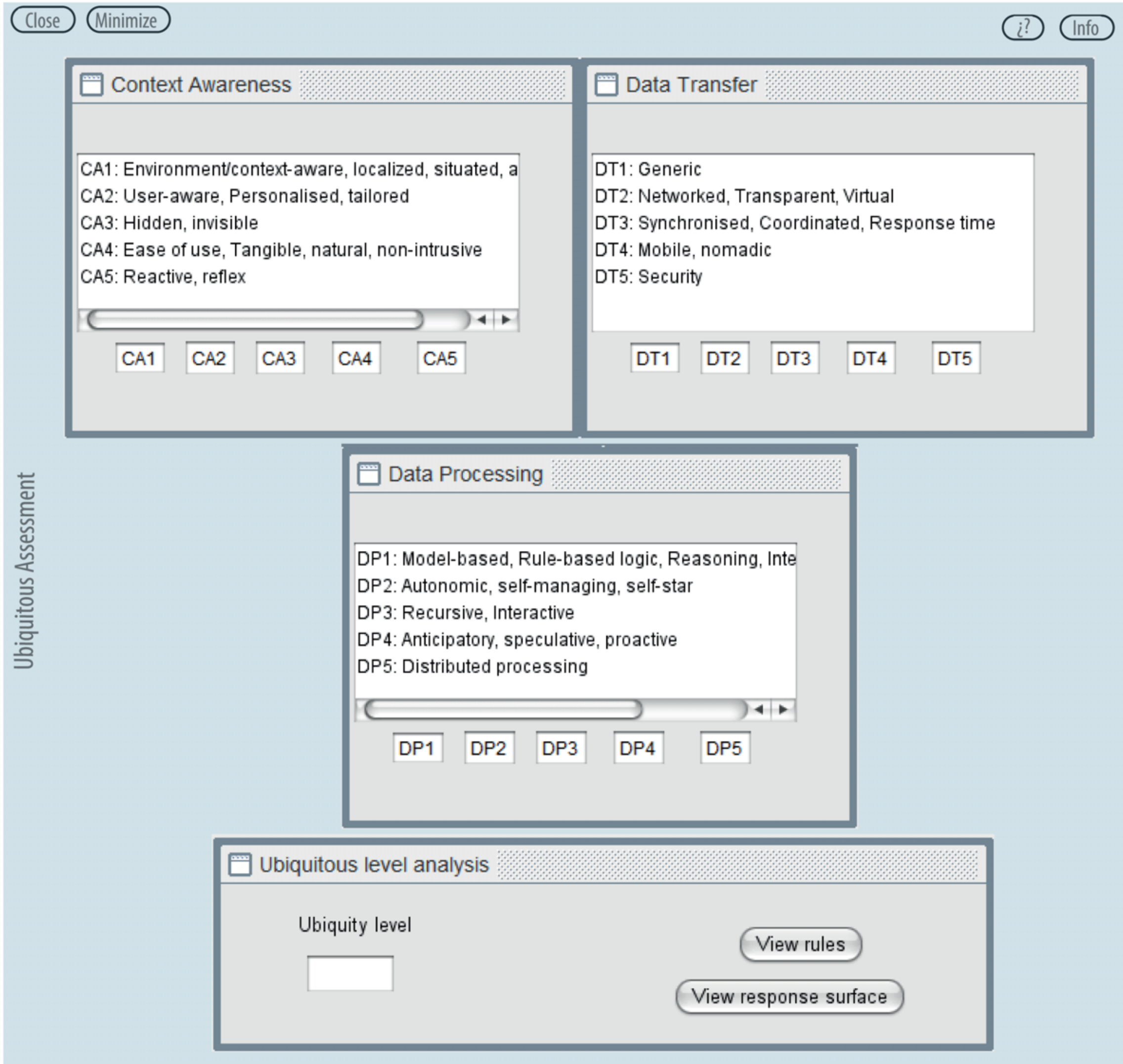

Fig. 7. Framework interface on ubiquitous assessment.

lifecycle information (since the early design phases, through the manufacture until disposal/recycling).

PLM implementations are challenging due to the large scope reached by these technologies that goes beyond CAD and PDM tools. Current researches on PLM look for developing methods, techniques and technologies to support engineering activities to allow design teams to understand the entire development process to improve collaboration and coordination in project development [27].

The adopted PLM platform that supports the Ubiquitous Conceptual Design is the Open-source software called *ARAS Innovator*®.[2] This platform has demonstrated to be a good alternative for emerging markets as it does not demand up-front licensing costs, enabling savings up to 68% as reported by Gill [28] as well as improvements in productivity by connecting distributed teams.

5. Case study

In textile and apparel industries there is a sensitive issue with illegal importations and with low cost competition from foreign markets with products that are often sold at a fraction of the price of national wares. This situation has recently affected the stability of small and midsize thread, fabric and clothing fabricants where most of the activities are carried out in a manual way and no funds have been invested in new technologies and markets. In this way, this industry has lost the drive and now it needs to reinvent itself [29].

The textile industry in Medellín, Colombia, offers direct employment to more than 200,000 people and more than 600,000 workers are employed in related industries, representing more than 30% of national exports, which include the manufacture of more than 950 million square meters of production [30]. Among production, 24% is made in the sector of textile apparel, and it is important to recall that in this sector, most of the work is carried out by SME and it is manual labor. This situation recalls a great social responsibility in order to improve the working environment in this sector and direct efforts into searching, design and development of technological and innovative solutions based on UTs.

This section will describe the experience and findings of a support system based on UTs aimed at the enhancement of productivity and real-time monitoring in small and midsize textile and apparel industries, identifying process and context variables and product parameters. In order to tackle this situation, the analysis has started by considering all these aspects through

[2] www.aras.com.

Fig. 8. Work unit.

the understanding of the dressmaking process, specifically of shirts, identification of machines, intermediate goods and human resources and context layouts. Then, a CAD virtual model for a specific facility was used to identify the location of input devices (sensors) for a smart processing application in order to define measuring points throughout the process. The flexibility of the virtual model has allowed the evaluation of possible changes in the layouts in order to improve the production process and obtain better results. Afterwards, the technological equipment has been selected according to its specifications, cost and availability. The processing system has been configured following process variables and constraints in order to measure the current efficiency of both the whole process and specific activities and to compare the current situation with expected results.

Considering the distinguishing features of a Ubiquitous Computing system, presented by Poslad [4] and Gerritsen and Horváth [6], the context dependence considers the presence of unobtrusive sensors to measure the manufactured units of each machine and worker, the data transfer is guaranteed by a wireless network with ZigBee protocol and an intelligent system processes data to give information in real-time, offering the facility for remote access, about either the whole process or personal productivity. Considering the variability of the manual process, specialized technical staff, who according to the historic data and suggestions proposed by the intelligent systems, defines the actions upon the system.

The objective of the systems is to keep awareness on productivity level in real time, allowing decision makers to be able to react upon inconveniences or, in the best case, to monitor the company goals, independently of their location. In the end it enables to reduce time and costs improving quality of the products, allowing workers to know their capabilities and encourages them to get better qualitative and quantitative results. It is also important to analyze and balance the implications of UTs from people's point of view, as described by Shrivastava and Ngarambe [31]. For example, what happens when employees feel that they are under surveillance instead of seeing the benefits (e.g. Self challenge by seeing real time goals achievement).

Finally, the resulting application has been assessed to validate the ubiquitous level, according to the methodology proposed in this document. This will highlight system strengths and weaknesses, in order to define the future research areas. However, further research would be oriented to measure the quality of the products as proposed application remains on the logistics and manufacturing control level, without verifying the quality of the performed processes.

5.1. Distributed design: first approach

In order to support the manufacture process for the textile industry in Medellín Colombia, by monitoring the production process, a multidisciplinary and distributed team was created. This team was composed of people from different cultures such as Latin, European and Indian interacting together, in order to achieve a common goal. Within the knowledge areas, design engineering and computer science were the most common. The main goal of the project was presented as the design and development of a support system based on UTs aimed at the enhancement of productivity and real-time monitoring in SME in textile and apparel industries. The work was developed in a distributed way, different sub-teams were created in different countries and working meetings were conducted using communication tools. The project lasted four months of concurrent work in the implicated countries. In order to support this collaborative work, different computer tools for information management and communication were used. This entire project was conducted under an international ubiquitous academic consortium (WWDSC 2011) presented by Moes et al. [32]. As a representative industry, a midsize textile company was chosen as they agreed to let the team know the whole dressmaking process, specifically of shirts.

In Fig. 8 a typical work unit in the textile sector of developing countries can be seen.

Requirements for the solution that the team should offer were elicited taking into account the company requirements, as well as the individual worker's criteria. These elements were combined with the designer team's criteria. The main factors defined for the solution were:

Fig. 9. AR validation of the concept in the SME.

Table 6
Components.

Main components list
Double layer printed circuit board
Microcontroller PIC16F876A
16×2 backlight enabled lcd display
Normally open (NO) standard button
4×4 matrix keypad
ZigBee transmitter and receiver
Computer

- internet access is constrained to the production boss computer;
- the device must be unintrusive;
- the information should be given in real time;
- because of the amount of workers, the device must be cheap.

During the understanding of the company's work, there were some factors that definitely affected the proposed solution. For instance, workers are trained to perform different activities in different places. So they do not have a specific workplace or special labor. This changes every day, moreover, some workers can perform tasks in two or three different workplaces the same day. Additionally, the cloth production line is not well defined. As a principal result of this first stage the team concluded that the dressmaking process was not standardized in the selected company. Before starting to prototype the functional design concept, a virtual validation through AR was performed in the company as shown in Fig. 9.

Based on the requirements that the solution should accomplish, a functional prototype was developed in order to implement a PoC and test its functionality. This initial device was composed by the main elements shown in Table 6.

The data processing was implemented in a microcontroller; from there the data transfer was performed using standard ZigBee protocol to a computer which places this data online. Giving information access to everyone with an internet connection and a company identification. Fig. 10 presents the whole configuration for the first solution.

As shown in Fig. 10 the implemented sensor was a button, and the operators were intended to press it each time one piece ended its work unit, in detriment of the ubiquity level of the solution. The information gathered by the button was transferred to a central computer and from there, to a web page in "real time". Having the data online provides managers the capacity for remote monitoring the work of each employee.

However the selected sensor had a large problem. At the beginning of the implementation, operators used the button, but after some time, they forgot or decided not to use it because it represented delays in their work. The resulting application was assessed to validate the ubiquitous level. The obtained results are presented in the following section.

5.2. Ubiquitous level assessment for the first approach

Considering the features of a ubiquitous system presented in this article and using the proposed methodology for the solution selection stage, an assessment of the ubiquitous level for the initial design was conducted by four experts. In Data Transfer cluster the highest qualification was achieved (0.8). The lowest one was in the Data processing cluster (0.34). This low qualification was expected because one of the main restrictions of the design was the low cost of the solution and the intelligence of the system was not a priority. In fact the company does not present a clear intention regarding the expected processing or intelligence of the system. About the User/Context/System Interaction cluster its result was 0.43. Considering that one of the main requirements expressed by the company workers was that the device be non-intrusive the design team gave special attention to this cluster looking to establish why the qualification was in the lower half. Inside the cluster, the worst value was in the hidden/invisible feature and this consideration conducted to the redesign of the interface of the system. In Fig. 15 the histogram of the developed evaluation is presented. As seen in Fig. 11 the ubiquitous level assigned by the FIS to the initial solution was 48.1%.

5.3. Redesign with ubiquitous conceptual design process

The redesign process began with the preparation of a generative session, which has been developed around the UDSE . Since the importance of reaching latent need during the session, different creative techniques were implemented during the sessions and were focused on experimental rather than physical or material concerns, which help to understand dreams and needs of the people [16].

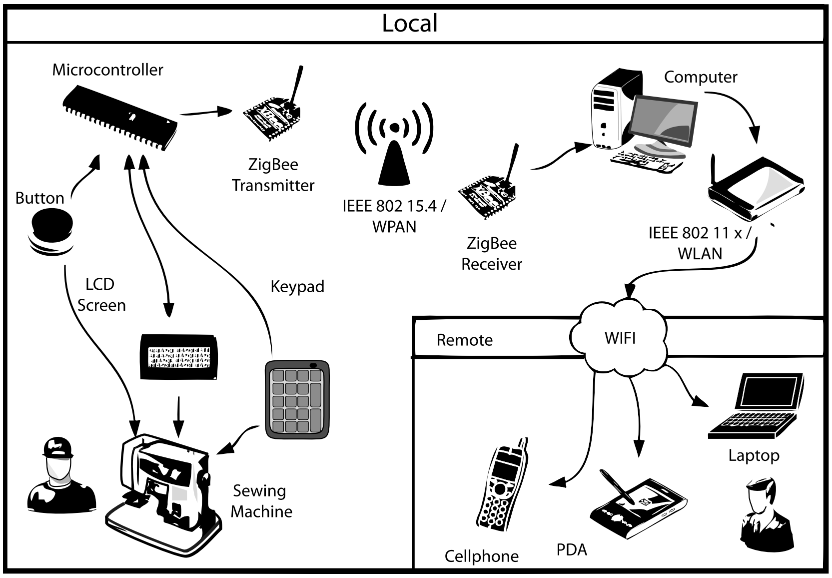

Fig. 10. Functionality scheme for the first solution.

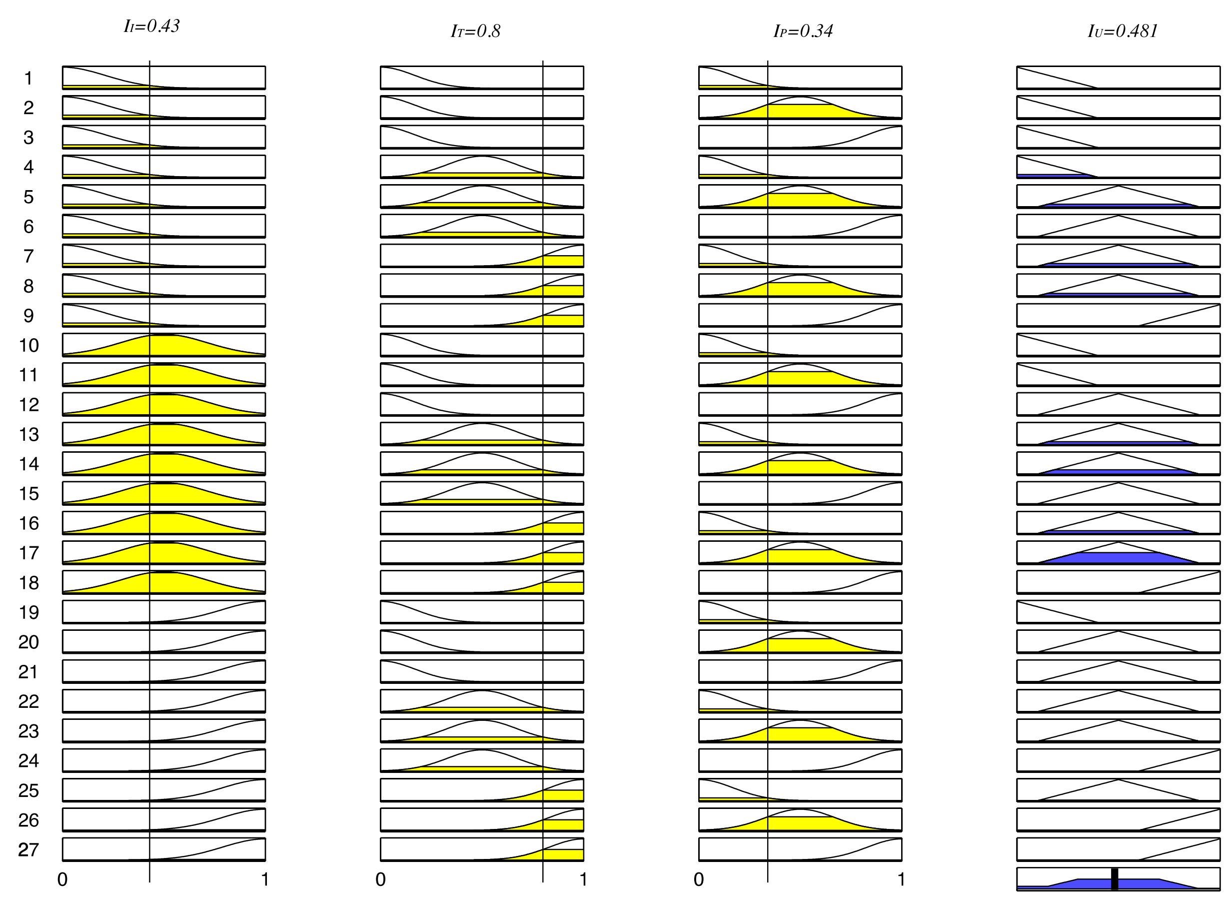

Fig. 11. Ubiquity level for first approach.

About this stage of redesign process, it is remarkable that the sessions were made on the platform described in Section 4.1, and were conducted on a mixed-ubiquitous environment. During the generative sessions, the platform helped to guide some parts during the sessions and it was useful in order to project and manipulate photos and the clustering of ideas was made easier on its surface. In Fig. 12 it can be seen the design team interacting with the platform while they were performing the redesign.

5.3.1. Ubiquitous conceptual redesign

The first part of the conceptual design, and according to the methodology adopted in the framework, was the processing of

Fig. 12. Platform to support product design processes.

Fig. 13. Comparison between work unit without any solution (a), work unit with the solution with the button (b) and solution with the sensor (c).

the requirements list. In this part, engineers played an important role as researchers (on needs), because "the knowledge researchers gained is grounded in the members of the design team and can be of benefit further in the design process" [33].

Regarding the analysis made on this step, the insights found during fuzzy front end stage were clustered into four main aspects: ubiquity, how to sense, business factors and sensors.

As long as the redesign process was made on the SUI supported on the developed framework and its embedded conceptual design method, a working structure was developed (step 4 and 5[3]) centered on a two system solution, which was a sensor located on all working units and an RFID solution, which was contemplated that at the beginning of the line, each cloth was going to be attached with an RFID tag, and while the cloth was going through the production line, antennas will locate the position of the cloth in real time, and will also avoid the problems that the other sensor might have, which became a solution that has two ways to do the task.

Finally, when last steps of conceptual design were made on the SUI the second system solution was dismissed because of the high costs and this RFID extra system exceeded the budget that was available in the project.

Regarding the final solution selected, it was centered in a system that could track, on whole working units, when a cloth leaves the unit. This solution is ubiquitous enough to allow operators working as normal as they usually work (it is not necessary to press

3 Steps 4 and 5 of Pahl & Beitz conceptual design 10 steps.

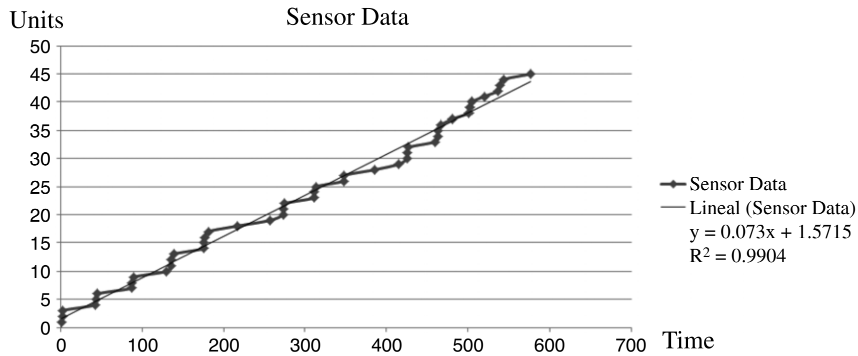

Fig. 14. Processed units per seconds.

any button) and empowers the company the possibility to track on real time, the status of the production.

In Fig. 13 the comparison between the three scenarios in the company according to the implemented solution can be observed. In (a) the work unit without any device to track the production in real time can be evidenced, in (b) the previous design can be seen, where the operator must press a button every time a piece is done and in (c) the implementation of the redesign can be observed, where a sensor tracked every time a piece was finished, allowing a more transparent process for the operator.

5.4. Results

5.4.1. Implementation in the SME textile industry

Because of the conclusions detected in the initial solution, the necessity of a standardized production line became imperative. It was because of this that a new textile SME was contacted in order to redesign the solution based on their production way. In the new company the cloth making process follows a defined line and the workers were trained in a specific labor. These key aspects provide the design team a new bunch of opportunities to improve the new design.

As presented in Section 5.1, the main difficulty of the initial solution both, in the functional and the ubiquity aspects, was the implemented sensor. Given the obtained results for the Data Transfer cluster and the necessity to develop a low cost ubiquitous solution to monitoring the performance of the textile company, the efforts for the ubiquitous redesign were focused on the User/Context/System Interaction cluster specifically on its feature about the system's hiddenness and invisibility. Seeking to sense the operator without changing its work habbits and to detect when a piece leaves a work unit, the redesigned solution uses a low cost parallax ultrasonic distance sensor. This sensor is located at the end of each work unit when the finished pieces are thrown. Making the solution more ubiquitous by doing the interaction with the user more transparent and invisible. For the redesign an "Arduino uno" microcontroller board was used as a base for a rapid prototyping hardware. The signals processed in the arduino are plotted as shown in Fig. 14.

As seen in Fig. 14, the data is useful in order to estimate an average work speed for long periods of time. The context awarenesses of the implemented sensor guarantees that the worker does not have to worry about the device measurement. However, in practice the same property implies that the device is sensitive to any change in the context, that could carry mistakes in the data because of many points that can be sensed as interruptions for the sensor but in fact they represent just one finished piece. In order to avoid this behavior a linear regression was made (Fig. 14) where the partial derivative of units with respect to time befits the productivity level of the worker, so, using the line equation it is possible to determine the average production for any given time. Ideally the device should be calibrated for each production station and operator.

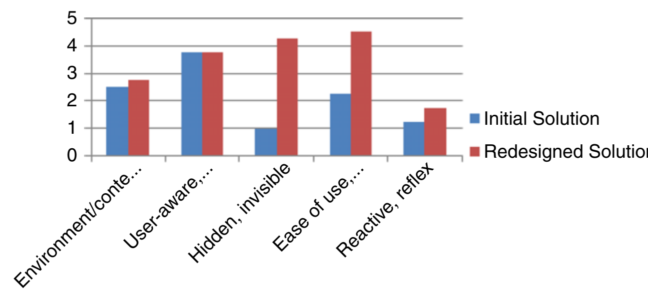

Fig. 15. User/Context/Environment interaction cluster.

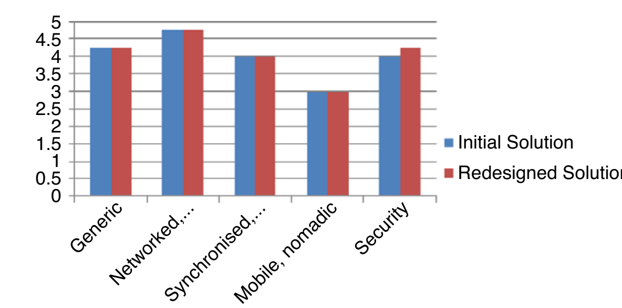

Fig. 16. Data transfer cluster.

5.4.2. Ubiquitous level assessment for redesigned application

The redesigned solution was intended to improve the ubiquity of the first approach, as presented above specifically the feature called "Hidden, invisible" belonging to the User/Context/System Interaction cluster as it has a low ubiquity qualification. In Fig. 15 a clear improvement in this aspect can be appreciated. This advancement was possible because of the selected sensor. The implementation of a distance ultrasonic sensor to detect when a piece ended its process in a work unit allowed to keep the system cost down and does not increase the time related to the workers' activity; which clearly means a more unobtrusive, hidden and invisible application.

Figs. 15–17 present the comparative ubiquity evaluations for the initial solution and the redesigned solution, divided by clusters and features.

The average ubiquitous level assigned by the FIS for the redesigned solution was 56.1%. There is a difference of 8% over the initial solution, as seen in Fig. 18. The little difference between both solutions is explained because the change included in the redesign

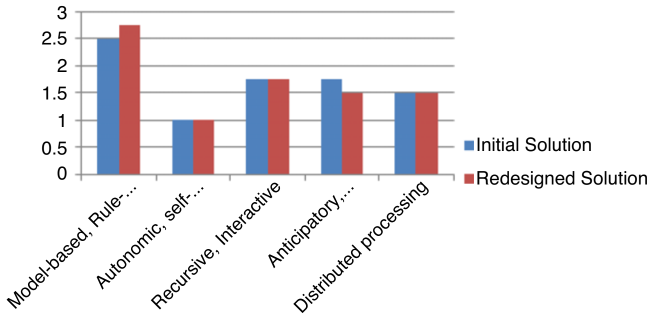

Fig. 17. Data processing cluster.

was only about the monitoring device. It was expected that little change in the device implies little change in the ubiquity level.

5.4.3. Methodology fulfillment assessment

The redesign process was performed in the platform and its framework supported and guided the redesign process in a transparent way. This allowed a ubiquitous design but it is important to recall that the design is made by the design team and the role of the platform is to provide a collaborative environment for the design and to guide the team through the design process by offering the tools for each stage and task of the design, especially in the conceptual design stage, because it was at this stage where the framework contained a module that guided the whole process.

In terms of information management tools, it is important to notice that the platform was conceived to fully support PLM tools, and so, to store the information created during design processes according to these collaborative work methodologies.

6. Conclusions

The increasing tendencies of remote collaboration are leading practitioners to face ubiquitous conditions during the product design. This Ubiquitous Design process has been tackled in this article by contributing with an approach that enables engineering teams to enhance collaboration and thus a space to motivate creativity and concept generation in the Conceptual Design stage.

Additionally, the measurement of the ubiquitous level is an important developed tool within the frame of the present article. The presented ubiquity assessment can be used as a rapid assessment method in future academic exercises as well as in any design process which intends to create a ubiquitous ASC in order to evaluate the ubiquitous level of the proposed solutions directly during the process and not in advanced stages of the design. With the presented tool, the design group would be able to identify the strength of the different ubiquity aspects to consider. Taking into account the key properties of a ubiquitous system is a key factor to evaluate in a correct way the ubiquitous level of an application. Besides, and how it was deployed, the measurement is a useful tool in terms of redesign, because it shows the weakest ubiquity points on determined ASC .

About the platform and framework developed to support ubiquitous design processes, with special efforts on the conceptual design stage, this system is a keypoint in terms of further research. The further research centers on improving the ubiquity of other design stages, but the research can also center on improving

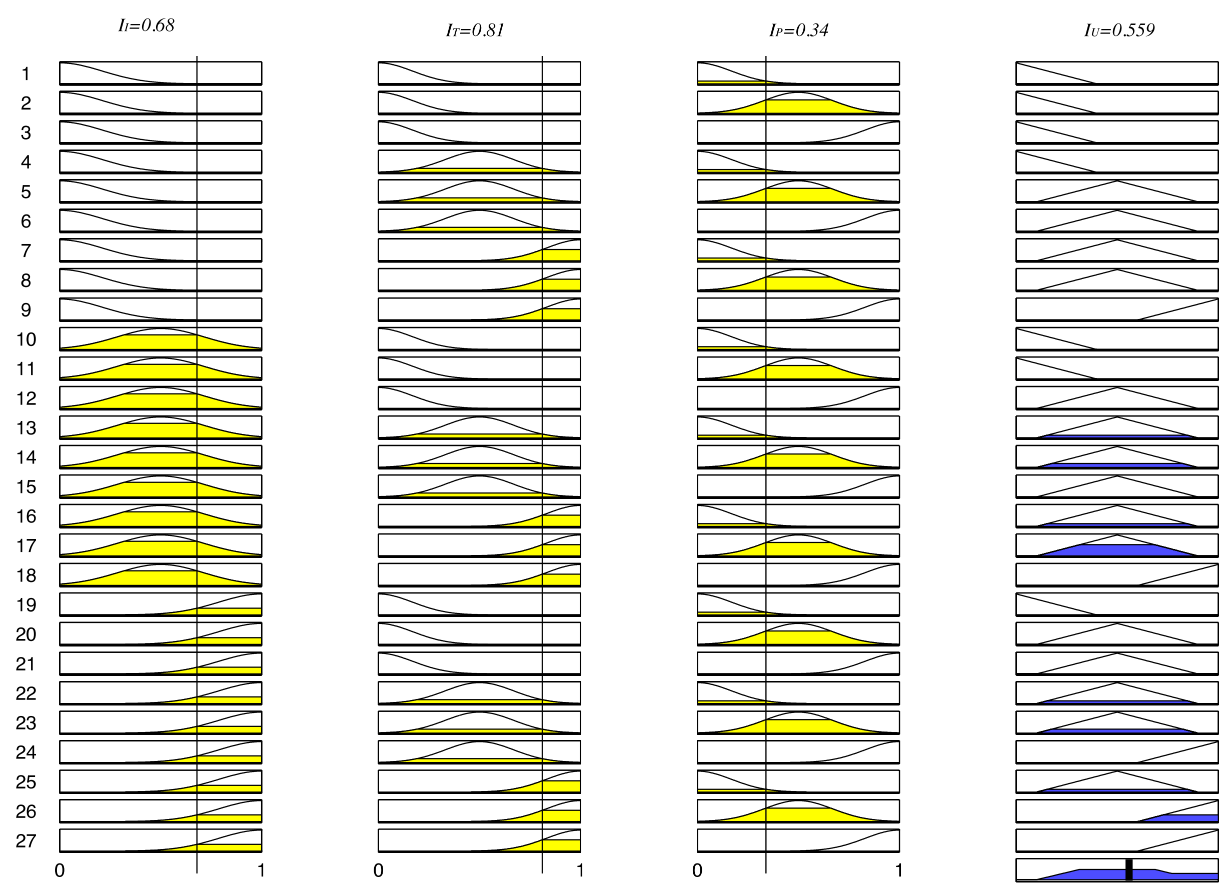

Fig. 18. Ubiquity level for redesigned approach.

the human–computer interfaces, generating better Ubicom User Interfaces.

Additionally, the system is suitable to be tuned up in order to allow its implementation at the industrial level. This process will empower interaction between academy and industry, and collaborative projects between both can be done using the platform that can guide design processes supported by different computer tools.

The implementation in the textile industry presented during the Section 5 shows that the ubiquity of a new ASC is a key aspect for a successful adaptation in market. This was proved by the fact that Colombian textile workers are paid by finished pieces, but as they usually do not have a real time monitoring of its process they do not know exactly how much is going to be the pay until the day is over. Despite the initial and the final solutions give that information to them they prefer not to use the initial one as it consumes some time of the work and they believe that it decreases the productivity, and with a little more ubiquitous device (the redesigned) the acceptance was totally positive.

References

[1] Friedewald M, Raabe O. Ubiquitous computing: an overview of technology impacts. Telemat Inform 2011;28(2):55–65.
[2] Horváth I, Rusák Z, Opiyo E, Kooijman A. Towards ubiquitous design support. ASME; 2009.
[3] Osorio-Gómez G, Mejía-Gutiérrez R, Sierra-Zuluaga L. An academic design methodology for electrical mobility products—from necessity to functional prototype. In: Kovacevic A, Ion W, McMahon C, Buck L, Hogarth P, editors. Proceedings of the 13th international conference on engineering and product design education, E&PDE11. 2011.
[4] Poslad S. Ubiquitous computing. Wiley; 2009.
[5] Sakao T, Lindahl M. Introduction to product/service-system design. London: Springer; 2009.
[6] Gerritsen B, Horváth I. The upcoming and proliferation of ubiquitous technologies in products and processes. Strojniški vestnik-J Mech Eng 2010; 56(11):765–83.
[7] Weiser M. Some computer science issues in ubiquitous computing. Commun ACM 1993;36(7):75–84.
[8] Kwon O, Kim J. A methodology for assessing the level of u-transformation of ubiquitous services. Ubiquitous Comput Syst 2006;28–40.
[9] Fano A, Gershman A. The future of business services in the age of ubiquitous computing. Commun ACM 2002;45(12):83–7.
[10] Kuniavsky M. Smart things: ubiquitous computing user experience design. Morgan Kaufmann; 2010.
[11] Milne A, Winograd T. The iloft project: a technologically advanced collaborative design workspace as research instrument. In: Proceedings of the ICED'03. 2003.
[12] Yoo Y, Lyytinen K. Social impacts of ubiquitous computing: exploring critical interactions between mobility, context and technology:: a special issue for information and organization. Inform Organ 2005;15(2):91–4.
[13] Churchill E, Nelson L, Denoue L, Murphy P, Helfman J. The plasma poster network. CSCW Series, Kluwer; 2003.
[14] Suh S, Shin S, Yoon J, Um J. Ubidm: a new paradigm for product design and manufacturing via ubiquitous computing technology. Int J Comput Integrated Manuf 2008;21(5):540–9.
[15] Visser F, Stappers P, Van der Lugt R, Sanders E. Contextmapping: experiences from practice. CoDesign 2005;1(2):119–49.
[16] Sanders E, William C. Harnessing peoples creativity: ideation and expression through visual communication. In: Focus groups: supporting effective product development. 2001.
[17] Mamdani E, Assilian S. An experiment in linguistic synthesis with a fuzzy logic controller. Int J Man-Mach Stud 1975;7(1):1–13.
[18] Zadeh LA. Fuzzy sets. Inf Control 1965;8(3):338–53.
[19] Osorio-Gómez G, Mejía-Gutiérrez R, Ríos-Zapata D. A computer tools classification based on collaborative engineering environments and its value on education. In: Proceeding of the 6th international technology, education and development conference, INTED2012. 2012.
[20] Prasad B. Concurrent engineering fundamentals—Integrated product and process organization. Upper Saddle River, NJ: Prentice Hall PT; 1996.
[21] Baecker R. Readings in human–computer interaction: toward the year 2000. San Francisco: Morgan Kaufmann; 1995.
[22] Pahl G, Beitz W, Feldhusen J, Gote H. Engineering design: a systematic approach. Springer Verlag; 2007.
[23] Ulrich K, Eppinger S, et al. Product design and development. Boston, MA: McGraw-Hill/Irwin; 2004.
[24] Baxter M. Product design. A practical guide to systematic methods of new product development. Chapman & Hall; 1995.
[25] Cingolani P. Open source fuzzy logic library and FCL language implementation. 2012. Sourceforge.net, http://jfuzzylogic.sourceforge.net/html/index.html [Last viewed on: 2013.05.15].
[26] Krumm J. Ubiquitous computing fundamentals. Chapman & Hall/CRC; 2009.
[27] Wognum N, Trappey A. Editorial: Plm challenges. Adv Eng Inform 2008;22(4): 419–20.
[28] Gill T. Textron and other Fortune 500 companies move to Aras enterprise open source PLM software. 2010. TAG consulting, http://bit.ly/12lfXoV. [Last viewed on: 2010.06.30].
[29] Mapfre C, Marzo. Informe sector textil y confecciones Colombiano. Tech. rep. Análisis Sectorial. 2010.
[30] Colombiatex, July 2009. Colombiatex: datos de utilidad sobre el sector textil confección de Colombia. http://www.inexmoda.org.co/Laferia/Datosdeutilidad/tabid/180/language/en-US/Default.aspx.
[31] Shrivastava M, Ngarambe DA. Sustainability implications of ubiquitous computing environment. In: Proceedings from the international conference on advances in engineering and technology. 2006. p. 514–21.
[32] Moes N, Mejía-Gutiérrez R, Osorio-Gómez G. Solving social problems using ubiquitous technologies in an educational multi-x design context. In: Proceedings of TMCE 2012. 2012. p. 211–26.
[33] Visser F. Bringing the everyday life of people into design. Ph.D. thesis, Technische Universiteit Delf. 2009.