INSTITUTO TECNOLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

CAMPUS MONTERREY

DIVISION DE INGENIERIA Y ARQUITECTURA

PROGRAMA DE GRADUADOS EN INGENIERIA

TECNOLÓGICO DE MONTERREY®

THE APPLICATION OF INCLUSIVE DESIGN APPROACH IN THE CONCEPTUAL DESIGN OF MECHATRONIC PRODUCTS AND RECONFIGURABLE MANUFACTURING SYSTEMS

TESIS

PRESENTADA COMO REQUISITO PARCIAL PARA OBTENER EL GRADO ACADEMICO DE:

MAESTRO EN CIENCIAS

ESPECIALIDAD EN SISTEMAS DE MANUFACTURA

LUIS MANUEL GUIZAR CASTREJON

DICIEMBRE DE 2004

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Dedicatoria

A Dios por llenarme de felicidad y permitirme ser lo que un día soñé.

A mi mamá Maricarmen que lo ha dado todo por ayudarme a aprovechar esta gran oportunidad en mi vida con todo su amor.

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Mira que te mando que te esfuerces y seas valiente: no temas ni desmayes, porque yo soy Jehová tu Dios que estaré contigo en dondequiera que vayas. *Josué 1:9*

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SUMMARY

In the current rapidly ageing world, there is no commercial or social sense to design, develop or attempt to market products and services whose usability is unnecessarily, challenging to people, whether they be young or old, able-bodied or less able. There is the need to design and develop products with some functional capabilities that fulfill the needs of the widest possible population.

This thesis is a research of how the inclusive design concepts can be applied and integrated in the process of product planning and its conceptual design. The methodology consists of a series of methods, considerations and activities that must be undertaken to perform a good design focusing on disabled people with the help of useful tools of the inclusive design.

In addition, in this thesis is given a methodology for incorporating inclusive design concepts in reconfigurable manufacturing systems to enhance their key characteristics with the focus on a user centered approach, considering fully able users. The methodology comprehends an evaluation system for a FMS and the proposal to improve the system oriented to users.

This thesis represents the use of wireless sensor technology to improve the assistive characteristics of products in the first part of mechatronic product design; and the addition of automation characteristics to the reconfigurable manufacturing systems to improve the system features and provide a better customization to users.

Two case studies are developed in this thesis; the first one is the conceptual design of three mechatronic products and their improved capabilities with inclusive design. Then, a second case study with the addition of inclusive design to a existing manufacturing cell to achieve reconfigurability and improve its characteristics with the inclusive design approach.

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Chapter I - INTRODUCTION

1.1 Background

Nowadays there are many products designed for one or many purposes. Companies always look for increased revenues and due to this aim; they develop products with an expectation of customer satisfaction by giving a variety of functions, presentations, objectives and performances.

Most of design companies engaged to design and manufacture of products, have forgotten the user-centered approach, this is, a design to fit, a universal design that involves the widest possible population, contemplating their cleverness, acceptability and usability.

The preoccupation of Governments such of England, Japan and United States of America, concerning the respect for disabled and old people, they have created laws to protect and to promote the design of products that considers these excluded people.

However, Governments around the world are responding to the ethical arguments in favor of greater social inclusion facilitated by the appropriate inclusive design of products, services and environments with new legislation.

Much of the legislation is focused on prohibiting discrimination on the grounds of functional capability. In many countries, such legislation is regarded as an extension of comparable laws countering discrimination based on gender or ethnicity. Perhaps the most commonly known example of this is the 1990 Americans with Disabilities Act (ADA, 1990), which was enacted as civil rights legislation.

In the United Kingdom, the 1995 Disability Discrimination Act (DDA, 1995) provides much of the same directions on employers, manufacturers and service providers to avoid discrimination against employees, customers and service users with functional impairments.

In Mexico, much of the laws concerning disabled people are specifications for making buildings and facilities accessible and usable by physically handicapped people. Although, these laws do not forbid the discrimination of disabled population, and are only focused on physical impairments and facilitating access into building and public places.

The adoption of inclusive design is not just of benefit when considering customers. Employers will find themselves having to increasingly consider making their work-places more accessible and inclusive. The concept of "work-places accessibility" is typically associated with building design and wheelchair access in particular. An accessible work-place requires not only that employees can get to and from their work-place, but also that they can interact with the equipment and tools necessary for productivity.

In most of cases, the equipment used to perform the job places additional demands on the user over and above those required for the task itself. In such cases, the user can be considered to have been disabled by the equipment.

1.2 Research Justification

Due to the lack of interest and attention of companies and government in Mexico to the disabled people and workplace environments, it is necessary to create a model that comprises both issues of products and services designed to fit basic and affordable necessities of people; and in the other hand, to improve workplaces within factories to create products.

In a rapidly ageing world it no longer makes commercial or social sense to design, develop or attempt to market products and services whose usability is unnecessarily challenging to people, whether they be young or old, able-bodied or less able.

According to the need of inclusive design into products and services, this research work is directed towards elaborate a methodology for designing products with an inclusive design focus, considering the user acceptability and usability, utilizing a user-centered approach to provide a useful guideline. Develop an inclusive design guide. A logical first step is to create a document that provides design teams with information about the nature of the various types of disabilities and various strategies for addressing their needs.

The development of technology, and in particular new technology and the products based on it, has the potential to provide solutions to many of the causes of exclusion encountered by people with functional impairments. That is the reason to take advantage of the new technology available to enhance and add functionality to products and services. However, its potential can only be realized if the needs of the wider population have been taken into account during its application in the design of the products based upon it.

1.3 Objective of the Research

- To develop a methodology that incorporates inclusive design concepts into mechatronic product design, with the purpose of improving characteristics of products in order to adapt them to the user main disability and needs; a key technology used to improve mechatronic product design was the use of wireless sensor technology.
- To demonstrate that the concept of inclusive design can be implemented in product design, covering specific needs with effective results.
- To develop a methodology for a flexible manufacturing system in order to reconfigure it and convert it into reconfigurable manufacturing system with the use of inclusive design concepts to improve the Reconfigurable Manufacturing Systems characteristics and to make it easy to use, understand its functionality and reconfigure it by the user.
- To demonstrate the feasibility to configure virtual and physical arrangements of cell with the inclusive design approach.

1.4 Scope of the Research

- Action Research Methodology has been used in this thesis to plan, to observe and to act, and reflect on the implementation of inclusive design in mechatronic product design and later in the reconfiguration of a flexible manufacturing cell.

- The use of Inclusive Design concepts to cover the user-centered approach based on the User Pyramid to denote the user requirements.

- The Inclusive Design Cube is used in this thesis to provide three functional axis of users, these are motion, cognitive and sensory to classify the user interaction.

- Three products have been planned and conceptually designed as case studies to demonstrate inclusive design concepts and accomplishment of user needs.

- Wireless Technology has been used as an underpinning technology to add functionality to products features, to satisfy the different user level requirements.

- An additional case study has been developed related to the Analysis and assessment of a Flexible Manufacturing System to achieve reconfigurability, and the addition of Wireless Sensor Networks to improve its operation, converting this FMS into a Reconfigurable Manufacturing System.

1.5 Key Contributions

- Develop a conceptual mechatronic product design with the incorporation of Inclusive Design concepts.

- Develop a methodology for integrating the Inclusive Design approach in the developing of Reconfigurable Manufacturing Systems.

- Integration of Wireless Technology to conceptual design of mechatronic products and into reconfigurable manufacturing systems to add functionality.

1.6 Thesis Organization

This thesis project is organized in eight chapters.

Chapter 1: Introduction
Chapter 2: Literature Review
Chapter 3: Research Methodology
Chapter 4: Methodology for Product Design incorporating Inclusive Design
Chapter 5: Case study for designing three products with inclusive design
Chapter 6: Methodology for integrating inclusive design in a flexible manufacturing system in order to achieve reconfigurability
Chapter 7: Case study for reconfigurable manufacturing system
Chapter 8: Results and Conclusions with further research

Chapter 2 brings important literature review about Inclusive Design, describing concepts, trends, applications and state of the art. Also, this chapter presents literature of Reconfigurable Manufacturing Systems and Wireless Sensor Networks with descriptions of the current studies about them.

Chapter 3 describes the Action Research methodology used through the case studies to demonstrate the planning, acting, observation and reflection of inclusive design approach implemented first on product design and later in reconfigurable manufacturing systems.

Chapter 4, here the Methodology for product design is described, the methodology add the inclusive design approach to improve characteristics of mechatronic products to assist impaired and fully-able people.

Chapter 5 contains a case study that describes the application of the methodology through several steps, and demonstrates the applicability of inclusive design in the design of products.

Chapter 6, here is the Methodology to evaluate a FMS in order to achieve RMS characteristics, and a methodology to integrate inclusive design into a reconfigured FMC with the use of wireless sensor networks.

Chapter 7 the application of the methodology in a flexible manufacturing cell to demonstrate its reconfigurability through a series of steps, the integration of inclusive design approach to add characteristics oriented to users and the application of wireless sensor networks to add functionality and flexibility.

Chapter 8, here the author presents the results of application of the methodology and his conclusions about the process developed in both case studies.

Chapter 2 – Literature Review

2.1 Inclusive Design

Automation for Inclusive Design is characterized for facilitating accessibility to people who does not have normal physical and/or mental capabilities. In this way, it is necessary to develop devices, sensors and design practices forward to domestic and urban automation, so people with any disability is able to interact and to get adapted to products and services with no problem.

People not included in the normal design of products, buildings, houses, among others, are within the framework of exclusive design, an example of this are handicapped people, because of the existence of many people in conditions that disable them in some way and that makes evident the need of redesigning certain products and services so excluded people can use them normally, despite the difference in capabilities and accessibility.

When taking a look at products commonly used, immediately it is possible to detect inconveniences to use them in case of a disability. Many of these impairments are caused by design decisions made without considering users, because there are products that present unnecessary difficulties for many users. Their causes are trivial, but their solutions may also be trivial.

Solutions that are more inclusive will explicitly address the usability and accessibility needs for the widest range of users, and not necessarily require a deep review to improve products.

Many products seem to be designed for young population, excluding old people or people with functional impairments persisting in the view that these people are in some way undesirable customers. However, there is an urgent need of developing design methods based on a better understanding of such factors related to disabilities and aging, which will lead to minimize the impact of impairments and to improve life quality.

2.1.1 Inclusive Design – one among many terms

Inclusive design in one of many terms used nowadays in professions focused to environment, like construction industry, and in the action field of government. This term shares a similar background and also has objectives related to other terms such as universal design, design for all and, recently, "respect for people" (CEBE – Special Interest Group in Inclusive Design, 2002).

However, it is not the purpose to invest time in making distinctions among these different terms, nor evaluating which is better; the objective is to do an effective job independently of the terminology used, to determine the factors that should be modified when analyzing products from an inclusive perspective.

Inclusive design is a process that results in inclusive products or environments which might be used by all people no matter their age, gender or disability. It is an evolutionist and complex concept which definition can be extended in order to include not only age, gender and disability, but also ethnic group, income, education, culture, etc. (Shipley, 2000)

Not all the products exclude users, just some of them, and sometimes unnecessarily. A product designed to minimize exclusion will be called inclusive or universally designed.

Research has shown that while many companies agree with the principles of designing inclusively, they consider it impractical for them to adopt such practices. The reasons commonly cited are:

- Insufficient financial resources / time
- Inadequate access to product users
- Inexperience in dealing directly with users
- A lack of demand from commissioners of the designs

Despite these many companies could adopt inclusive design practices for many products and services as possible.

2.1.2 Why the interest in inclusive design?

There are arguments in favor of doing inclusive design practices, which address both the ethical case and the business case for adopting inclusive design.

The Ethical Case

The ethical motivations for wanting to design for a wider range of user capabilities and avoid unnecessary exclusion are easily identified. The foundation of the ethical case for inclusive design is that many users are excluded from sing everyday products and services because they do not have the necessary functional capability to interact with them. This is not the fault of the user, it is the fault of the design of the products and services for not providing enough support for the user.

The social argument reflects the changing nature of aging, disability and technological skills necessary to participate fully in modern society.

Inclusive design is not only about handicapped people, but also about those who due to their age have difficulties to walk, move or to chronicle ills like arthritis that disable some movements to take or use products designed outside inclusive design practices.

Nevertheless, old people, pregnant women, children, blind people are also important objectives who have the need, temporary o permanent, of living in an adequate environment adapted to their capabilities.

The Business Case

Governments around the world are responding to the ethical arguments in favor of a greater social inclusion facilitated by the appropriate inclusive design of products, services and environments with new legislation.

Much of the legislation is focused on prohibiting discrimination in the grounds of functional capability. In many countries, such legislation is regarded as an extension of comparable laws countering discrimination based on gender or ethnicity.

In other countries, governments consider a main fault that companies do not adequate their services to attend people with functional impairments.
As time goes, there is more population older than 50 years, retired and close to the third age to be considered as potential customers. Consequently, it has an economical sense to make sure they are not excluded, given that there is a global market of products and services designed or old people.

There is also a need that industry responds with products to facilitate the independency at work and at home for many people. And also to generate design methods based on a better understanding of age and capabilities, which should be focused to minimize the impact of disabilities and in this way, improve accessibility.

There are many products that are essential to facilitate the independency. These include, for example: household products, food containers, clothes, communication devices, formats to get information, lighting, infrastructure. These products and many others are part of an integral aspect of life for population in general.

It is indispensable to remark that the mentioned research about inclusive design has been carried out in developed countries like Japan, United States, England, etc. Also in Mexico part of the population is handicapped or has a disability due to their age; which is considered as part of excluded groups.

Next it will be analyzed the disabled population in Mexico.

2.1.3 In Mexico

In Mexico there are around 2 million people with some type of disability, which reveals that there is a wide need of redesigning many products and services in order to make them inclusive.

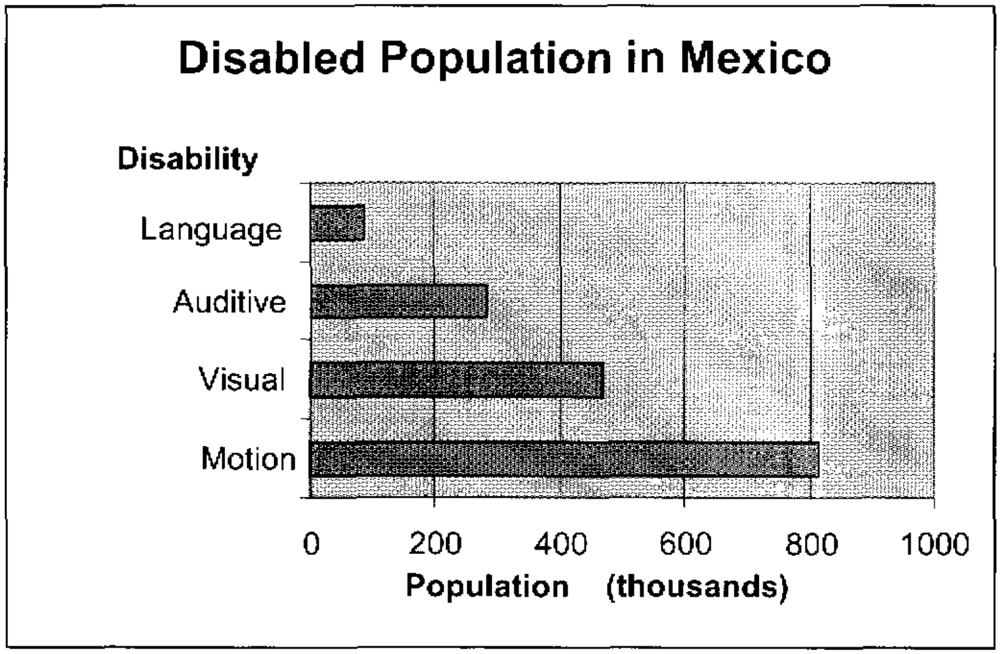


Figure 2.1 Disabled population in Mexico. Source: INEGI, 2000.

After analyzing the given information, it is worth to specifically emphasize that there is a need to develop knowledge and understanding about the user requirements for finished products.

Despite the national reality, normativity has focused just in the right to health; this has been recognized in the article 4th in the Constitution and regulated by the General Health Law. Physical disability is regulated by social assistance, by preventing disability and with rehabilitation of handicapped people. But the problem of handicapped people requires more than just the general health perspective.

Global trends are moving to leave the medical and social assistance model, to adopt the handicapped model as a human rights topic. And this is why the application of the Mexican legislation related to this subject is deficient, since it has been totally surpassed.

Perdomo, Gerardo. 2004, says about the legislative situation about handicapped people:

The subject of handicapped people rights is been taken to the legislative agenda. At this moment the commissions of health, social security, social development and legislative studies in the Senate are analyzing a memorandum and some law initiatives, with the purpose of condensing a specific ordering in this subject that allows the integration of handicapped people in social, economic and cultural processed in the country, based in a wide knowledge and warranty of their human rights and to the establishment of mechanisms that lead to equality of circumstances and opportunities within the society.

The new order must guarantee the rights of handicapped people, and it is necessary to protect and promote these rights. Among them figure the right to equality, right to not to be discriminated or excluded, and those that allow disabled people to have a full access to education, employment and training, health, social services, culture and sports, media mass and transportation. It also should include laws related to architectonic, urban development and housing support for the disabled population. The effective warranty of these rights will be the main objective of the law.

To achieve the feasibility of these legislature, it is indispensable a simple constitutional modification that supports its expedition, defining the competencies of the federation, the states and the Federal District, as the responsibilities of the different organisms that will apply and observe the achievement of the law.

There is much work to do yet, and it is necessary to sum efforts to apply, justify and dignify the handicapped population in Mexico.

For a better interpretation of functional needs of excluded people, it has been designed a tool called Inclusive Design Cube. (Clarkson & Keates, 2000)

2.2 Inclusive Design Cube

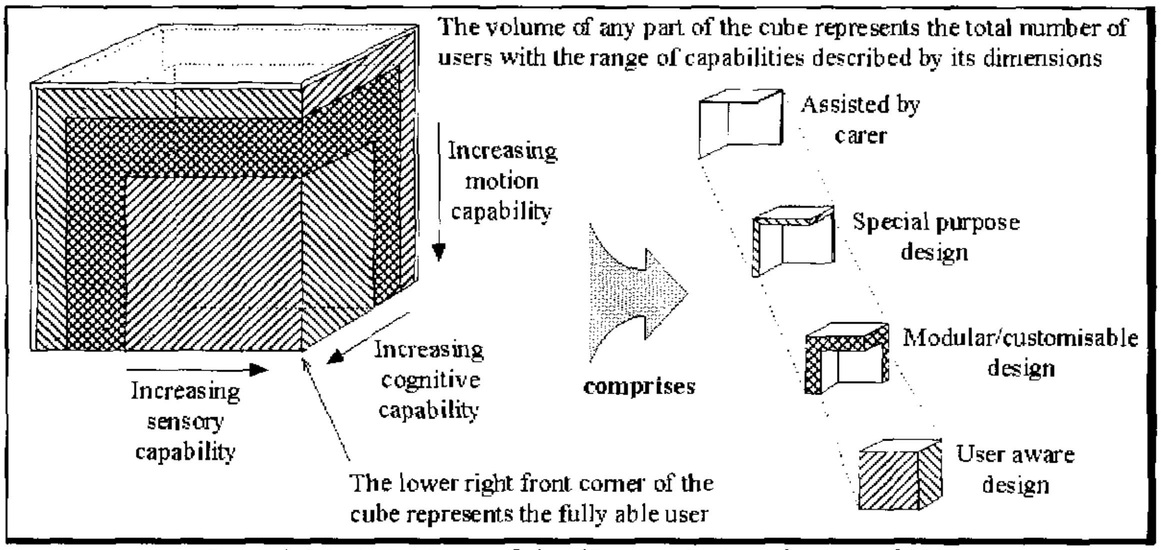


Figure 2.2 Inclusive Design Cube. (Source: Clarkson & Keates, 2000)

Individual parts of the cube represent populations that can be assisted by a particular design.

The cube in its current form has qualitative axes ranging from full capability to no capability. The motion axis represents such factors as strength and coordination capability; the sensory axis covers audio and visual capability; while the cognitive axis recognizes the range of intellectual capability.

At the low capability end of each scale, it is likely that many of the needs of daily living will be met by a carer. As capability increases, special purpose design will provide products to suit specific needs., for example, wheelchairs, walking frames, hearing aids and spectacles where such products are not intended for general use by the whole population. Modular or customizable design allows for variations in product user interfaces to accommodate a wider range of abilities than a standard interface. Finally, user aware design is intended to result in products which appeal to as wide a range of capability as possible.

The cube is essentially an extension of the user pyramid proposed by Benkzton (1993), and shown in the next figure.

2.3 Users pyramid

Figure 2.3 Users Pyramid (Benkzton, 1993)

- As can be seen in the figure, the most dependent people are those which are in wheelchairs and people with very limited strength and mobility in their arms and hands, and they are found in the upper part of the pyramid.
- In the middle are the people with reduced strength and mobility caused by disease and age-related impairment.
- Finally, in the bottom of the pyramid are found the able-bodied of fully capable users together with elderly people who have minor disabilities like reduced strength and mobility, or impaired hearing or sight.

Automation for inclusive design applied in the upper part of the pyramid is considered the hardest to do because the person does not have the motion ability to access, move or control any automatic device to do a specific activity independently. In this case it is necessary to automate using sensors that interpret certain movements done by the person so after that it can be easily carried out any predetermined action by the automation technology.

In the middle level of the pyramid it can be applied an automation technology that comprehends a conjunctions of controls and sensors for those people who does not have an extreme motion impairment, and that in some way are able to control an automated system through pushing buttons, walking or just moving their hands or arms.

According to the available information related to handicapped people (visual, motion and hearing), the main difficulty they have and that makes them more dependent on others is moving through any place, it can be in any building, when getting into a public transportation unity or just when going out to the street.

For these is necessary to make a detailed observation of these people movements, their anthropometry and basic functional needs, to understand and then propose a solution in design and in technology.

2.4 Using the Inclusive Design Cube to identify the potential market

The inclusive design cube is intended to be used as a diagnostic tool to assess the potential for expanding the market for a product. It is believed that by focusing on the market benefits of inclusive design is more likely that companies will be encouraged to develop new, more accessible products.

The inclusive design cube is initially intended to be used as a qualitative tool. However, it would be more useful as a quantitative tool coupled to recent demographic and impairment data. In addition, if it was also linked to the latest ergonomic data and guidelines it would allow the designer to understand what user interface features are required to meet the user capability targets.

2.5 Automation Technologies

According to the objective of this thesis the author is providing useful information about wireless technology, its characteristics and functionalities that will be considered to support the products and facilities.

There are Technologies based on sensors, actuators, computers, transmitters-receivers, radio frequency devices and more; to automate houses and buildings that are required by customers for comfort and home entertainment.

2.5.1 X10

X10 is a communication language that allows compatible devices to talk to each other using an existing electrical installation at home. Many compatible products with X10 are very accessible and the fact that they use the same electrical cables at home means that do not require additional expenses for installation.

The installation is simple: a transmitter is connected somewhere in the house and sends its control signal (on, off, bright, attenuation, etc.) to a receiver which is connected somewhere else in the house.

X10 is easy to use, just push a button in the transmitter and the signal is sent through the electric cable in the house to a receiver.

With simple digital dialing or buttons each product is assigned to one of the 256 supported addresses in the system. If it is wanted that two products turn on or off simultaneously, is needed to set the same address in the desired devices. All compatible products with X10, can be used and configured to create an automation network at home. The brands that work directly with X10 are: Leviton, Stanley, IBM, JDS, ACT, HomePro, etc.

It is estimated that there are approximately 10 million of American homes with compatible products with X10. This is because the system has many advantages above other systems and types of remote control products:

- Cheap
- Does not need new electric cable installations
- Easy installation
- Hundreds of compatible products
- Controls up to 256 lights and electric devices
- Around 20 years of experience

It is worth to mention the benefits of automation with X10, as:

Comfort

It is possible to control the TV from the coach, or to attenuate the lights when getting ready for watching a movie. Adjust the temperature from bed or control the volume of all the home audio system from any room. Or just turn on the heating in the bathroom 5 minutes before waking up, so it is warm when taking a shower.

Safety

Have different products that make it easier to access a house, since opening the garage, getting in the house with the lights already turned on. Lock doors and windows, putting an active alarm that detects any movement or intrusion suspicion.

2.5.2 MOTES

MOTES are wireless sensors that consist in Processor and Radio boards, connected among themselves in a network of various sensors and controlled by an operative system called TinyOs, support radio signals from two channels.

MOTES are thin and small, autonomous, are computers that have batteries as source of power and radio terminals which enable them to communicate and exchange information with others, as auto-organize in ad hoc networks. MOTES can be used to detect objects in movement and draw their path.

Currently Intel Company is working in collaboration with researchers' community to explore the potential of new applications for MOTES and sensor networks. Potential markets in a future include transportation and deliveries, fire fight and rescue operations, home automation and even interactive toys.
Intel is interacting with home and industrial automation companies to develop and promote low energy consumer radio frequency technology.

An application for MOTES would be the Sense Table, which is a simple application of MOTES in a network for their use in a tangible interface. Sixteen MOTES are wireless connected. Each MOTE uses a magnetometer for sensing metallic objects on the table. The sensors network calculates and looks for an object position once it has changed its position.

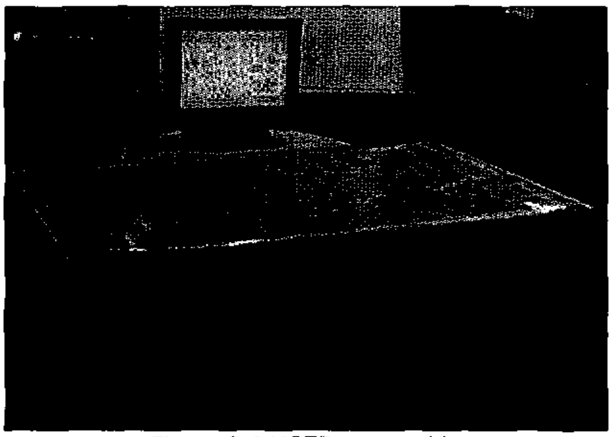


Figure 2.4 MOTE sense table

The system operates independently of any PC externally connected. In the application of the Sensors Table, a mote added to a PC gets the information from the motes that are in the Sensors Table and generates an appropriate visualization of the obtained data.

2.5.3 RFID (Radio Frequency Identification Technology)

Radio Frequency Identification (RFID) uses radio waves to communicate to the RFID reader to identify individual items on which RFID tag is placed. RFID tags placed on items listen to the query generated from the RFID reader and responded back by transmitting their unique code id. There are two types of RFID, depending on the communication methodologies and power source of RFID tag. The two types of RFID are – Active RFID and Passive RFID.

- Passive RFID

Passive RFID tags does not have own power supply, but absorbs power from the radio frequency generated from the reader and transmitted back a response. Passive RFID response contains typically the unique ID number only due to low power availability. Lack of power supply makes the passive RFID range of transmission from inches to 20 feet.

- Active RFID

Active RFID has its own power source and has more memory to keep additional information other tan the unique id. Due to own power source its transmission range can extend up to 100 feet. It can store additional information received from the RFID reader.

How does RFID tracking work?

A RFID based system; each item is fitted with a RFID tag. The RFID tag is basically an electronic radio transmitter comprising of a micro-chip and an antenna and a tiny battery, everything fabricated on a thin plastic sheet. It can be easily attached to a variety of items directly. Each RFID tag has a few bytes of memory built on to it which contains its unique identification number and it periodically sends out a radio signal carrying the same. A receiver device, called the RFID reader detects the signal emitted by each tag as soon as it enters into its radio range and interprets the identification number. The RFID tags that are powered with a tiny battery are known as Active RFID tags and can be read from a distance as high as 100 feet. The detection range of a RFID reader can be adjusted so that it defines an area in the enterprise. Simply put, when a RFID tag is detected by a particular RFID reader, it's known that the item where the tag is put on is present in the area where the reader is sitting.

System Architecture of RFID Subsystem

The RFID based asset tracking and inventory management solution uses a simple yet scalable architecture for the RFID subsystem to suit the needs of a variety of application domains. It uses a number of individual software components that work collaboratively for smooth processing of the RFID tag information (such as Tag ID, time of detection, area where detected, etc) and feed the information to the inventory management solution.

A number of RFID readers are place within the sensing place, depending on its shape, size, number of strategic detection points and other factors. Each RFID reader defines an area in the enterprise. Data that is captured by the readers are sent to a software called Concentrator. The concentrator software can receive RFID information from several reader devices. It processes the information and buffers them for a predefined time period. There is another piece of software called Collector which collects buffered data from the Concentrators. For higher tag densities, additional Collectors can be added to the system. The Collector software performs additional processing and finally puts the data into an SQL Server database.

The RFID based asset tracking and inventory management solutions can be developed depending on customer requirements as suitable for the business process of the organization.

Areas of application of RFID Technology

The major application area of RFID tracking is in manufacturing, service and retail chains. However it can be applied in many other ways. RFID tracking can be used in any area where some kind of tracking is necessary. Some interesting applications are described here:

- In Hospitals and Health care, each patient can be tracked by a RFID tag. RFID tags in form of wrist-bands are now available in the market. Doctors and nursing staff can see detailed information of the patient on a hand-held PC or PDA, just by standing near the patient's bed.

- In large farms, dairies, etc., RFID tags can be used to track live stock. Active RFID tags in form of ear tags have started coming to the market.

- RFID tracking can be used in any organization for employee/visitor tracking within its premises.

- In Airlines, RFID technology can be used for tracking baggage with 100% accuracy.

- In a city transport system, RFID tags can be used on high priority vehicles such as police cars, ambulances, fire trucks, etc., so that when they arrive at a crossing, the traffic signaling system can automatically switch on green lights only for that lane and red lights for all other lanes.

As it can be seen, RFID Technology can achieve the wireless sensor network characteristics:

- Low power consumption: By only receiving energy from the radio frequency generated from the reader and transmitted back.

- Wireless Sensor Network: Their architecture allows an arrangement that intercommunicate several receivers to a concentrate in order to obtain more information.

2.5.4 Wireless Sensor Networks

Wireless sensor networks are a sensible choice for data acquisition frameworks as wireless sensors can be conveniently placed in non-accessible places, support mobility and dynamic topology and can scale better than their wired counterparts. As such, they are widely used in sensing applications like temperature, pressure, acoustics, and motion detection as well as for data acquisition in monitoring, manufacturing, biodevices etc.

A wireless sensor network is a collection of wireless sensors covering a small area, typically less than 10m. Every sensor performs independent sensing, processing and transmission of data over wireless link to a data collection node. The data collection node aggregates data from multiple sensors and processes it.

In general, wireless sensor networks are deployed for data acquisition purposes. They have a fixed pattern of data flow. Sensors transmit small amount of data at periodic intervals of time. The data may be as small as few bytes. Usually the data contains the value of one or more sensed attributes. The time interval between successive data transmission by a sensor depends on the requirement of the application. For example, for a sensor for surveillance purposes, the data transmission can be quite frequent while for environment monitoring it could be significantly infrequent.

Wireless network sensors are a strategic solution to acquire signals from tool machines, like speeds, vibration, temperatures, and the very advantage of this kind of sensors is that they do not need wires for power supply and signal transmitting, since they are equipped with batteries and the signal acquired is transmitted through radio waves.

Constituents of Wireless Sensors

A wireless sensor can have size of the order of millimeters. In this, resides a transducer unit that converts the sensed analog signals to digital, a control unit that receives digital input from the sensing unit and performs protocol operations, a radio unit which transmits the packet over wireless link and a battery which is the power source of the entire device. The control unit can function at micro-watts level while the radio transmissions typically require energy in miliwatts.

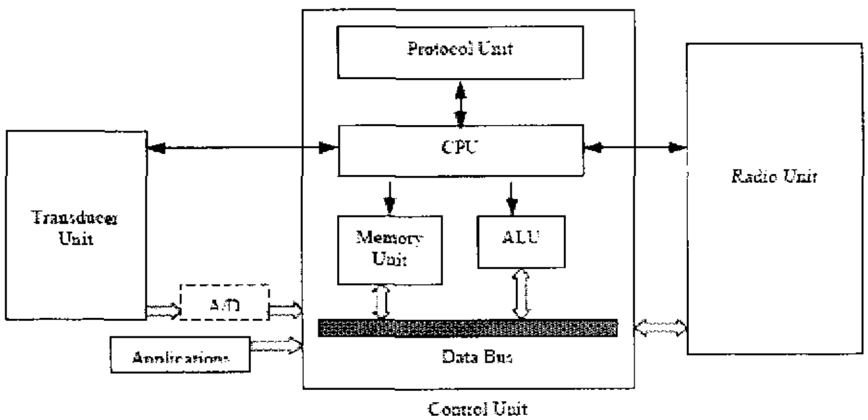


Figure 2.5: Functional components of a typical wireless sensor (Agrawal, et.al., 2003)

The network protocol is realized in the control unit which is a microcontroller. The network protocol runs through the information and configures the sensor dynamically. The data flows unidirectionally from transducer unit to the control unit. The control unit contains memory units to save data, an Arithmetic and Logic Unit (ALU) to do calculations, comparisons and other data manipulations, a timer unit to schedule data transmissions, a protocol unit to implement the network protocol functions, and finally a CPU to control all the above units. For low power consumption, the CPU should function at low speeds. The radio unit hosts the MAC protocol functionality. The MAC protocol handles data transmission over wireless link.

One of the important characteristics of sensor networks is that the data transmission does not require higher power radio signals as the sensors are located close to each other.

Fixed network or Ad-hoc network

The characteristics of wireless sensor networks are highly related to their topological configuration. A wireless sensor network can be an ad-hoc network or a fixed network. In an ad-hoc network, sensors can organize themselves in clusters of sub-networks and perform higher level functions of routing or mobility management between themselves. In the fixed network, a higher peer usually called an access point manages communication between groups of sensors. Sensors of different groups communicate via their access points. Thus, for fixed wireless sensor networks, much of the functionality of IP layer may be redundant.

They are easily deployed and depending on the type of network they can achieve a throughput of approximately 40 Kbps that can be sufficient enough for all the recompiled data sent. They are usually organized in a multi-hop network, and each node has its own sensors, embedded processors and low-power radios, every single one running with batteries. (Ye, Heidemann and Estrin, 2002)

Actual manufacturing systems require the unconditional support that technology can offer nowadays and the integration of WSN to Reconfigurable Manufacturing Systems facilitate the monitoring, data acquisition (signal conditioning), signal processing techniques, and decision making routine to analyze the data and classify the results. (Mehrabi and Kannatey-Asibu Jr, 2000)

The major challenges in the design of a wireless sensor network are the power, storage, processing and computing limitations of the sensor.

Wireless Sensor Networks Applications

A typical application can be an automatic guided vehicle where a wireless sensor network is used for positioning, guidance and interaction with surrounding machines and robots. In the extreme case the product itself can be equipped with a radio node, making it possible for the assembly robots to interact wit the product during the assembly. This would make it possible to conduct tests, software downloads and identification during assembly process of complex and variable products.

Wireless sensor network (WSN) is a recent research topic. This network is composed of hundreds or thousand of autonomous and compact devices called sensor nodes.

Wireless Sensor Network has the potential for many applications: e.g. for military purpose, it can be used for monitoring, tracking and surveillance of borders; in industry for factory instrumentation; in a large metropolis to monitor traffic density and road conditions; in engineering to monitor building structures; in environment to monitor forest, oceans, precision agriculture, etc. Others applications include managing complex physical systems like airplane wings and complex ecosystems.

A sensor node is composed of a power unit, processing unit, sensing unit, and communication unit. The processing unit is responsible to collect and process signals captured from sensors and transmit them to the network. Sensors are devices that produce a measurable response to a change in a physical condition like temperature and pressure. The wireless communication channel provides a medium to transfer signals from sensors to exterior world or a computer network, and also a mechanism of communication to establish and maintenance of WSN, which is usually ad-hoc.

Characteristics and Requirements of Sensor Node

Energy-Efficiency
Sensor node must be energy efficient. Sensor nodes have a limit amount of energy resource that determines their lifetime. Since it is unfeasible to recharge thousands of nodes, each node should be as energy efficient as possible. Hence, energy is the major resource, being the primary metric for analysis.

Low-cost
Sensor node should be cheap. Since this network will have hundreds or thousands of sensor nodes, these devices should be low cost.

Distributed Sensing
Using a wireless sensor network, many more data can be collected compared to just one sensor. Even deploying a sensor with great line of sight, it could have obstructions. Thus, distributed sensing provides robustness to environmental obstacles.

Wireless
The sensor node needs to be wireless. In many applications, the environment being monitored does not have installed infrastructure for communications. Thus, the nodes should use wireless communication channels. A node being wireless also enable to install a network by deploying nodes and can be used in many others studies for example liquid flow of materials.

Multi-hop
A sensor node may not reach the base station. The solution is to communicate through multi-hop. Another advantage is that radio signal power is proportional to r4, where r is the distance of communication. It can be more energy economic to transmit many short-distance messages than one-long distance message.

Distributed processing
Each sensor node should be able to process local data, using filtering and data fusion algorithms to collect data from environment and aggregate this data, transforming it to information.

2.5.5 Honeywell – Hometronic

Are technologies developed with the purpose of satisfying some comfort needs at home, such as:

Opening of blinds
Closing water and gas valves (safety)
Security systems like alarms and motion sensors
Remote control with mobile telephony
Control panel for lights and temperature
Automatic locks for opening doors
Room access with security numeric keyboard

Among other products fabricated by this company. These products receive and transmit signals by:

- Radio frequency
- Electric cables
- Infrared port
- Temperature, illumination and motion sensors
- Computer serial port

Its objective market is homes, because nowadays they have no other application, they are directed to those people that look for comfort in their automated houses and with operations than can be executed by a central system automatically.

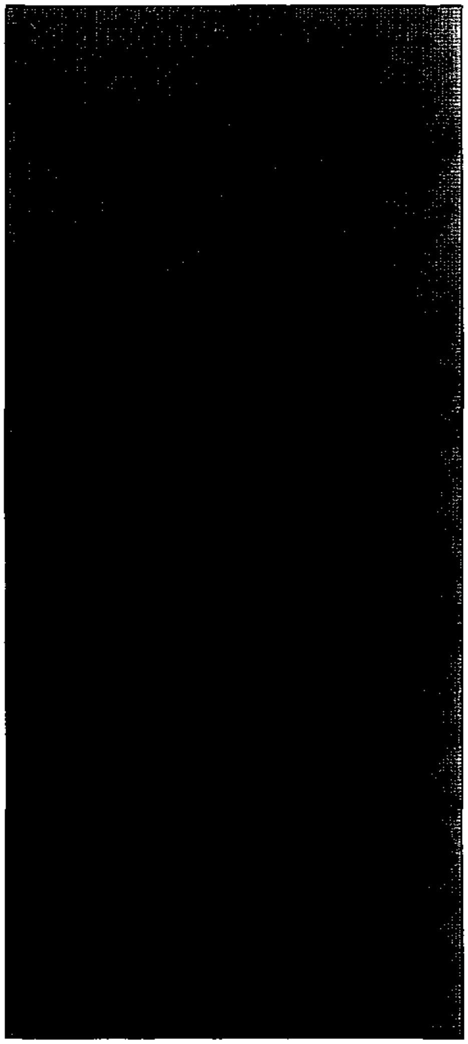
The integration of this technology with other mentioned above, would be easy due to the open source software they use, that can be configured to work with applications related to X10 and MOTES. Also because to their flexibility to operate through traditional electric cables in any installation capable of receiving signals.

Based on the needs and with the existing products that use the technologies X10 and MOTES it is proposed to automate what already has been produced and/or develop new automated products and services.

In a further description of the methodology, there will be a part of observation and interview with the user or people who assist handicapped and old people, whit the purpose of detecting those needs that require to be fulfilled with a product.

Once obtained the types of disability, functional need, technologies with their respective advantages, is fundamental to analyze the coupling they can have among them to offer technologic solutions.

Next is given a series of types of handicapped people and age-related impairments, with the functions of the existing technologies that can cover those deficiencies.



Available technologies
X10
MOTES

Devices / Functions:

Movement and approximation sensors
Temperature and humidity sensors
Detection of vibrations and paths
Switches
Dimmers
Pistons
Solenoid valves
RF Transceivers
Reprogrammable controls
Answer machines
Water and air thermostats
Transistors
Modules on/off for electric devices
Electric locks
Motors for blinds
Motors for curtains
Pneumatic actuators
Remote controls

Note: The need of moving through halls, rooms, or in public places has been the most important to handicapped people with moving impairments and old people.

Once the customer requirements have been identified and the technological options reviewed, it is convenient to create "kits" of products categorized according to the main disability of the user.

Inclusive Design

Motion
Wheelchairs
Access to buildings
Up / down stairs

Reduction of Strength
Arthritis
Open door handles
Open jars

Group of Applications
Open doors
Activate ventilation
Turn on / off lights
Interconnected presence sensors
Modify level of tables

Visual Impairment
Bright and flashing switches
Remote controls
Detection of paths

The operative system that controls the MOTES is open-source software called TinyOS, which can be modified to intercommunicate with the interface of the Firecracker software that controls the X10 to execute output signals.

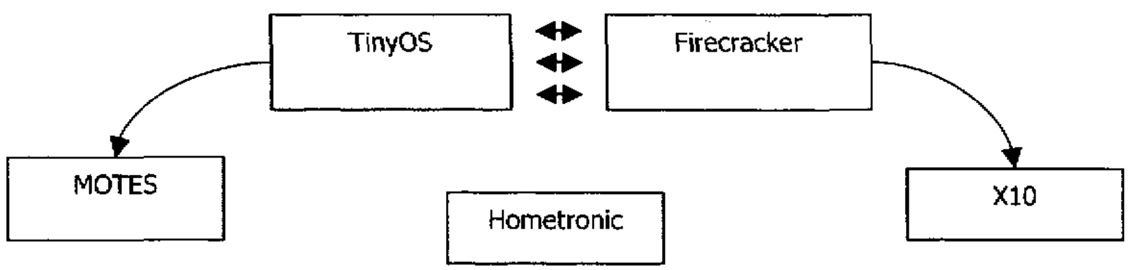


Figure 2.6 Integration of various technologies through software

This is a schematic description of the integration of various technologies using software, without modifying the principle of functionality of each one of them, but adding the efforts and advantages that each one provides with the purpose of facilitating the user interaction with his or her environment.

Following some products that might be able to be fabricated with the integration of the technologies X10, MOTES and Hometronic will be proposed. These options are useful to visualize the different solution alternatives for the existing needs, and thus understand the flexibility given by each technology to integrate to the objective of a solution.

Answer with X10 and MOTES
Proposed products:

1. MOTES sensors that detect presence and turn on the lights with X10 devices according to luminous conditions, and at the same time open the doors when passing through.
2. Detection of inside temperature and regulation of environmental weather using air conditioner or heating as needed.
3. Detection of proximity to doors and their automatic opening for less frequented places. On the other hand, the most used doors will be controlled by a portable radio-control.
4. Manual and automatic temperature control for shower, by a main hermetic control that regulates temperature without using handles.
5. Remote Control with illumination functions and to open / close and lock doors.
6. Self-adjustable height table for having meals or for reading (wheelchairs).

Table 2.1 Proposal of products to respond to a variety of impairments

The six proposed products are composed by X10 and MOTES Technologies, their functional characteristics must be analyzed in accordance to their achievement of the Inclusive Design Cube qualitative axis with the labels:

- IMC Incremental Motion Capability
- ICC Incremental Cognitive Capability
- ISC Incremental Sensory Capability

Products designed for assisted people are the ones that require sensors and on/off devices completely automated that do not imply any interaction from the user. The type of modular / customizable design goes for those people that do not have a severe impairment and that can be designed and adjusted to specific needs. These can be also operated in a manual mode for people who assist disabled customers.

A specific purpose product is designed to fulfill those specific needs and that can not be configured for other functions, but for those that it was designed to perform.

Qualitative Axis	Product 1	Product 2	Product 3	Product 5	[illegible]	Product 6
[illegible]	*Minimum*	*Minimum*	*Minimum*	Minimum strength, Medium Coordination	Low Strength, Low Coordination	*Minimum*
[illegible]	Minimum	Minimum	Medium	Medium	High	Minimum
[illegible]	Only visual perception	Only tactile perception	High Visual	Only tactile perception	Only visual perception	Only visual perception
[illegible]	Assisted by carer	Modular / Customizable	Modular / Customizable	Modular / Customizable	Modular / Customizable	Assisted by carer

Table 2.2 Table of relationship between IDC axis and products proposed

Qualitative Axis	MOTES	X10	HOMETRONIC
IMC Strength and Coordination	Senses extremities position	Provides control for doors, windows and other devices	Provides control for blinds, windows and electronic devices
ICC Intellectual Capability	Not needed	Medium	High
ISC Auditive and Visual Capability	Detects movement, presence and paths	Provides help with illumination and visual signals	Provides with illumination and control of several devices

Table 2.3 Relationship of how wireless technology improves the IDC qualitative axis

MOTES sensors reach a higher level in the user pyramid, where people with motion, visual and auditive impairments are located, and do not require cognitive capability from the user because it is a component of active automation.

X10 devices make easy the movement, coordination, auditive and visual operations, just getting instructions from the MOTES to carry on its functions, although the control require some intellectual capability to be operated.

HOMETRONIC technology demands a wide knowledge in the control of electronic devices, weather, illumination and other devices, but also can be controlled with MOTES sensors to perform its functions.

2.6 Usability, accessibility and inclusive design

According to Jakob Nielsen (1993) system acceptability is the goal that designers should be aiming for and can be achieved by meeting the social and practical acceptability objectives for the system.

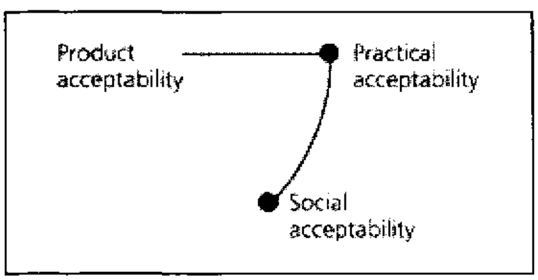


Figure 2.7 Acceptability: A combination of practical and social issues (Nielsen, 1993)

Nielsen further identifies usefulness, constituting usability and utility, as a key objective to providing practical acceptability.

2.6.1 Designing for social acceptability

Inclusive design does not require the application of new skills or techniques. Instead it requires the designer to modify his or her perception of what the user really wants.

The encapsulation and presentation of the user-wants should include the additional factors such as the effects of age, experience and impairments, so that the designers can respond to them.

Common approaches often focus on providing inspiration to the designers, encouraging the right frame of mind, rather than a list of specific requirements.

A model such as IDEO generates specifications based on user requirements, identified by store-telling approach, and that is how this company knows about the user interaction with the environment. It is a direct contact with the user.

Another approach is simply to expose designers to end-users. This is the approach used for empathic design proposed by Gheerawo and Lebbon (2002).

2.6.2 The goal of social acceptability

Social acceptability, as defined by Nielsen (1993) is achieved when the product meets the expectations and aspirations of the user. For brevity, we shall refer to these as the "user wants". Social acceptability requires that issues such as the following are addressed:

- Does the product look nice?
- Do I trust this product?
- Does this product stigmatize me in any way?
- Do I want this product?
- Is this product 'cool'?

Although this list is not exhaustive, merely indicative of the type of attributes associated with social acceptability. When considering the design of assistive products in particular it is also important to add 'non-stigmatizing' to the list of attributes.

In other words, a socially acceptable product must be one that the user is happy or content to use.

As Cooper (1999) says, the only successful products are those that the users want to use.

While this may be true for most mainstream commercial products, it does not necessarily apply to so-called assistive or rehabilitation products, which are often bought on behalf of the user by an intermediary, such as a health authority.

Designing for social acceptability requires the designer to be provided with information about what constitutes a socially acceptable product for the target users and then using a suitable design approach that is responsive to those requirements. Keates & Clarkson (2003).

2.6.3 Identifying what user wants

Before applying any design model for the inclusive design of a product, it is important to observe and question the customer, to understand what really needs and wants; this is relevant because in a first instance there is a need to be satisfied with a product and after that a desire of the user. This means that once the product has been designed to fulfill the specifications it is necessary to add an aesthetic value that will make the product acceptable.

Some people want a product that draws attention to itself, such as a memory aid or prompt to take medication, while others would prefer something more discreet, especially if the product is to be used in public.

Traditionally, defining the user expectations for a product has been a remit of market researchers, or other specialist professionals, such as ethnographers, who study customs, habits, trends and life styles in specific regions.

Keates y Clarkson (2003), provide a brief summary of typical methods to identify what user wants:

- Questionnaires: A series of pre-prepared questions asked either in writing or orally.
- Interviews: Either pre-structured or free-form.
- User observation: Watching the users perform the task, either using an existing product or prototype.
- Focus groups: Discussion groups addressing a specific topic.
- Ethnographic methods: Use of 'cultural probes' (cameras, diaries, etc.)

Each of the above methods has its limitations, as mentioned next:

Questionnaires are only as useful as the questions that are on them. If the wrong questions are being asked, then the information obtained will be of limited use. Also, if the questionnaires are mailed out (as compared to being completed in the presence of a researcher), then they often suffer from low response rates.

Conversely, interviews are time-intensive, requiring one-on-one time between the interviewer and the interviewees, so are only really practical for small samples.

Similarly, user observation is also time-intensive, and also often requires the use of specialist equipment for recording and analyzing the observation sessions. The observers also have to be aware of the need to not interfere in how the user performs the task, to avoid influencing the data collected.

Focus groups are a current favorite among market researchers. They offer feedback form many users in a short space of time, and so are considered good value for money. However, the principal weakness of focus groups is that they can be influenced by a small vociferous minority who impress their opinions on the other participants.

Ethnographic methods rely on providing the users with recording media ('cultural probes'), such as cameras, diaries and tape recorders. The users then make use of the media to keep a record of what they consider to be important over a period of between a few days to a week. The strength of this approach is that the user is left at complete liberty over what to record, thus preventing the researcher from influencing the outcome.

However, the principal weaknesses of ethnographic methods are that the user may not record anything that is relevant and also that the data collected needs to be interpreted and this is in turn subject to the interpretation of the researcher performing the analysis.

After knowing about these different methods, it is also necessary to make additional considerations in particular the effects of age and experience need to be addressed. (Keates and Clarkson, 2003)

The Effect of Age

When designing for a different age range, the designers need to be attuned to the aesthetic and aspirational values of the users. Similarly, each generation will have developed different sets of technological skills, knowledge and experience.

The Effect of Experience

When asking or identifying user's opinions, many of those opinions will be tempered by the past experiences of the users.

When considering the design of a radical new technology, the usefulness of the feedback will potentially be restricted by the ability of the participants to understand the potential of the new technology.

When considering the issues for designing inclusively, it has to be remembered that many older users may have different educational background to younger ones, especially when talking about computers and electronic devices.

The Effect of Disabilities

A person who has suddenly developed or acquired a functional impairment, for example from a stroke or an accident, will feel an immediate loss in capability. The psychological effect of this can be devastating and can be difficult to come to terms with.

However, someone who acquires or develops a functional impairment over a long period of time, often with gradual erosion of capability, may be more accepting of the decrease in capability, especially if it is a result of the aging process.

Finally, someone who has born with a congenital impairment that is present from birth often has a completely different view of what to expect from life from that of someone who has experienced full functional capability.

Identifying and understanding the psychological impact of the impairments is often as important as understanding the physiological factors. The impact is also very user-dependent and often varies significantly from person to person.

2.6.4 The goal of practical acceptability

Having considered designing for the goal of social acceptability, the next step is to consider practical acceptability.

Jakob Nielsen's (1993) definition of practical acceptability divided it into:

- Cost
- Compatibility
- Reliability
- Usefulness

Of these, usefulness is subdivided further into utility and usability, where utility is the provision of the necessary functionality by the product or service to perform the desired task.
Usability is defined as including:

- Ease or learning
- Efficiency of use
- Ease of remembering
- Low (user) error rates

Most designers focus on providing the necessary utility, or functionality of the system required for the task, and the social acceptability, such as the aesthetic characteristics, for user who match their own capabilities and preferences. There are two reasons for these. The first is that these are indisputably very important objectives to address. The second is that a minimally effective solution can be obtained in the minimum of time.

This is the easiest way to achieve a product design without adapt it to non-required specification from the user, these are more commercial products and non-customized.

However, as Poulson (1996) says that such minimally effective solutions are increasingly unacceptable to the wider population. He argues that usability, i.e. the extent to which a product can be used by specified users to achieve specified goals (ISO, 1998), is also important and needs to be designed directly into the product or service.

The usability and acceptability principle proposed by Nielsen is contained in the next figure.

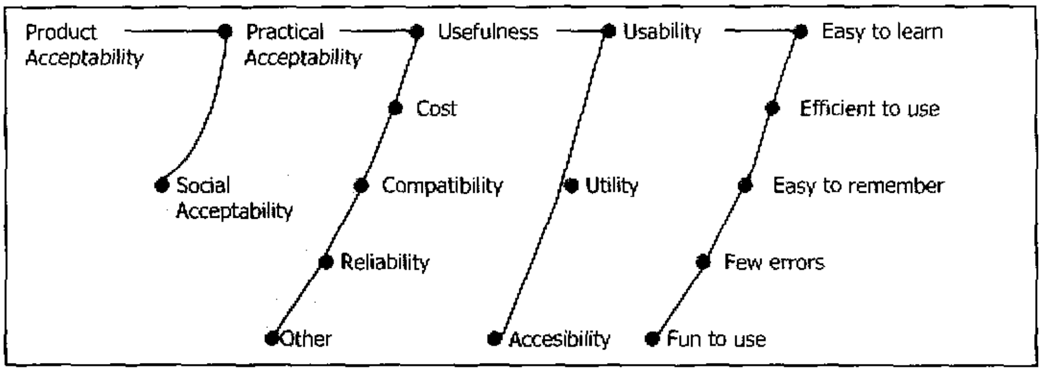


Figure 2.8 Usability and Acceptability principles (Nielsen, 1993)

Usability is often regarded as a specialist activity. Many usability professionals would claim that is sufficiently complex that most designers need specialist help in identifying and achieving usability goals. However, they are severely limited in their suitability for design for accessibility. The limitation arises from the wide variation of functional capabilities across the population. This is that a commonly accepted as usable system product development can be used by all people.

Many valid usability techniques are also limited because of their configuration for accessibility design, which classifies them as inflexible.

A traditional usability approach would take a user selected on the basis of his or her skill and experience, and a solution would be developed that was usable by that individual. An accessibility approach needs to consider an extra level of information, that of how the specific user maps to the target population in terms of functional capability and not just skill and experience.

When designing for accessibility, and thus for inclusivity, the users identified should represent the observed spread of capabilities in the population. Hence, some users should have high functional capability (low impairment), others should have moderate functional capability (moderate impairment) and finally there should also be users with low functional capability (high impairment).

However, identifying and securing access to representative users can be expensive and time-consuming, so an increasingly popular approach to inclusive design is to design for the more extreme end-users.

The principal weakness of working only with extreme users is that unless the designers have been briefed that these users are still only a representative simple, and do not span the entire spectrum of users, then they may be tempted to optimize for those individual users only.

Accessibility design approaches have had to be developed to complement traditional usability approaches and encourage broader interpretations of the end-users. These approaches are variably referred to as 'design for all' (Europe), 'universal design' (USA and Japan) and 'inclusive design' (UK) and are typically specific implementations or derivations of 'user-centered design' (Newell and Gregor, 2002).

There are several existing approaches to designing more inclusive products. However, there are shortcomings of each of these approaches that prevent from being useful across all circumstances. The principal weakness stem from the targeted nature of the approaches.

Initially it was recognized that the disabled and elderly people were the principal groups excluded form using most products. The solution appeared obvious, if such users could not use the products, then developing special products designed specially for them would solve the problem. Thus concepts such as 'design for disability' (Coleman, 2001) appeared.

While many good products were developed using design for disability approaches, they were outnumbered by those that were either expensive, inappropriate or simple did not offer the necessary utility. The focus of the products developed, including many assistive technology products, was often on very specific needs arising from very specific circumstances. Also, many of the products had to be designed from scratch. This made for very long development times, with resultant high costs.

Many products were developed with no thought of whether someone would actually want to use, or be seen using them. As people rebelled against using ugly, stigmatizing, expensive products with poor usability, it was clear that new approaches to design were required.

"Design for all" was another early concept in the debate about how to design more inclusive products. There is no single clear definition of its goal, unlike for example the seven principles of universal design (Story, 2001).

The Principles of Universal Design
1. Equitable use
2. Flexibility in use
3. Simple and intuitive
4. Perceptible information
5. Tolerance for error
6. Low physical effort
7. Size and space for approach and use

Table 2.4 Universal Design

It is commonly, but incorrectly, interpreted as being a 'one product for all' type approach. A more accurate description it is a philosophy that encourages designers to consider the needs of the wider range of users and typically results in products designed for the largest possible population, but not the entire population.

A number of newer, more focused design approaches were developed to overcome the shortcomings of the earlier methods. For example, 'transgenerational design' (Pirkl, 1993) focuses on designing products that do not exclude on the grounds of age. 'Rehabilitation design' focuses on design for specific impairment types (Hewer et al., 1995).

However, each of these design approaches has been developed to meet the needs of designing for specific user groups. Consequently, when combined the existing approaches may offer a complete coverage of the population needs, individually they do not.

One of the most fundamental questions facing a designer when considering how best to design inclusively is that of whether to adopt a 'top-down' or 'bottom-up' approach.

2.6.5 Mainstream Products vs. Assistive Technology

Design approaches such as rehabilitation design and design for disability correspond to top-down approaches and the products developed are typically classified as assistive technology. That is they provide remedial assistance to restore or replace a functionality capability.

The corollary to top-down is bottom-up, in other words, taking a mainstream product and pushing the boundaries of the design to include as many potential users as possible. This is the type of approach that is most commonly associated with inclusive design. Here, mainstream products are considered to be products that have been developed purely for the commercial market and without explicit reference to user functional capabilities.

2.7 Product Design Models With Inclusive Design Approach

2.7.1 Top-down approaches

These approaches for inclusive design are conceptually the easiest to understand and appreciate. They also come as close as possible to guaranteeing that the least able users will be able to use the product. If done well, the products and services developed using this approach should be so fundamentally accessible that other people outside of the initial user group considered should be able to use them.

The principal weakness on the top-down approach is that products and services developed using a top-down approach may be too specialized and optimized for a small user group and fail to be transferable to other sections of the population. Thus the products may end up only being sold to the small target group for which they were originally designed and fail to penetrate the mainstream market.

The inherent small market for over-specialized products was the pitfall that trapped and ultimately killed many rehabilitation robotic products, expensive technology, and long development cycles, and in some cases, the development of rival mainstream technologies.

Another issue that frequently affects the success of products developed using top-down approaches is the perception that they are 'medical' devices. Many were designed to meet a specific 'medical' need, and were often purchased by health authorities, for whim aesthetic value was a low priority compared to functionality and longevity. This is known as the medical model of inclusive design.

For products developed using the top-down approach is essential that they are designed to appeal to the largest possible audience if they are to have any chance of succeeding commercially.

2.7.2 *The bottom-up approach*

Bottom-up approach aim to take a mainstream product that is to be designed for able-bodied users and make it more inclusive.

In this approach, most designers will design for themselves, based on the assumption that most users will be like them, unless told specifically to do otherwise.

Bottom-up approaches offer great potential for commercially successful products. Starting at the bottom of the users pyramid and expanding upwards means large numbers of people are included by the product.

However, it must be noted that for each unit move up the pyramid, the additional number of people included diminishes.

Another difficulty with bottom-up approaches is that they can only go a limited distance up the pyramid. The products being developed will still be fundamentally based on those optimized for the mainstream market, albeit with any unnecessary barriers to access and use removed.

It is unlikely that extreme user requirements will be met using a bottom-up approach and thus the products developed this way will probably never cover all of the potential users. This is an unfortunate limitation as it is likely that it will be the same extreme users who will be unable to access many of the products developed using bottom-up approaches.

Thus it is highly probable that bottom-up approaches will always need to be complemented by top-down ones to provide coverage of the needs of the whole population.

2.7.3 *Designing for the whole population*

For inclusive design it is preferable to adopt whichever approach is more suitable for the intended users (bottom-up for more mainstream users, top-down for more assistive products) than to risk producing a product that fails to satisfy either the end of the market because it was designed as an unhappy compromise between the two approaches.

Indeed, the recognition of the limitations of each design approach and how they tend to apply to one extreme of the user population or the other indicates that the prospects of ever designing a single acceptable product for the entire population are slim.

However, there are other approaches, as the modular design proposed by Beitler, Harwind and Mahoney (1996). In the case of modular design, a common base unit is developed and a range of interfaces is made available to the user, who is able to select his or her preferred choice.

Rapidly customizable design takes the same principle of choices made by the user, but instead of offering a determined interface, it modifies the structure base to get adjusted to the user preferences.

The need for rapidity is important to keep the process simple, cheap and attractive to the customer.

The ability to tailor or customize the interface to the needs of the user appears to be an intrinsically sound idea. However, there is a potential difficulty when relying on the user exploring the various interfaces configuration to discover the best set-up for their needs.

The problem is that many users will tend to settle on the first 'satisfactory' configuration even if there is a better solution available. The reasons for this include:

- The desire to comply with the norm – User wants to use the same that other people for not feeling different.
- The difficulties of exploration – Selection among different options take too long, it is better to have a settled one.

Another cause of difficulty is that if the interface is rigidly optimized for the user's current needs and then those needs subsequently change, the interface may need to be changed or modified as well.

In summary, the different approaches to designing for the whole population fall into three fundamental categories:

- User aware design: pushing the boundaries of 'mainstream' products to include as many people as possible.
- Customizable/modular design: design to minimize the difficulties of adaptation to particular users.
- Special purpose design: design for specific users with very particular needs.

2.7.4 Design Models

There are many models of design that help to describe the nature of the design process. However, because of the special focus on inclusive design, it is necessary to consider some theories and models that would be useful in mechatronic product development to be proposed on Chapter 5.

The Inclusive Design Cube is a tool that helps to visualize and communicate the needs from different population sections. Therefore, for the application of inclusive design practices it is necessary to have a rigorous methodology. Next, some models that can be used to establish an inclusive design methodology will be analyzed.

Design is subdivided into a series of activities that enables the initial market need or idea to be converted into the manufacturing instructions that fully describe the product that is to be made:

Clarification of the task

The starting point for the design process is an idea or a market need, often stated in vague, and sometimes contradictory, terms. Before the subsequent design phases start, it is important to clarify the task by identifying the true requirements and constraints.

Conceptual design
Concepts with the potential of fulfilling the overall functional and physical requirements listed in the specification are generated.

Embodiment design
In this phase the foundations are laid for the detail design through a structured development of the concept.

Detail design
Finally, the precise shape, dimensions and tolerances of every component have to be specified. The result of this phase is detailed manufacturing instructions, which can take various forms including detail drawings, programs for CNC machines, test schedules, etc.

However, these activities are not considered as rigorous steps to be followed, but it is a guide to understand the general design process of a product. Many of the product design descriptions are normally focused to the process design more than on the end user and that is why any of the models for design go toward achieve the maximum of acceptability.

Waterfall Model

The waterfall model is an approach to design with a focus on evaluation, verification, validation and review.
In this model, verification and validation may be defined by:

- Verification: "Are we building the thing correctly?"
- Validation: "Have we built the correct thing?"

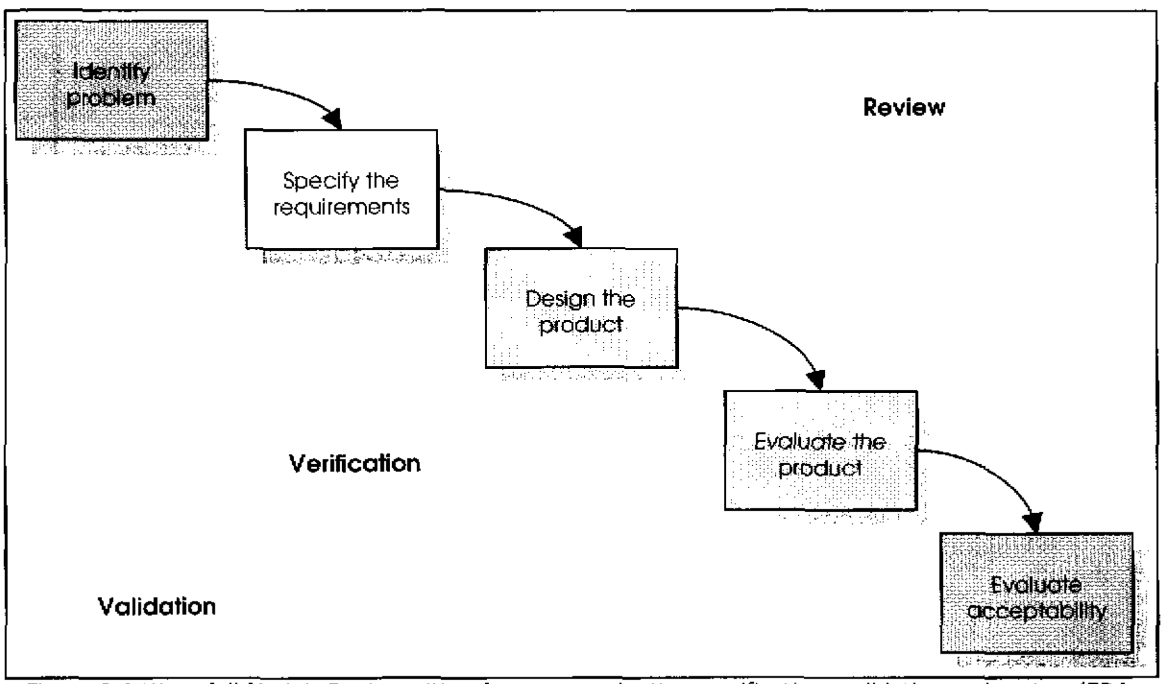


Figure 2.9 Waterfall Model: Design with a focus on evaluation, verification, validation and review (FDA, 1997)

Evaluation of acceptability, in the form of verification and validation, emerges as a critical component of inclusive design, ensuring that evidence of performance (whether satisfactory or otherwise) is available. Of particular importance is the early definition of the evaluation requirements, which in turn may influence the design.

In addition, the evaluation of the design must also be done in the context of its expected use. Ideally, this involves a range of tests, including user trials, to provide representative performance data. For genuine inclusivity, where a product is used as a part of a system, the full system must be evaluated.

Evaluation of acceptability must be done together with the specification of requirements, living feedback continuously to the precedent product design step, with the purpose of that when the product is evaluated and the acceptability is implicit the modifications to the prototype would be minimal.

V-Model

The V-model adapted from a software design emphasizes the importance of user-product interaction design and product evaluation.

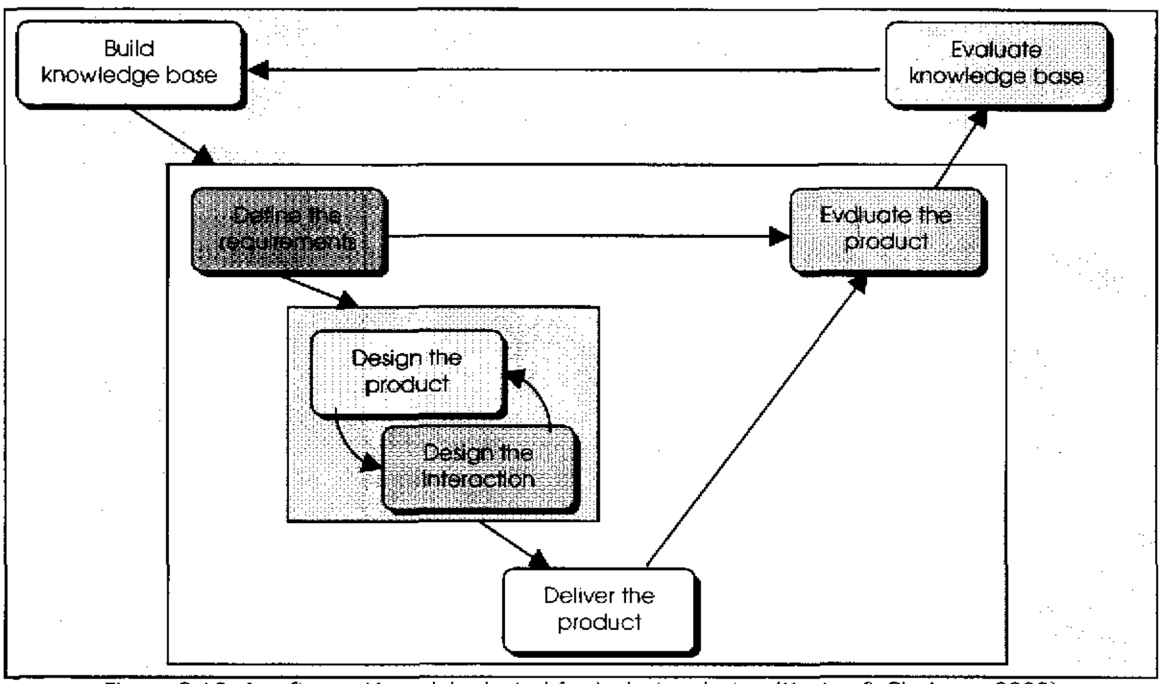


Figure 2.10 A software V-model adapted for inclusive design (Keates & Clarkson, 2000)

The addition of a knowledge base to support the product design reflects the importance of user-information and the 'knowing user' activities within the knowledge loop to evaluate the product from the designer and the end-users point of view.

Shigley and Mischke Model

This model of design process emphasizes two facets of design – analysis and optimization; and iteration of the evaluation, analysis and optimization toward the recognition of the need and problem definition; as part of a continuous observation of the development as function of the main requirements.

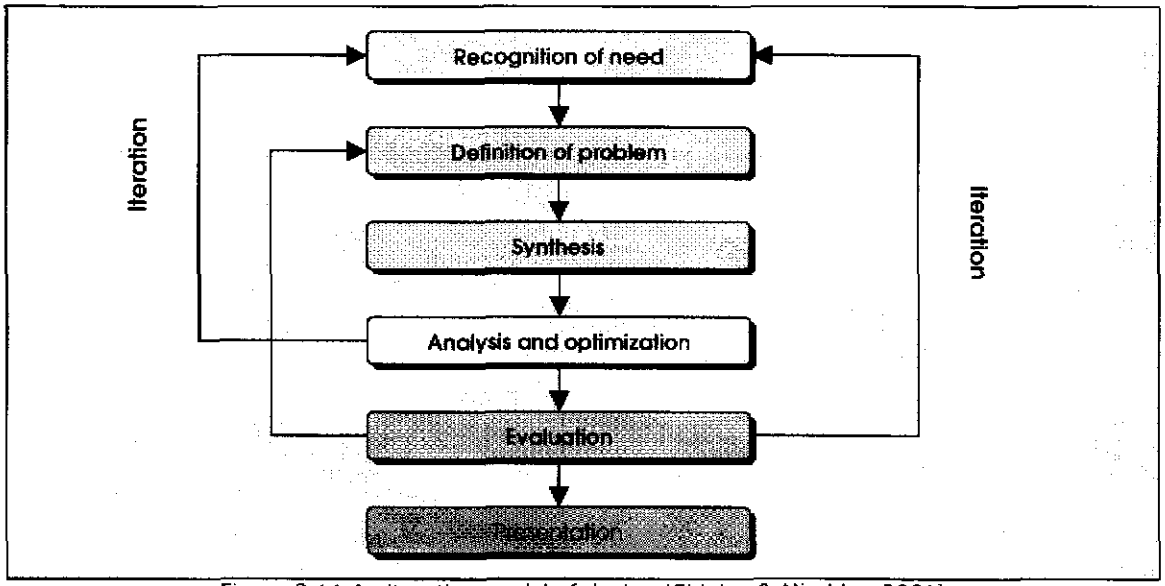


Figure 2.11 An iterative model of design (Shigley & Mischke, 2001)

Thus far the design approaches discussed have their origins in engineering design. Product design approaches typically have a different focus, away from rigorous 'define/design/evaluate' cycles and more towards identifying and satisfying the user social acceptability requirements. A good example of this is the model used by IDEO (Myerson, 2001).

IDEO Model

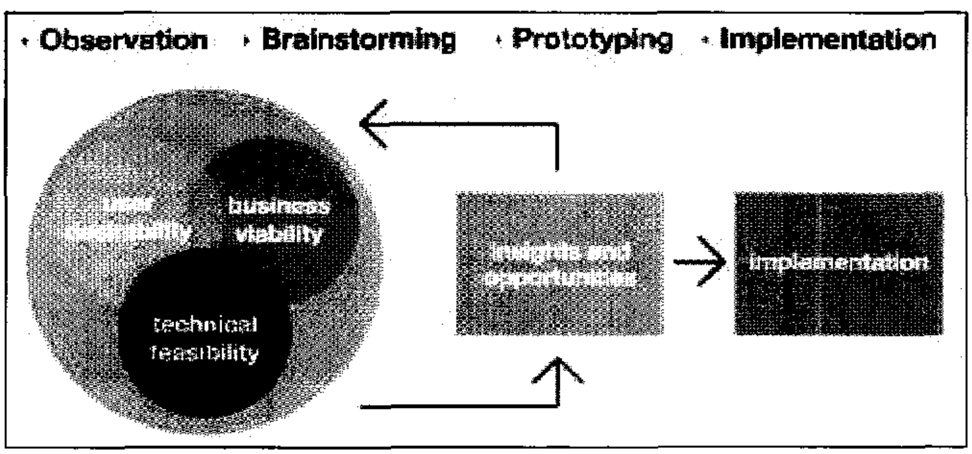


Figure 2.12 IDEO design model, (IDEO, 2004) http://www.ideo.com/about/?x=3&y=4 (obtained on March 2004)

User observations are the starting point for every design program. All IDEO designers are seasoned observers of people and how they interact with the world. We engage end users throughout the design process to evaluate the desirability of new ideas and possible solutions.
Brainstorming is part art, part science. Promote every kind of ideas trying to be visual, defer judgment, encouraging wild ideas, building on the ideas of others, and staying focused on a topic. Brainstorming is not just a good idea but an inexhaustible source of inspiration and fresh thinking to get a wider spectrum of the needs to have in mind when designing.

Prototyping is the language of innovation and a way of life at IDEO. Prototyping is problem-solving in three dimensions. Ranging from simple proof-of-concept models to looks-like/works-like prototypes that are practically finished products, prototyping lets you fail early to succeed sooner.

Implementation completes the cycle of ideation to drive the concept to its final form. All the possibilities have been evaluated, the prototypes validated and refined, and what is left is to do it. The project team performs detailed design and engineering, chooses manufacturing partners if necessary, and works with the client to perform a timely and successful launch.

IDEO has a 5-step methodology:

1. **Understand** the market, customer, technology and the identified limitations of the problem. After that, during the project development attack those constraints, and, first of all, it is important to understand the current perceptions.

2. **Observe** people in real life situations to find what identifies them, what confuse them, what they like, what they do not like, which needs are not covered by products and services in the market.

3. **Visualize** new concepts and the customer that will use them. This is the phase in the process where the brainstorming has to be more intense. Visualization takes the form of a renderization or simulation done by computer. In this step a video is done where customer is interacting with the future product, before the product is manufactured.

4. **Evaluate and y refine** prototypes in rapid iterations. Try to not get limited to the few prototypes generated at the beginning of the process, because these will change. There is no good idea that can not be improved, and plan a series of improvements. Here ideas from the internal team, customers, stakeholders and people who know the primary market are taken into account. The product is observed: for what it works, for what functions it does not work, what confuses people, what they seem to like about the product, and is in this way how the product is improved increasingly on each step

5. **Implement** the new concept for commercialization.

This methodology in appearance simple has been useful for designing from toys until e-commerce business. IDEO is recognized by its methodology centered on the user, in which analyzes its prototype directly with the customer and is a part in the product development process.

One of the most straightforward approaches to design states that there are three principal stages of design (Blessing, Chakrabarti y Wallace, 1995):

1. Define the problem: The problem definition should explicitly include reference to the intended target users.
2. Develop a solution: An appropriate design approach should be adopted for the target users.
3. Evaluate the solution: The target users should be included in the evaluation process.

These stages apply to all design processes, whether designing product interfaces, or design approaches.

Developing a usable and accessible solution for a wider range of user capabilities involves understanding the fundamental nature of the interaction. Typical interaction with an interface consists of the user perceiving an output from the product, deciding a course of action and then implementing the response.

These steps can be explicitly identified as perception, cognition and motor actions (Card, Moran and Newell, 1983) and relate directly to the user's sensory, cognitive and motor capabilities respectively.

The 7-level approach is an extremely flexible design approach. It forms the basis of all of our inclusive design activities and also shares many elements with other models.

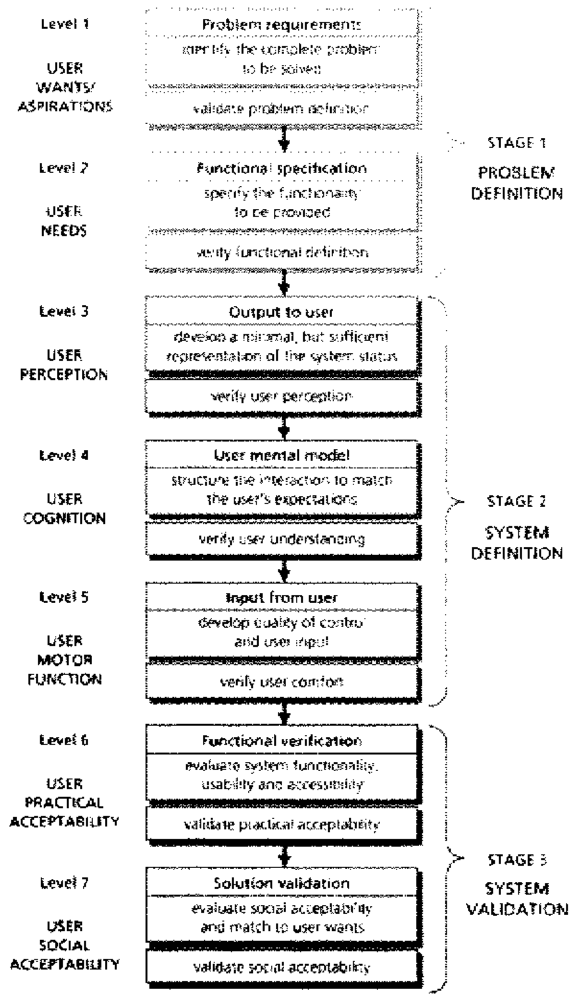


Figure 2.13 The 7-level design approach (Keates & Clarkson, 2003)

Both the 7-level approach and the inclusive design cube (IDC) share the same inherent emphasis on the interaction consisting of perceptual, cognitive and motor actions. Consequently, if the 7-level approach has been adopted as the framework for the development, then the inclusive design cube can be adopted to monitor the population coverage achieved by different design choices.

By using the 7-level approach in combination with the Inclusive Design Cube it has been identified a deficit in the use and accessibility of products, which suggests going back to the product design or redesign.

All mentioned models contain in some way the next steps and formats:

- Structure
- Needs analysis
- Evaluation
- User focus
- System focus
- Representation
- User involvement
- User information and Analysis

Combining the 7-level approach with the inclusive design model allows highlighting the need for frequent review stages and iteration.

A more comprehensive approach to inclusive design is shown next:

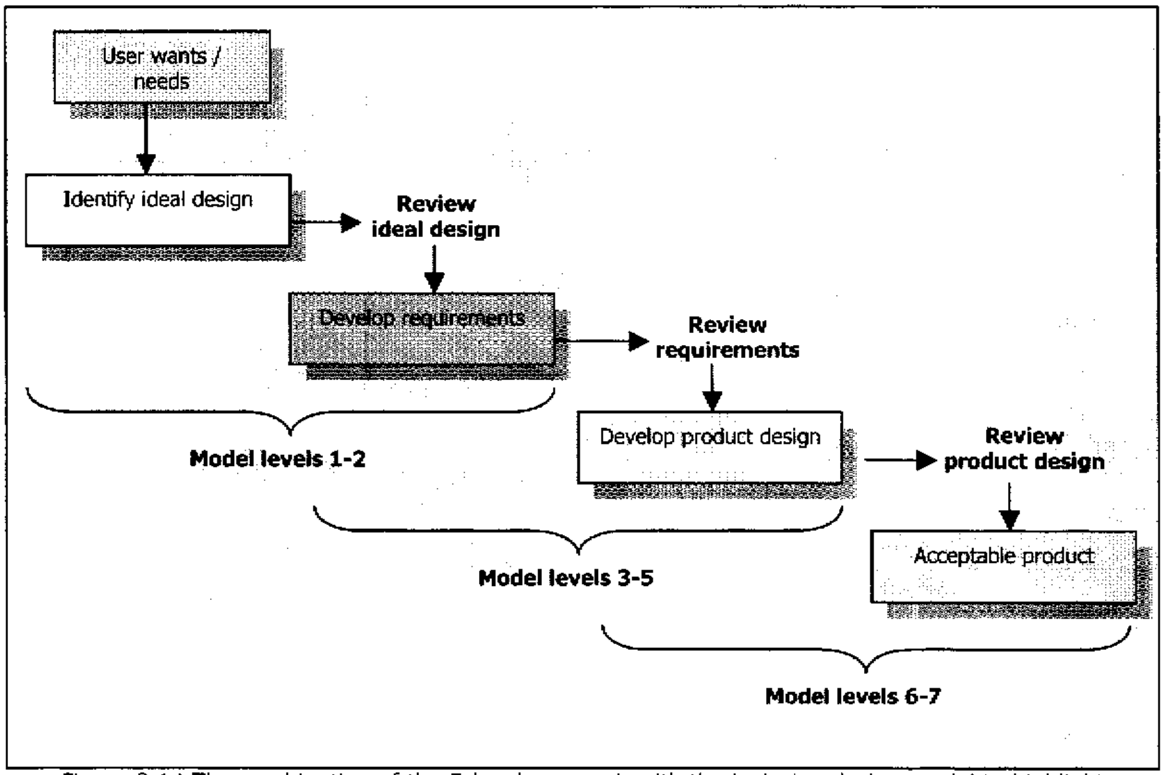


Figure 2.14 The combination of the 7-level approach with the inclusive design model to highlight the need for frequent review stages and iteration. (Keates & Clarkson, 2003)

2.8 Reconfigurable Manufacturing Systems

A Reconfigurable Manufacturing System (RMS) is designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements. (Koren, 1999)

Reconfigurable systems must be designed at the outset to be reconfigurable, and must be created by using hardware and software modules that can be integrated quickly and reliably; otherwise the reconfiguration process will be both lengthy and impractical. Reconfiguration allows adding, removing, or modifying specific process capabilities, controls, and software or machine structure to adjust production capacity in response to changing market demands or technology (See Table 2.5).

For a manufacturing system to be readily reconfigurable, the system must possess certain key characteristics:

Modularity. In a reconfigurable manufacturing system, all major components are modular (e.g. structural elements, axes, controls, software and tooling).

Integrability. Machine and control modules are designed with interfaces for component integration. The integrated system performance is predicted based on a given performance of its components and the interfaces of both software and machine hardware modules.

Customization. This characteristic has two aspects: customized flexibility and customized control. Customized flexibility means that machines are built around parts of the family that are being manufactured and provide only the flexibility needed for those specific parts, thereby reducing cost. Customized control is achieved by integrating control modules with the aid of open-architecture technology, providing the exact control functions needed.

Diagnosability. Detecting unacceptable part quality is critical in reducing ramp-up time in RMS. As production systems are made more reconfigurable and are modified more frequently, it becomes essential to rapidly tune the newly reconfigured system so that it produces quality parts.

Convertibility. In a reconfigurable system the optimal operating mode is configured in batches that should be completed during one day, with short conversion times between batches. Conversion requires changing tools, part-programs, and fixtures, and also may require manual adjustment of passive degrees-of-freedom.

Modularity, integrability, and diagnosability reduce the reconfiguration time and effort; *customization and convertibility reduce cost. Therefore, these key RMS* characteristics determine the ease and cost of reconfigurability of manufacturing systems. A system that possesses these key characteristics has a high level of reconfigurability.

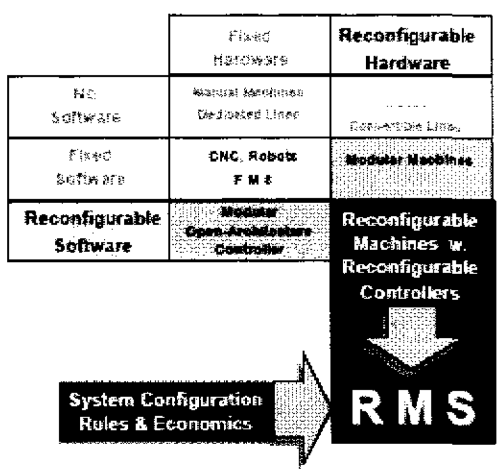


Table 2.5 – Comparison of the key hardware and software features of manufacturing systems (Koren, 1999)

There are many aspects of reconfiguration. These include various configurations of the production system, reconfiguration of the factory communication software, configuration of new machine controllers, building blocks and configuration of modular machines, modular process and modular tooling. (See Figure 2.15).

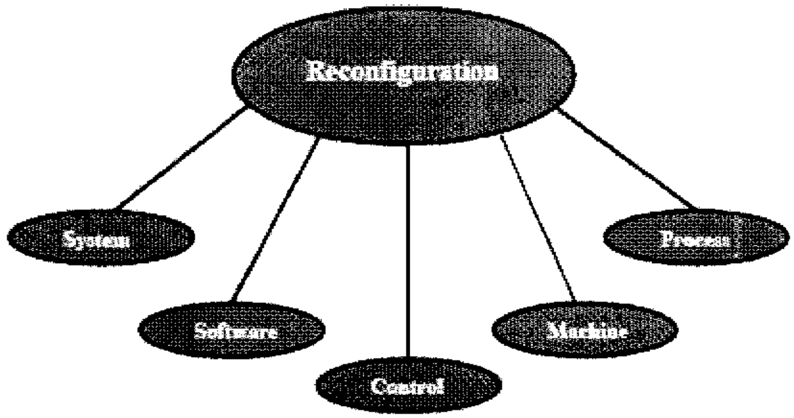


Figure 2.15 – Aspects of reconfiguration (reconfigurable system, software, controller, machine, and process) for RMSs (Koren, 1999)

At the system level, there can be several system configurations for production of the same part family. Development of the necessary tools and methodologies to design the system, and evaluation of various configurations is needed. According to the software / hardware architecture, it should have certain features to support the five key characteristics of RMS. Some of these are:

It must own a modular structure and be open-source such that upgrading and customization of the system is practical while integration of new software is possible.

Control of RMSs is another important subject to be studied. The controller should have the ability to reconfigure and adapt itself to the new conditions based on market demand, such as damping, mass, and inertia will change accordingly.

A development of a unified approach for design and construction of reconfigurable machine-tool systems is needed because is another important challenge in the design or RMS.

The CAD techniques would help in the reduction of lead time, and that the system would be readily diagnosed for reliability and product quality problems. A rapid restructuring of a system requires component design for reusability and quick integration.

Ease of upgrading requires that the components be designed for substitution, and that the system be designed for a good integration of new technology and then a new functionality.

The RMS require technology applications in order to be more functional. They include system design and configuration for RMSs, their software and communications requirements, control and monitoring, machine design aspects of RMSs, processes and tooling, and intelligent sensors and multi-sensor data fusion for system reliability.

It is important to clearly observe the effects of changes in the system configuration on factors such as part quality, and system productivity, reliability, and cost of the system (Sood et al. 1993; Hassan, 1994)

An integral part of RMSs is the software required to handle tasks at various levels such as control, monitoring and communications among mechanical, electrical and electronic components (at low level) as well as higher levels tasks such as process planning, user interface, process control, data collection/report from the process, etc.

Therefore, the structure and functionality of the communication and control software is very critical and directly affects the performance of the entire system. The modular nature of RMSs requires that the software/hardware of the system be in a modular form; i.e., consist of separate entities totally decoupled from the rest of the system such that addition/modification of a component is possible. Furthermore, it should be extensible (i.e., be able to respond to new features, environments, and requirements), modifiable/reusable (easy to modify and usable in different programs, if necessary), and most importantly reconfigurable (able to accommodate different configurations and to support internal/external interactions of modules without modifications in the software). (Mehrabi, Ulsoy, Koren, 2002).

Some considerations must be performed; those are that the object-oriented programming is a reasonable choice as already has been used in other areas for real-time control applications (Awad et al. 1996). With the same importance is the hardware architecture that should be compatible and responsive to the properties of the software interacting efficiently to support the essential features of RMS.

2.8.1 Process and quality aspects of RMS

Once a RMS is reconfigured, the production system must typically be adjusted before it can consistently produce at the required quality and production volume, this is referred to as ramp-up. This objective requires diagnostics, calibration, and ramp-up methodologies.

One of the key factors in evaluating the product quality is precision in machining. To achieve that, the cutting operation is tightly controlled by using real-time data collected from sensors located at different locations of workpiece, tool, and machine-tool (Rao, 1986; Kannatey-Asibu, 1987; Rivin and Kang, 1992; Rivin, 1994; Ni, 1993).

Some variables are required to make the real-time measurements, these are:

- Dimensional errors
- Quality of surface finish
- Thermal deformations during machining
- Dynamic deformations of the workpiece: chatter vibration, cutting force, condition of the chip, and identification of the cutting for process monitoring (Chrysolouris et al. 1992);
- Thermal deformation, dynamic deformation of the machine elements, and structural vibration of the machine-tool (Ferreira and Liu, 1986)
- Wear failure, and thermal deformations of the tool (Rao, 1986; Li and Albestawi, 1996).

Regardless of the type of process, there are several key components in modern intelligent sensor-based machine monitoring systems including: data-acquisition system which consists of sensors and signal conditioning systems for collecting (remote/local; software/hardware; on/off line) data (for monitoring and reliability estimation), signal processing techniques to extract valid data (software), and decision making (software) routine to analyze the data and classify the results (software). In essence, the entire process of control and monitoring is very similar to the actions of humans and ideally, should duplicate the response of an experienced and efficient machine operator. Further details of general description and classifications of the sensors (contact/non-contact), techniques of measurements (direct/ indirect) and sensor-data fusion (to improve the accuracy and reliability) and their features and limitations are provided in (Mehrabi and Ulsoy, 1997-b).

Other major sensing applications are described in the further Wireless Sensor Networks topic.

2.8.2 Future trends of Manufacturing Systems

There is an existing need of improvements and standardization of various components, such as data interfaces, protocols, communication systems, etc., so that data can be transferred to the desired location at a faster rate.

As reported, there is a lack of available tools and methodologies to analyze the trade-off among processes, equipment, life-cycle costs, and initial investment. Also, there is a lack of effective communication among product designers, process designers and machine-tool designers as it is necessary for design of an optimized manufacturing system. (Mehrabi, Ulsoy, Koren, 2002).

The manufacturing systems need to advance with the proper machine-tools and equipment. Machine-tools are going to be changed in terms of their structure (modular structure), components (controllers, hardware / software, spindles, tooling, sensors, etc); and new design concepts and methodologies should be developed for these purposes (Garro and Martin, 1993). With those fundamental changes the success of the future Reconfigurable Manufacturing Systems is achieved.

Chapter 3 - Action Research

3.1 Overview

The present research work was developed using learning cycles, where instructions learned and understood from previous experimentations gave the improvement and capability to execute the research in both cases, the first case the author experimented with the creation and application of inclusive design methodology to mechatronic product design, then through this experimentation the author reflected and improved a new methodology that could be directed further to a reconfigurable manufacturing system.

This chapter contains information about the concepts and definitions of Action Research, also contains the research development carried out by the author and describes the steps followed through the process of experimentation and learning from each stage.

3.2 What is Action Research?

Action research can be described as a family of research methodologies which pursue action (or change) and research (or understanding) at the same time. In most of its forms it does this by using a cyclic or spiral process which alternates between action and critical reflection and in the later cycles, continuously refining methods, data and interpretation in the light of the understanding developed in the earlier cycles (Dick, 2001).

The action research consist of planning and experimentation, a process in which somebody poses an action, then act and later check if the action was well done. If this not occurs, then is deeply analyzed and observed what could be done differently, this process of act and check is repeated as much as it needs.

Action research has been recognized for its breadth as a field of research practice and its depth as a discourse of theoretical insight. (Kemmis, 2000). It does not have one widely accepted definition. According to some reasons for the difficulty of formulating a generally accepted definition of action research, and argues why action research should not be confined but should be both clarified for communication and open for development.

A working definition authored jointly by the participants at the Brisbane International Symposium on Action Research in 1989, is the following:

If the researcher is in a situation in which:

- Data-gathering by participants themselves (or with the help of others) in relation to their own questions;
- Participation (in problem-posing and in answering questions) in decision making;
- Collaboration among members of the group as a "critical community"
- Self-reflection, self-evaluation and self-management by autonomous and responsible persons and groups;
- Learning progressively by doing and by making mistakes in a "self-reflective spiral" of planning, acting, observing, reflecting, replanning, etc;

- Reflection which supports the idea of the "self-reflective practitioner"

- *Then this is a situation in which action research is occurring.*

- Action research has some characteristic differences from most other qualitative methods (Dick, 2000). Action research tends to be:

- Cyclic: Similar steps tend to recur, in a similar sequence;
- Participative: The clients and informants are involved as partners, or at least active participants in the research process;
- Qualitative It deals more often with language than with numbers; and
- Reflective: Critical reflection upon the process and outcomes are important parts of each cycle.

3.3 About the Action Research process

A pragmatic form of defining and explaining action research is a diagrammatical model as a spiral of cycles (Figure 3.1), each consisting of four moments or phases in action research:

1. Planning;
2. Acting;
3. Observing
4. Reflecting

This model is based on Kurt Lewin's work, explicated by Kemmis and McTaggart (1988). It is a simple, helpful model of the continuous and iterative process. It involves research and development, intellectual inquiry and practical improvement, reflection and action.

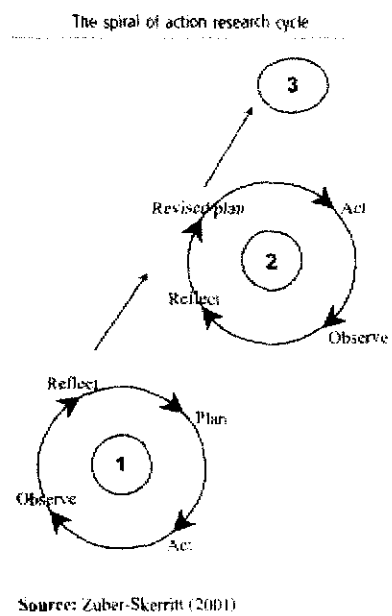


Figure 3.1 The spiral of action research cycle (Zuber-Skerritt, 2001)

These steps are basics in the spiral process through which the researchers work on:

- Develop a plan of critically informed action to improve what is already happening,
- Act to implement the plan
- Observe the effects of the critically informed action in the context in which it occurs, and
- Reflect on these effects as the basis for further planning, subsequent critically informed action and so on, through a succession of stages

It is thus an emergent process which takes shape as understanding increases; it is an iterative process which converges towards a better understanding of what happens.

Action research is generalized on the form that it has evolved (Zuber-Skerritt, 1992): All adopt a methodical, interactive approach embracing problem identification, action, planning, implementation, evaluation, and reflection. The insights gained from the initial cycle feed into planning of the second cycle, for which the action plan is modified and the research process repeated.

Most writers coincide that action research is cyclic, and it has a spiral structure. One crucial step in each cycle consists of critical reflection. The researcher and others involved first recollect and then critique what has already happened. The increased understanding which emerges from the critical reflection is then put to good use in designing the later steps.

The cyclical process of action research allow the researchers to take a course of action, make an experimentation, then analyze it and make the corrections properly in order to achieve a know-now that is going to be used in later situations. By this process, the objective of reflection is that the researcher will improve the next plans' executions and will connect similar events happened in both situations. The critical reflection is the core process, as it is seen on Figure 3.2.

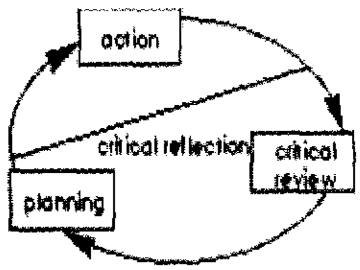


Figure 3.2. Critical reflection as a core process (Dick,2000)

3.4 Action Research focused on Inclusive Design applied to Mechatronic Product Design and further to Reconfigurable Manufacturing Systems

The Action Research process in this research work is applied on the development of products and cells by using the inclusive design approach as a model to improve the human-machine interaction.

The application of Action Research to both cases of the project is described in the following process:

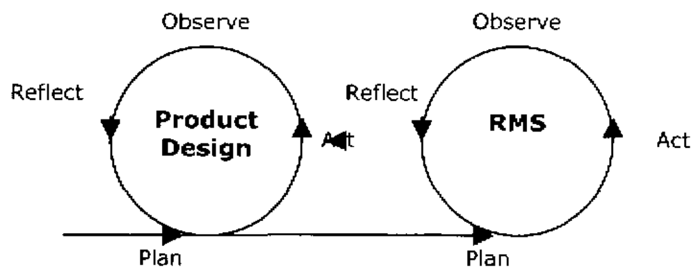


Figure 3.3 Action Reseach process

The stages developed in this process are described in the chapters corresponding to the case studies.

The case studies developed in this thesis project, are the following:

MECHATRONIC PRODUCT DESIGN

- Automatic Shower
- Automatic control for lights and doors
- Control for lights and doors

RECONFIGURABLE MANUFACTURING SYSTEM

- Flexible Manufacturing System

Chapter 4 – Methodology for Product Design incorporating Inclusive Design

4.1 Methodology

The main purpose of the methodology for design and manufacturing of mechatronic inclusive products is that of provide designers a simple and adaptable procedure that supports on each of the product development phases to achieve a right application focused on end-user needs.

This methodology incorporates several tools that will lead the designer in an analytical and evaluative way, with the aim of developing products with a high accessibility and usability for disabled or old people. In this way, the purpose of this methodology is to provide a guide for the development of any mechatronic product with the intention of automating a system or activity with comfort, health or any other purposes.

This Methodology is widely based on Product Planning and Conceptual Design for the products to develop, for each of the mentioned phases several activities are proposed for being carried out along the development process.

4.2 Product Design Phases

On each design phase there is information that will define the characteristics, details and constraints of the product, so it requires accuracy and reliability to carry out each phase properly to be sure that the results will be adequate for the product definition to develop.

Product Planning: Here, customer requirements are translated into technical requirements. It comprehends the process of gathering information related to main characteristics of the product to define. Also the objectives of the project as well as an action plan are stated.

Conceptual Design: Technical characteristics of the product are defined; design problems, functions and sub-functions are identified; design alternatives are proposed in accordance to the defined functions as well as solutions for contradiction problems within product variants; and evaluation of conceptual solutions to solve functionality difficulties.

Detail Design: In this phase the precise shape, dimensions and tolerances of every component have to be specified. The result of this phase is detailed manufacturing instructions, which can take various forms including detail drawings, programs for CNC machines, test schedules, etc.

Prototype: The purpose of generating a prototype is that of testing it to verify its functioning and its characteristics that are susceptible to failure during its use.

Table 4.1 Product Development with Inclusive Design

No.	Activity	Format	Tool	Approach	Recorded	Responsible
	Product Planning Activities					
1	User observation	F-ID-001	-	-	R-ID-001	LG
2	Needs identification	F-ID-002	Word	-	R-ID-002	LG
3	Classification of user ability	F-ID-003	Excel	User Pyramid	R-ID-003	LG
4	Categorize user according to his disability grade	F-ID-004	Excel	Inclusive Design Cube	R-ID-004	LG
5	Generate product specifications	F-ID-005	Word	-	R-ID-005	LG
6	Products proposal	F-ID-006	Word	-	R-ID-006	LG
7	Evaluate products according to user capabilities	F-ID-007	Excel	Inclusive Design Cube	R-ID-007	LG
8	Product selection	F-ID-008	Excel	Pugh Tables	R-ID-008	LG
9	Product definition	F-ID-009	Word	-	R-ID-009	LG
10	Project planning	F-ID-010	Project	Gantt Diagram	R-ID-010	LG
11	Market analysis - Benchmarking	F-ID-011	Excel	Benchmarking – Parametric Analysis	R-ID-011	LG
12	Patent Analysis	F-ID-012	Internet	Patent Analysis	R-ID-012	LG
13	Identify market needs	F-ID-013	InfoPath	Interviews (questionnaires)	R-ID-013	LG
14	Technical requirements	F-ID-014	Qualisoft – Word	QFD	R-ID-014	LG
15	Technical characteristics of the product	F-ID-015	Excel	How's generated in the QFD	R-ID-015	LG
	Conceptual Design Activities					
16	Functional Decomposition	F-ID-017	PowerPoint	Functional Decomposition	R-ID-016	LG
17	Generation of concepts	F-ID-018	Matrix Word	Morphological Matrix	R-ID-017	LG
18	Select the concept	F-ID-019	Word	Morphological Matrix	R-ID-018	LG

4.2.1 Product Planning Activities

1. User Observation

Objective: To observe the user according to the appropriate approach, so the designer gets closer to user experience, in a way that will be possible to emphatically analyze his/her interaction with the environment.

During observation it must be described in details which are the main needs of the customer, and also what the customer wants according to his perception.

2. Need Identification

Objective: Determine those needs perceived from the customer that are possible to improve using the top-down, bottom-up or a combination of both approaches, according to the type of user.

Once the need is detected, it is labeled as an objective to achieve by the designer, this is, the name of the problem to be solved.

3. Classification of User Ability

Objective: Determine user ability according to the user pyramid and to its specifications of users with low functional capability, moderate functional capability or high functional capability.

This analysis and classification will help the designer to determine the complexity of the system to develop, to define the grade of flexibility that should be applied to the design.

4. Categorize the user according to his/her disability grade

Objective: Utilize the inclusive design cube to determine the capability of the user related to the following factors:

- Motion: Mobility in their extremities, strength and precision.
- Cognitive: Intellectual capacity.
- Sensory: Auditive and visual.

Based on this, it will be determined the kind of product that is going to be designed, according to the user capability classified as:

- Assisted by a person
- Special purpose design
- Modular / customizable design
- Used-centered design

According to this, the product could be configured in accordance to the variables required by the user; the design will be called flexible.

5. Generate Product Specifications

Objective: To establish the product functions and needs to be satisfied, including those functional, sensory, motion, cognitive and capability needs identified.

The characteristics that must have the product to achieve the design objective will be described. This will be a brief description about product functions to give a clear idea about what is to be fabricated to then generate a proposal of products.

6. Products Proposal

Objective: In proposing products to be developed, it will be presented a table where a brief description of each product has to be done.

In many cases it will not be a variety of products to choose from, but it will be proposed only one type of product (solution) for the problem identified previously. Based on one type of product different solution alternatives and modifications will be proposed.

7. Evaluate Products in accordance to user capabilities

Objective: Determine the type of users that are able to use the proposed products; the product will be analyzed using the inclusive design cube to evaluate its practical acceptability.

This is done with the aim of ruling out those products that do not comply with users' capabilities. That is why some of the options proposed will not have ease of use for users with certain functional impairments.

8. Product Selection

Objective: Select the product that better fulfill user specifications and motion, cognitive and sensory capabilities.

Briefly, it means that the product should be easy to use and intuitive for the user. This is, the customer should be able to use the product without reading a user's guide.

9. Product Definition

Objective: Describe product operation characteristics such as mechanical, electrical, electronic and interfaces properties. Also it must include the main function to be carried out by the product and other functions that it will be able to perform.

This definition will be the starting point for the functional decomposition of the product, which will be detailed later.

10. Project Planning

Objective: Generate a schedule of the project in a table where all the activities to be done, responsible for each activity, objectives and sequences are to be chronologically specified.
In the planning of the project it will be estimated the time to be consumed on each phase from product planning to prototype, this is, to consider the operation time for each of the activities per day.

11. Market Analysis

Objective: To look for a product similar to the one proposed to obtain the main characteristics to make a comparison and then propose modifications to the new product, and to avoid the non-acceptable characteristics.

This market analysis of similar products, also called Benchmarking, has to be done with the idea that the new product will be better than the others, even they have similar functions.

12. Parametric Analysis

Objective: Identify possible connections between parameters, considering the evaluated products. It is suggested to prepare graphs about the parameters which are in some way connected, but for doing this it is necessary to get information from competitor products for comparing with the new product and locate it showing its position in the market and identify opportunity areas to make it competitive.

13. Patent Analysis

Objective: Search for patents of similar products to avoid copying and to find new ideas to generate a more refined product.

There are many sources where to get relevant information related to patents worldwide, such as:

- http://www.uspto.gov Search for patents within the USA
- http://es.espacenet.com Search for patents among European countries
- http://www.impi.gob.mx Search for patents in México

14. Identify Market Needs

Objective: To know more characteristics that might be added to the product based on experience and knowledge of people with similar products.

This knowledge is obtained from questionnaires and interviews to experts (which apply a specific technology), technologists (producers and developers) and customers (distributors and end users)

15. Technical Requirements

Objective: Determine technical specifications from information gathered in the customer and experts interviews, competitive benchmarking and patent analysis.

A tool is used to determine the mentioned specifications, making a match between customer needs and the desired characteristics in the product with its technical requirements.

16. Technical Characteristics

Objective: Translate the technical characteristics of the product as permanent requirements of the product development; these will be the most important issues to be satisfied with the design.

Once the technical requirements were generated from the information obtained with the QFD, it will lead the path for defining the main specifications of the product, those that will achieve the customer expectations and needs, but in engineering terms.

4.2.2 Conceptual Design Activities

17. Functional Decomposition

Objective: Decompose the product into its main functions and sub-functions, in a way that the resultant model shows the relations between functional elements, making it easy to visualize and understand.

Creativity is enhanced by the ability to decompose problems and manipulate partial solutions. By first decomposing a design task into its functional elements, solutions to each element are more apparent due to the reduction of complexity.

18. Concept Alternatives

Objective: Propose solution alternatives for each product sub-function, using the morphological matrix tool.

In the morphological matrix options for each system sub-function will be described, from the functional decomposition, were improvements or simple modifications are going to be proposed without changing the product original integrity.

19. Concept Selection

Objective: Select the best configuration of the product evaluating the options for each function and physical characteristic of the product with the appropriate criteria.

The proposed solution has to be defined and it is necessary to explain why the other alternatives were discarded for future references.

4.3 Product Planning Activities

In this phase, the idea of the product that is going to be developed is established, for doing this it is necessary to get as much information as possible to be used on the conceptual design phase, and for these a set of formats is proposed.

The general objective of this phase is to propose a product which specifications satisfy the needs detected on observation of users, market analysis and technical requirements.

This methodology stresses the importance of users' opinion through the whole development of design process.
The mentioned formats have a classification that consists of six digits in the form **F-ID**-###, where: **F** refers to format, **ID** refers to Inclusive Design, and **###** the last three digits refer to the format number.

Next the formats proposed for each activity in the product development will be shown and described.

4.3.1 User Observation

Logo	**User Observation**	F-ID-001
Needs	Description	Difficulty Identified

Table 4.2 Format for User Observation activity

In the needs column the observed needs have to be written down, these might be related to motion, manual activity, grasping of objects, among others. These fields are open for designers to include any other activity that needs to be considered.

In the column labeled Description, each activity done bye the user has to be described in detail.

On the column of identified difficulties, the limitations of the user when interacting with the product will be described, and in case the user can not perform a determined activity it is necessary to specify the origin of that impairment.

4.3.2 Need Identification

Logo	**Need Identification**		F-ID-002
Difficulty	Type	Description	

Table 4.3 Format for Need Identification activity

Difficulty refers to the limitations to carry out a determined activity.
Type refers to the kind of difficulty identified; it can be classified as motion, cognitive and sensory.
On Description, observed details and other comments will be written down, and the difficulty identified will be labeled.

4.3.3. Classification of User Ability – User Pyramid

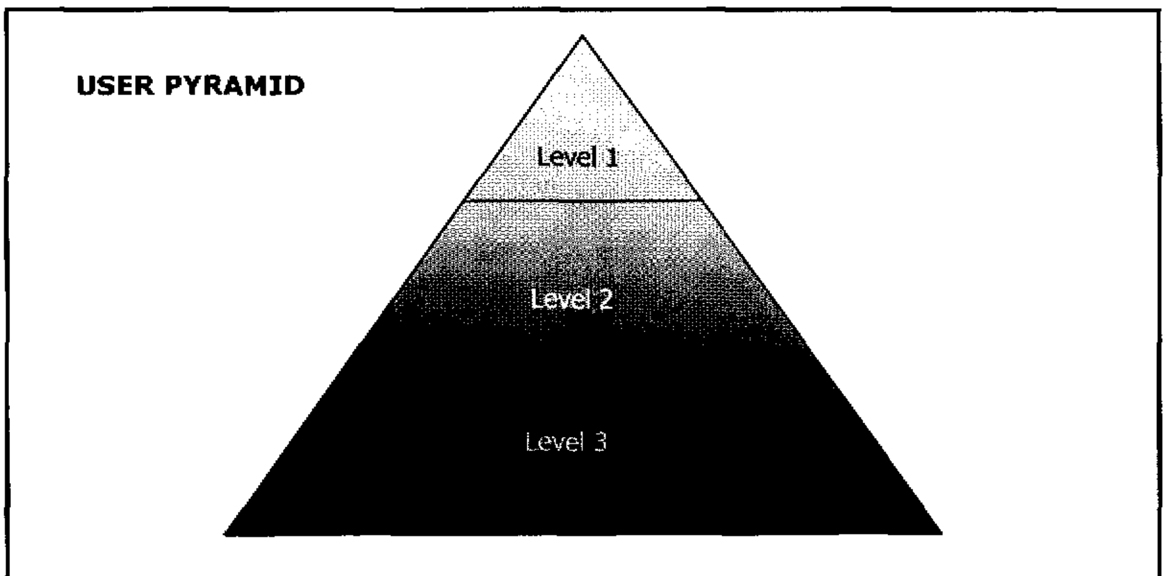


Figure 4.1 User Pyramid Scheme

On the level 1 people with the lowest capability (extreme users) and with more dependence will be included, such as people in wheelchairs or have a severe visual or auditive impairment.

On level 2 people with reduced strength or mobility caused by disease or age-related impairment that do not require to be assisted by carer.
On level 3 are included able-bodied or fully capable users together with elderly people who have minor disabilities like reduced strength and mobility, or impaired hearing or sight.

4.3.4. Categorize the user according to his/her disability grade

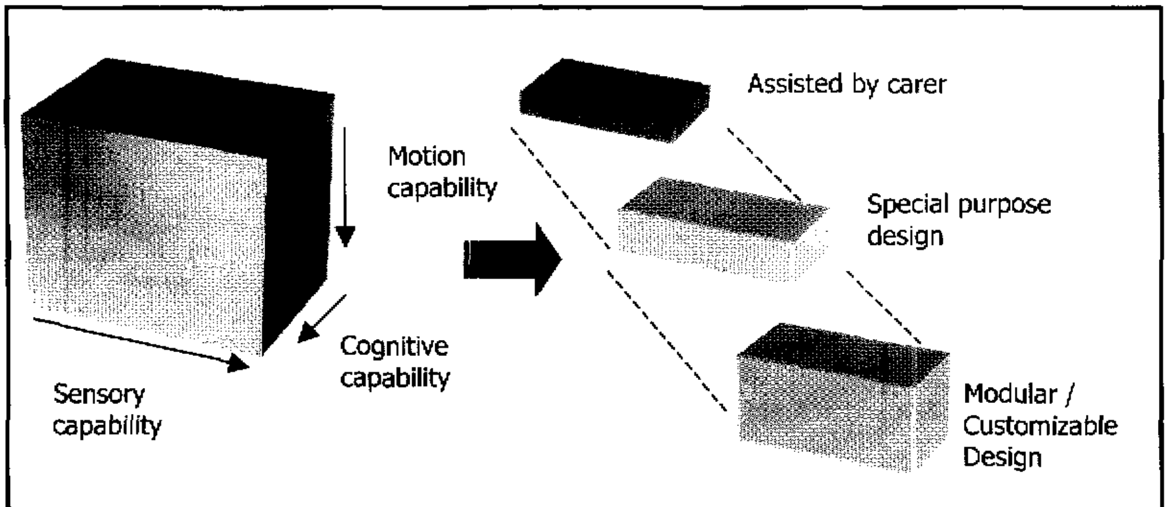


Figure 4.2 Inclusive Design Cube Scheme

Depending on user motion, sensory and cognitive capability, users will be cataloged as Assisted User, Special Purpose Design according to user needs, and Modular/Customizable Design conformed by different interchangeable or removable functions.

4.3.5. Generate Product Specifications

Logo	**Product Specifications**		F-ID-005
Function	Motion	Cognitive	Sensory

Table 4.4 Format for Product Specifications activity

In the column Function, a function to be performed by the product will be described, and if it corresponds to any of the abilities included in the Inclusive Design Cube, it has to be described in the appropriate field according to the grade of difficulty of product use.

4.3.6. Products Proposal

Logo	Products Proposal		F-ID-006
Product	Description	Image	

Table 4.5 Format for Products Proposal activity

On Product, the name of the proposed product will be stated.
The Description will be brief about the main function of the product and the need satisfied with it. On Image, a picture of the proposed product will be presented, in case of having one.

4.3.7. Evaluate Products in accordance to user capabilities

Logo	Product Evaluation using the Inclusive Design Cube		F-ID-007
Qualitative Axis	Product 1	Product 2	Product *n*
Strength and Coordination Capability			
Intellectual Capability			
Sensory Capability			
Type of Design			

Table 4.6 Format for Product Evaluation using the Inclusive Design Cube activity

Following annotations will be placed in the intersection of the qualitative axis row with each product column:

In the row related to Strength and Coordination: Void, Minimum, Minimum or Maximum Strength, Minimum or Maximum Coordination.

On the Intellectual Capability row: Void, Minimum, Medium, High.

And on Sensory Capability: Only visual, tactile or auditive perception, High, Medium or Low visual perception; High, Medium or Low auditive perception; High, Medium or Low tactile perception.

On the row of User Aware Design the corresponding type of design is selected according to the Inclusive Design Cube and its qualitative axis as Assisted User, Modular and Customizable, or Specific Purpose.

4.3.8. Product Selection

Logo	**Product Selection**			F-ID-008
		Product Ideas		
Criteria	Importance	Product 1	Product 2	Product *n*
Criterion 1				
Criterion 2				
Criterion 3				
Criterion 4				
Criterion 5				
Criterion 6				
	Total +			
	Total -			
	Sum			
	TOTAL			

Table 4.7 Format for Product Selection activity

With this format, the product alternatives are evaluated to select the most economically and technically feasible. At least five criteria are to be evaluated.

The Pugh table is a specialized tool for product concept evaluation to make a selection among several alternatives.

Examples of the criteria to evaluate can be:

- Ease of use
- Technology
- Antiquity
- Knowledge
- Popularity, among others.

On the fields in the column Importance a value is given in the range from 1 to 10, where 10 is the most important.

On the fields of the Products' columns a + (positive) sign has to be assigned for those options that satisfactory achieve the criterion, a 0 for neutral options or for those that do not apply, and a – (negative) sign for options below the stated criterion.

4.3.9. Product Definition

After the activity of product selection; it is required to give a detailed description of the product, including its main objectives, primary and secondary markets and all the assumptions made about the product.

The information that has to be defined in this activity is:

- Product Description
- Key Business Goals
- Primary Market
- Secondary Market
- Assumptions
- Stakeholders

The proposed format is:

Logo	**Product Definition**	F-ID-009
Name of Product		
Product Description		
Key Business Goals		
Primary Market		
Secondary Market		
Assumptions		
Stakeholders		

Table 4.8 Format for Product Definition activity

4.3.10 Project Planning

A schedule is to be stated (Gantt Diagram) to determine the scope of the project in accordance to available time. In this, the product development phases to be included are: Product Planning, Conceptual Design, Detailed Design and Prototype.

The format is:

Logo	**Product Definition**						F-ID-010
Name of Product		Time					
	Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week *n*...
Product Planning							
Conceptual Design							
Detailed Design							
Prototype							

Table 4.9 Format for Product Definition activity

4.3.11. Market Analysis– Competitive Benchmarking

Search for all available information about similar or analogous products. Gathered information will be related to technical parameters or product properties.

Information must be arranged in the following sections:

- General Function of Product
- Most important properties of the Product (at least five)
- Similar products or competence products
- Matrix Analysis
- Correlations
- References

Tool used: Parametric Analysis

The format is the next:

Logo	**Competitive Benchmarking**	F-ID-011

i. Describe general function of Product.

ii. Define the most important properties of the Product (at least five).

Property 1 ______
Property 2 ______
Property 3 ______
Property 4 ______
Property 5 ______
Property 6 ______
Property 7 ______
Property 8 ______
Property 9 ______
Property 10 ______

iii. Name of similar products or competence products:

Product 1 ______
Product 2 ______
Product 3 ______
Product 4 ______
Product 5 ______

iv. Matrix Analysis

	Product 1	Product 2	Product 3	Product 4	Product 5
Property 1					
Property 2					
Property 3					
Property 4					
Property 5					

v. Correlations

vi. Referentes

Table 4.10 Format for Competitive Benchmarking activity

4.3.12 Patent Analysis

<table>
<tr><td>Logo</td><td colspan="5">Patent Analysis</td><td>F-ID- 012</td></tr>
<tr><td>Title</td><td colspan="6"></td></tr>
<tr><td>Patent No.</td><td></td><td colspan="2">Date of registration</td><td></td><td>Date of Issue</td><td></td></tr>
<tr><td>Assignee</td><td colspan="3"></td><td>Inventors</td><td colspan="2"></td></tr>
<tr><td>Analyzer</td><td colspan="2"></td><td colspan="2">Date of Analysis</td><td colspan="2"></td></tr>
<tr><td colspan="7">Pages of interest:</td></tr>
<tr><td colspan="7">Functions:</td></tr>
<tr><td colspan="7">Results:</td></tr>
<tr><td colspan="7">Important Figures:</td></tr>
<tr><td colspan="7">Claims:</td></tr>
</table>

Table 4.11 Format for Patent Analysis activity

4.3.13 Identify Market Needs

Logo	**Market Needs Identification**	F-ID-013

Name of Product:			
Customer:		**Interviewer:**	
Address:		***Date:***	
Would you like to get information about the design process?			
User type:			
Question	**Customer Answer**	**Interpreted Need**	**Importance**
Typical Use			
What do you like?			
What do not you like?			
Suggested Improvements			

Table 4.12 Format for Market Needs Identification activity

4.3.14. QFD Quality Function Deployment

QFD is an evaluation tool for technical requirements, using the format the obtained information will be an importance value for each technical requirement ("How").

QFD is a format that shows the relations between customer requirements ("What's") and technical requirements ("How's"); each customer requirement is a 'what' that has to be satisfied by a technical requirement, 'how', which has to be tangible and is presented with its measure unity at the bottom of the diagram. At the top of the diagram the relation between technical requirements, 'which's' are presented as weak, medium or strong, positive or negative. The diagram also gives an evaluation for each competitor using information gathered from customer, and on the other hand by using technical information.

QFD format used for proposed products should be the next:

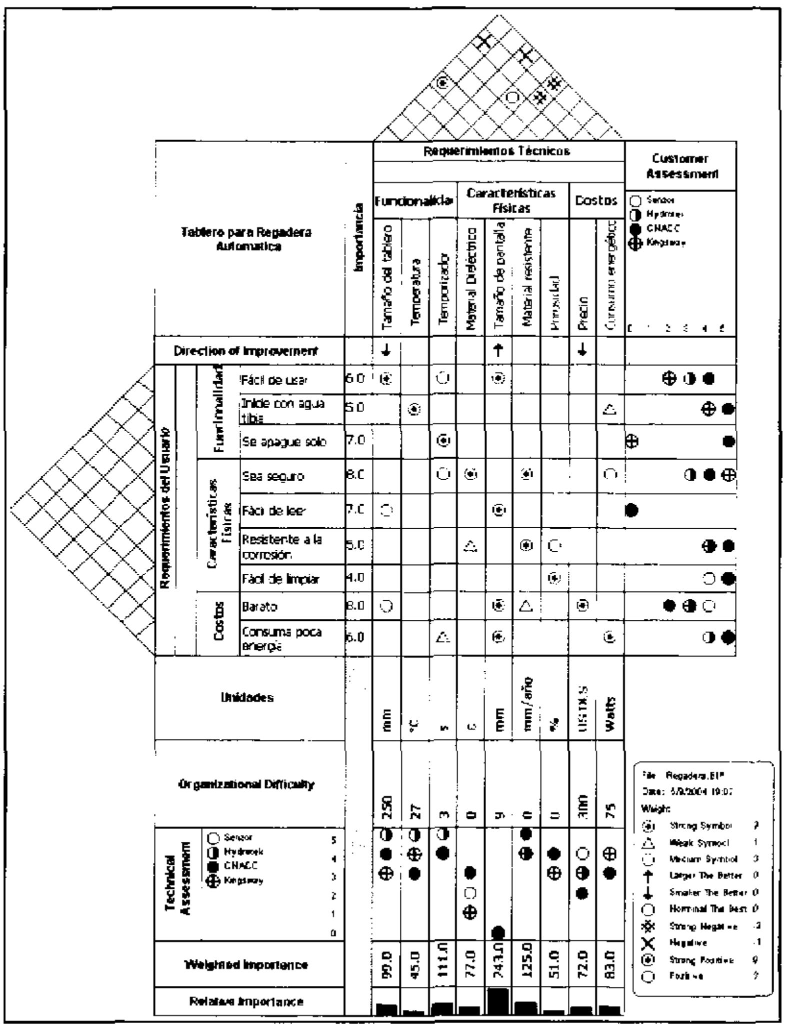


Figure 4.3 Format for Quality Function Deployment activity

This QFD diagram was obtained with the Qualisoft QFD Designer® software.

4.3.15 Technical Characteristics of the Product

Once the technical requirements were defined on the QFD, the objective values to be improved have to be stated on the following format.

Logo	**Technical Characteristics of the Product**	F-ID-015
Important Technical Requirement (How)	Objective Value	
Req. 1		
Req. 2		
Req. 3		
Req. 4		
Req. 5		

Table 4.13 Format for Technical Characteristics of the Product activity

4.4 Concept Design Activities

4.4.1 Functional Decomposition

To have a better visualization of the information gathered during the functional decomposition activity the proposed format is presented with the following arrangement:

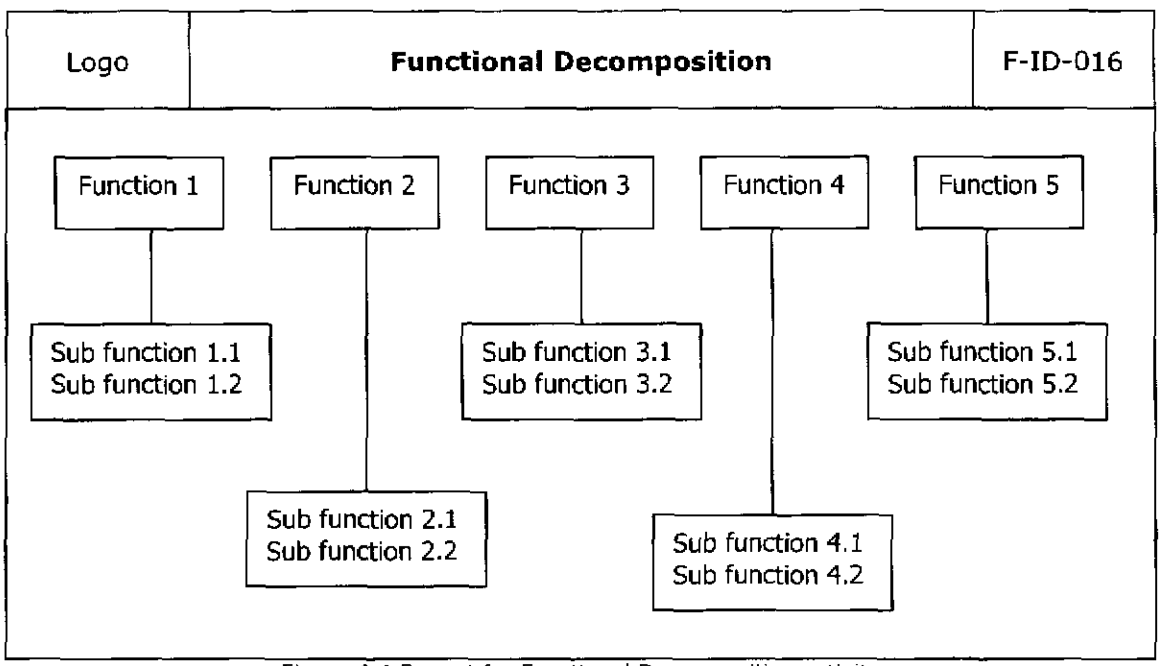


Figure 4.4 Format for Functional Decomposition activity

4.4.2 Concept Generation

This activity refers to the different morphologies that can be found for each function performed by a product, and from which the product might adopt the configuration that better contributes to achieve its specific objective.

Logo		**Morphological Matrix**				F-ID-017	
		Possible Solutions					
		Current Solution			**PATENTS**	**New Ideas**	
Function	**Sub-function**	**1**	**2**	**3**	**4**	**5**	**6**
1.0	1.1						
	1.2						
	1.3						
2.0	2.1						
	2.2						
3.0	3.1						
	3.2						

Table 4.14 Format for Concept Generation activity

4.4.3 Concept Selection

The best concept is selected based on a criterion applied to each possible solution, and with this procedure it is easier to make a more accurate selection of solutions for each product functions and sub-functions.

Logo		Morphological Matrix				F-ID-017	
		Possible Solutions					
		Current Solution			**PATENTS**	**New Ideas**	
Function	**Sub-function**	**1**	**2**	**3**	**4**	**5**	**6**
1.0	1.1			●			
	1.2		●				
	1.3					●	
2.0	2.1					●	
	2.2						●
3.0	3.1			●			
	3.2				●		

Table 4.15 Format for Concept Selection activity

4.5 PRODUCT DESIGN MODELS APPLYING INCLUSIVE DESIGN

The product design models proposed in the present research job are based on an inclusive design approach.

The proposed model is centered on the user as an issue to be considered along all the phases in the product design; this is that the user participates on each stage of the product development to evaluate the product characteristics and the proposed solutions.

Models for Product Planning and Conceptual Design phases are proposed as follows:

Figure 4.5 Model for mechatronic product design with inclusive design approach - Product Planning

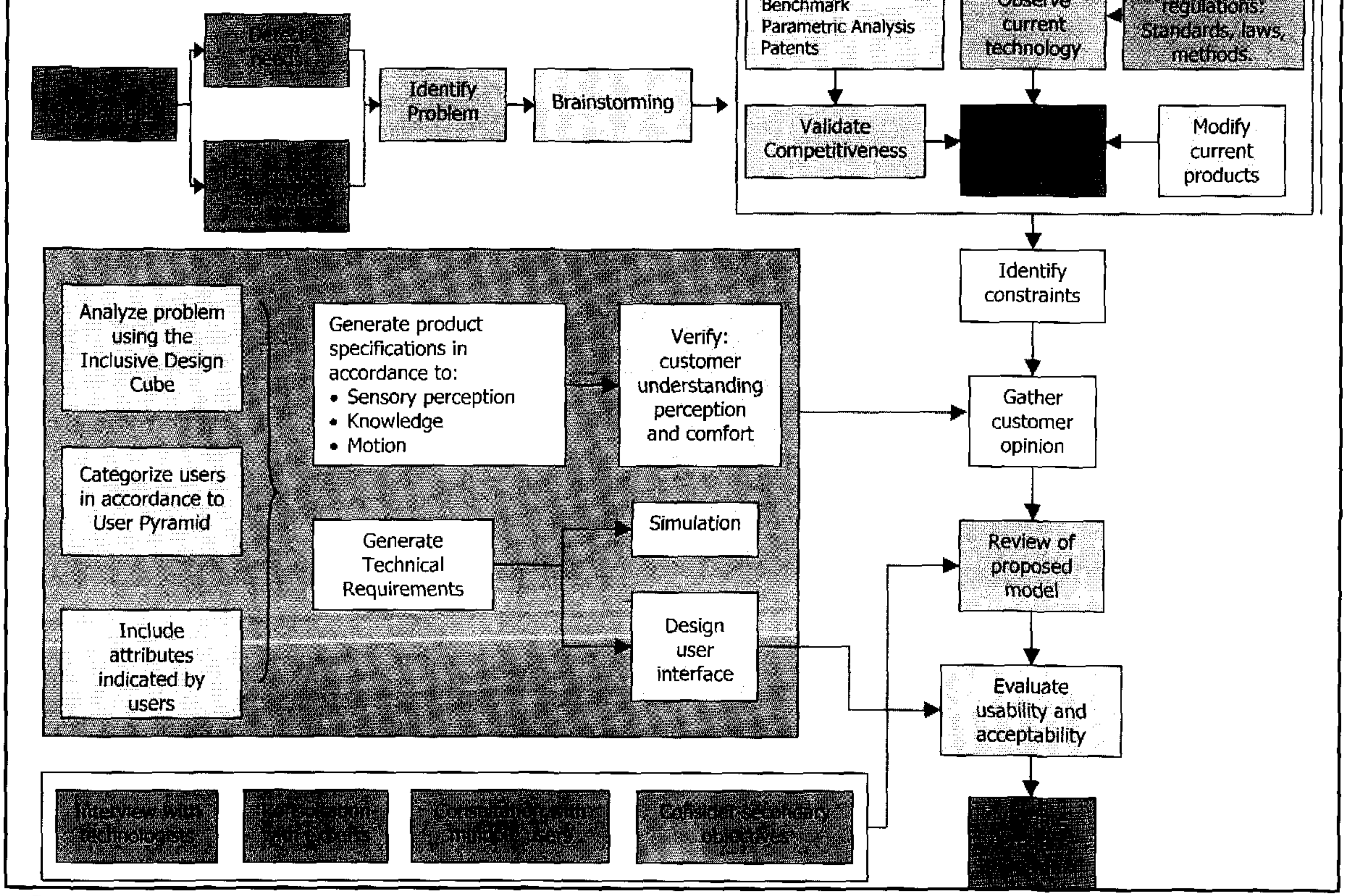
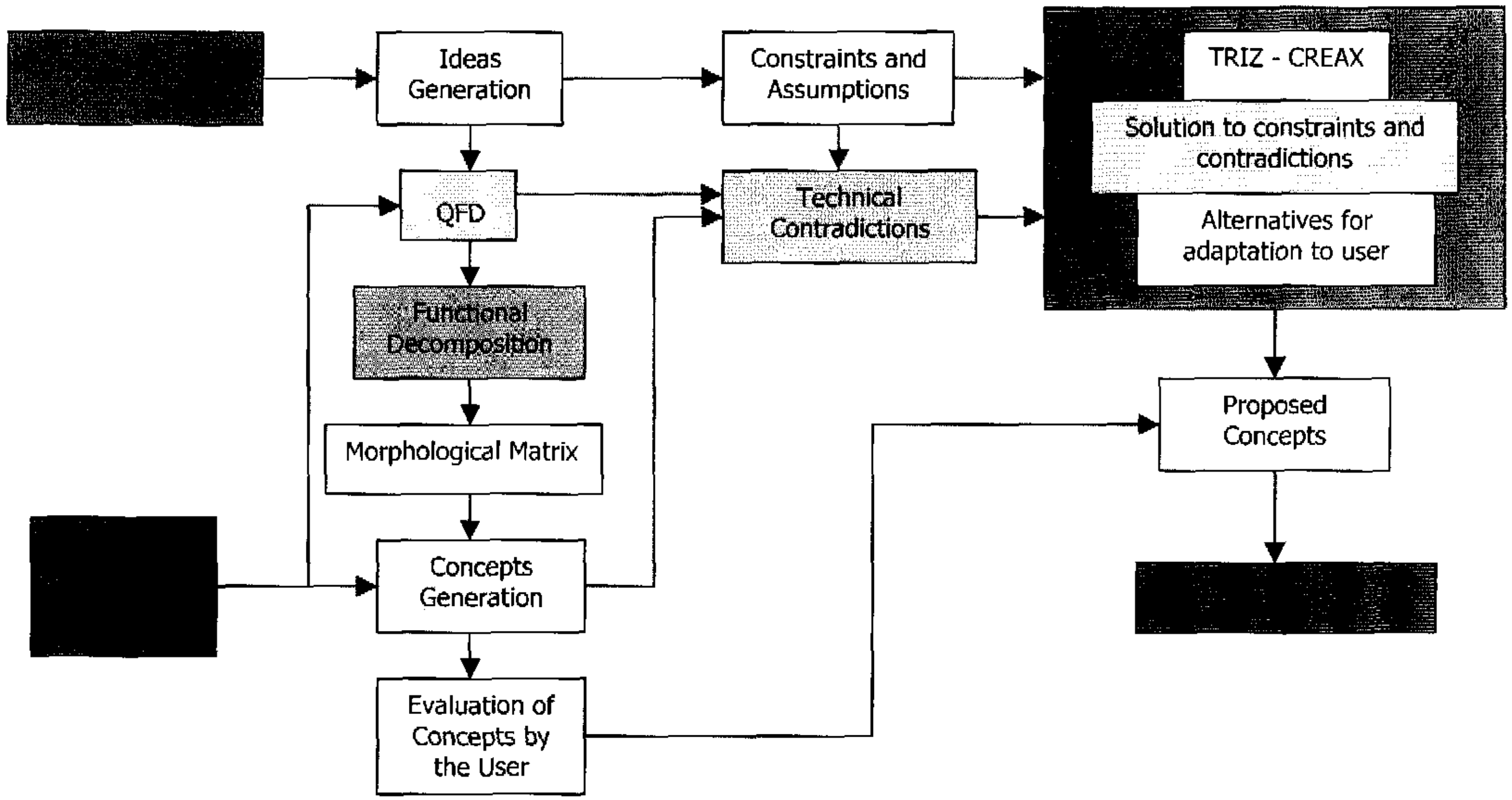


Figure 4.6 Model for Mechatronic Product Design with Inclusive Design Approach – Conceptual Design



Chapter 5: Case study for conceptual design of three products with inclusive design

5.1.1 Introduction

The present chapter describes the implementation of the proposed methodology for Inclusive Products Design.

Proposed products include a combination of two technologies, X10 and MOTES, described in Chapter II.

Only the X10 technology is available in the market with several products for home automation, but no one of them is designed to fulfill an inclusive design approach, but they are designed for fully capable users.

On the other hand, MOTES are not available yet, but they are being subjected to laboratory testing and research for different scientific areas. However, experimentation with MOTES has been carried out on home automation applications, reason for which they could be of great use on Inclusive Design products.

The proposed products are:

1. Automatic Shower Control Panel
2. Remote Control for Lights and Doors
3. Lights and Doors Control Sensors

The proposed methodology for the development of these products will follow a logical sequence of activities that will lead the designers to obtain satisfactory results on each stage of the design.

5.1.2 Phase of Product Planning

Activities of product planning are intended to lead designers to obtain a product definition, project planning and technical requirements for the product to be designed depending on what the customer wants.

Phase	No.	Activity	Format	Tool	Technique	Responsible
Product Planning	1	F-ID-001	-	-	R-ID-001	LG
	2	F-ID-002	Word	-	R-ID-002	LG
	3	F-ID-003	Excel	User Pyramid	R-ID-003	LG
	4	F-ID-004	Excel	Inclusive Design Cube	R-ID-004	LG
	5	F-ID-005	Word	-	R-ID-005	LG
	6	F-ID-006	Word	-	R-ID-006	LG
	7	F-ID-007	Excel	Inclusive Design Cube	R-ID-007	LG
	8	F-ID-008	Excel	Pugh Tables	R-ID-008	LG
	9	F-ID-009	Word	-	R-ID-009	LG
	10	F-ID-010	Project	Gantt Diagram	R-ID-010	LG
	11	F-ID-011	Excel	Benchmarking – Parametric Analysis	R-ID-011	LG
	12	F-ID-012	Internet	Patent Analysis	R-ID-012	LG
	13	F-ID-013	InfoPath	Interviews (questionnaires)	R-ID-013	LG
	14	F-ID-014	Qualisoft –Word	QFD	R-ID-014	LG
	15	F-ID-015	Excel	How's generated with the QFD	R-ID-015	LG

Table 5.1 Format that defines the activities, techniques, tools and formats stated for product planning.

Next, each activity in the product planning phase is developed in accordance with the product to be developed.

Product 1
5.2 Automatic Shower Control Panel

1. User Observation

Objective: To observe the user according to the appropriate approach, so the designer gets closer to user experience, in a way that will be possible to emphatically analyze his/her interaction with the environment.

Logo	**User Observation**	F-ID-001
Needs	Description	Difficulty Identified
Control water temperature	Combine cold and hot water from both faucets to get warm water	Calculate adequate temperature in accordance to handles position
Control pressure	Control faucets opening moving both handles	Increase pressure keeping desired temperature
Open faucets	Open hot and cold water faucets for water outlet	Turn handles

Table 5.2 Format for User Observation applied to Automatic Shower Control Panel product.

2. Need Identification

Objective: Determine those needs perceived from the customer that are possible to improve using the top-down, bottom-up or a combination of both approaches, according to the type of user.

Logo	**Need Identification**	F-ID-002
Difficulty	Type	Description
Calculate adequate temperature in accordance to handles position	Sensory Motion	User has to regulate the temperature by gradually turning the handles. It is difficult to have an exact control of temperature while turning the handles. Due to this, an automatic control for temperature is required
Increase pressure keeping desired temperature	Sensory	Pressure has to be increased or diminished without changing the temperature, which indicates synchronization in the turning of both handles.
Turn handles	Motion	Movement of handles can be substituted by the use of buttons to regulate water temperature and pressure.

Table 5.3 Format for Need Identification applied to Automatic Shower Control Panel product.

3. Classification of User Ability – User Pyramid

Objective: Determine user ability according to the user pyramid and to its specifications of users with low functional capability, moderate functional capability or high functional capability.

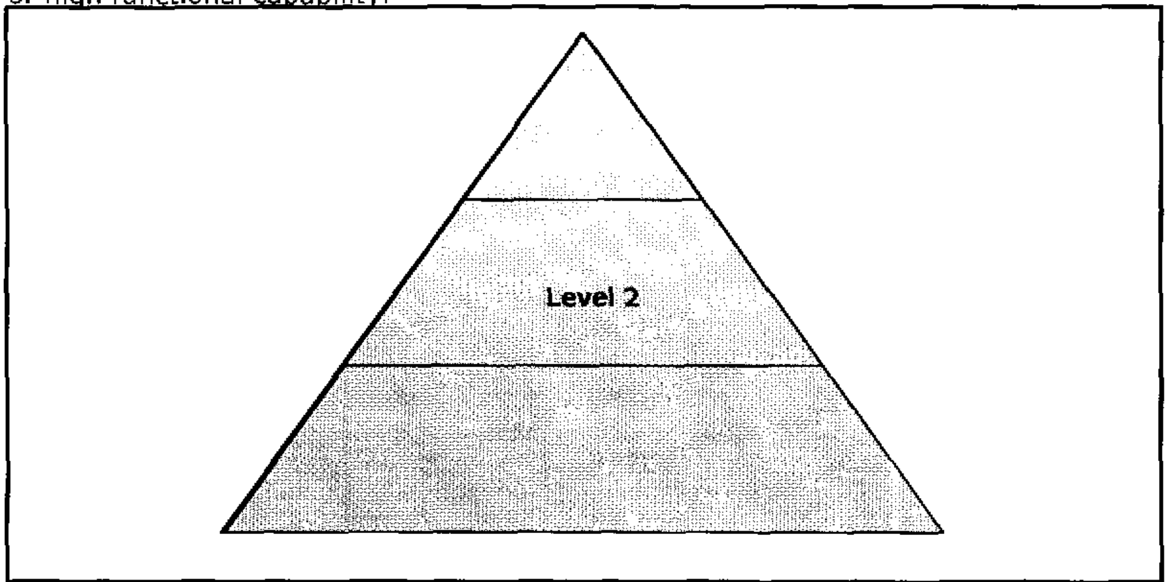


Figure 5.1 User Pyramid applied to Automatic Shower Control Panel product.

4. Categorize the user according to his/her disability grade

Objective: Utilize the inclusive design cube to determine the capability of the user related to the following factors:

- Motion: Movement of extremities, strength and precision.
- Cognitive: Intellectual capability.
- Sensory: Auditive and visual.

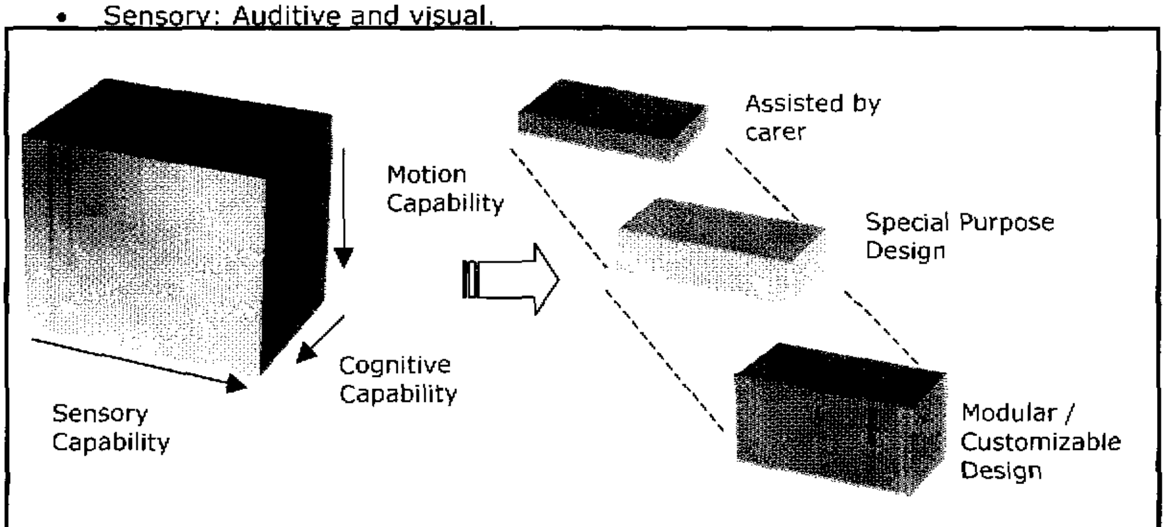


Figure 5.2 Inclusive Design Cube evaluation applied to Automatic Shower Control Panel product.

Low Motion Capability
Low Sensory Capability
Low Cognitive Capability
} Special Purpose Design

5. Generate Product Specifications

Objective: To establish the product functions and needs to be satisfied, including those functional, sensory, motion, cognitive and capability needs identified.

Logo	**Product Specifications**		F-ID-005
Function	Motion	Cognitive	Sensory
Regulate temperature	-	Show a water temperature display (temperature, blue / red color, etc.)	Will assure that the user will not feel changes on temperature
Regulate pressure	-	Show a water pressure display (a drawing with the different faucet outlet sizes)	Control panel will adjust the pressure level without changing temperature
Open / Close faucets	Will avoid wrist twisting over the handles	Will avoid that user confuse the handles	-

Table 5.4 Format for Product Specification applied to Automatic Shower Control Panel product.

6. Products Proposal

Objective: In proposing products to be developed, it will be presented a table where a brief description of each product has to be done.

Logo	**Products Proposal**	F-ID-006
Product	Description	Image
Control Panel	Automatic Temperature Control Panel embedded in frontal or lateral wall of the shower, it will have solenoid valves in the system to regulate water flow.	Not available
Sensor for Water Control	A sensor embedded in the wall will turn on the water and pressure on a predetermined mode.	Not available

Table 5.5 Format for Products Proposal applied to Automatic Shower Control Panel product.

7. Evaluate Products in accordance to user capabilities

Objective: Determine the type of users that are able to use the proposed products; the product will be analyzed using the inclusive design cube to evaluate its practical acceptability.

Logo	**Product Evaluation using the Inclusive Design Cube**		F-ID-007
Qualitative Axis	Control Panel	Water Providing Sensor	-
Strength and Coordination Capability	Minimum	**Null**	-
Intellectual Capability	Minimum	Null	-
Sensory Capability	Low Visual and Tactile Perception	Low Visual and Tactile Perception	-
Design Type	Specific Purpose	Assisted by carer	-

Table 5.6 Format for Product Evaluation using the Inclusive Design Cube applied to Automatic Shower Control Panel product.

8. Product Selection

Objective: Select the product that better fulfill user specifications and motion, cognitive and sensory capabilities.

Logo	**Product Selection**			F-ID-008
		Product Ideas		
Criteria	Importance	Control Panel	Water Providing Sensor	-
Ease of Use	10	0	+	-
Safe	10	-	-	-
Technology	6	+	0	-
Modernity	7	+	-	-
Flexible	9	+	-	-
Appearance	7	+	0	-
	Total +	4	1	-
	Total -	-1	-3	-
	Sum	3	-2	-
	TOTAL	23	-16	-

Table 5.7 Format for Product Selection applied to Automatic Shower Control Panel product.

9. Product Definition

Objective: Describe product operation characteristics such as mechanical, electrical, electronic and interfaces properties. Also it must include the main function to be carried out by the product and other functions that it will be able to perform.

Logo	**Product Definition**	F-ID-009
Shower Temperature and Pressure Control Panel		
Product Description	Electronic control panel to facilitate water temperature and pressure through a digital display and by graduated buttons.	
Key Business Goals	Prototype presentation on October 2004 Product launching on January 2005 Substitute conventional systems for showers Approximate product cost: $300 USD	
Primary Market	Handicapped population. Old people. People with arthritis.	
Secondary Market	Dressing rooms at universities or sporting installations. Homes, as a comfort device. Companies that sales bathroom accessories. Hotels.	
Assumptions	The control panel is designed for people with motion impairments. The control panel is safe against electrical shocks. It is easy to handle. Does not require maintenance, only cleaning.	
Stakeholders	People with reduced strength and mobility in arms and hands. People in wheelchairs. Nurses who assist people with impairments due to age. People who wants comfort.	

Table 5.8 Format for Product Definition applied to Automatic Shower Control Panel product.

10. Project Planning

Objective: Generate a schedule of the project in a table where all the activities to be done, responsible for each activity, objectives and sequences are to be chronologically specified.

Logo	**Project Planning**						F-ID-010
Name of Product		Tiempo					
	Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week n ....
Product Planning		To define	To define	To define	To define	To define	To define
Conceptual Design		To define	To define	To define	To define	To define	To define
Detailed Design		To define	To define	To define	To define	To define	To define
Prototype		To define	To define	To define	To define	To define	To define

Table 5.9 Format for Project Planning applied to Automatic Shower Control Panel product.

11. Market Analysis – Competitive Benchmarking

Logo	**Benchmarking**	F-ID-011

a. Describe general function of Product.

Temperature and Pressure Control Panel for automatic shower

b. Define the most important properties of the Product (at least five).

Property 1	Price
Property 2	On / Off Function
Property 3	Button for temperature control
Property 4	Optoelectronic Presence Sensor
Property 5	Indicator of person presence
Property 6	Display with indicators for pressure and temperature
Property 7	Pressure Control
Property 8	Thermostat
Property 9	Water saver
Property 10	Stainless
Property 11	Easy to clean, smooth surface
Property 12	Button for pressure of water outlet selection
Property 13	Use of batteries and electric current
Property 14	Activation with hands movements
Property 15	Records of temperature and pressure combinations
Property 15	Minimum number of buttons

c. Name similar products or competence products:

Product 1	Senzor - Saba 1 TLB
Product 2	Hydrotek - H9000C
Product 3	CNACC - YD-450
Product 4	Kingsway Technology - Ku-620
Product 5	

Table 5.10 Format for Competitive Benchmarking applied to Automatic Shower Control Panel product.

d. Matrix Analysis

	Saba 1 - TLB	Hydrotek H9000C	CNACC YD-450	Kingsway Tech. Ku-620
Price	N/A	N/A	N/A	N/A
On / Off Function	YES	YES	YES	YES
Button for temperature control	NO	NO	NO	NO
Optoelectronic Presence Sensor	YES	YES	YES	NO
Indicator of person presence	YES	NO	NO	NO
Display with indicators for pressure and temperature	NO	NO	NO	NO
Pressure Control	NO	NO	NO	NO
Thermostat	YES	NO	NO	NO
Water saver	YES	YES	YES	NO
Stainless	YES	YES	YES	YES
Easy to clean, smooth surface	YES	YES	YES	YES
Button for pressure of water outlet selection	NO	NO	NO	NO
Use of batteries and electric current	YES	YES	Elect. Current	Battery
Activation with hands movements	YES	NO	NO	YES
Records of temperature and pressure combinations	NO	NO	NO	NO
Minimum number of buttons	N/A	N/A	N/A	N/A

Table 5.11 Format for Matrix Analysis applied to Automatic Shower Control Panel product.

e. Correlations.

It is not possible to generate any correlations due there is no information about the price of the product, but it is possible to detect characteristics that are missing in the analyzed products in comparison with the proposed product.

12. Patent Analysis

Objective: Search for patents of similar products to avoid copying and to find new ideas to generate a more refined product.

Logo	**Patent Analysis**				F-ID-012
Title					
Patent No.		**Date of Registration**		**Date of Issue**	
Assignee			**Inventors**		
Analyzer		**Date of Analysis**			
Pages of interest:					
Functions:					
Results:					
Important Figures:					
Claims:					

Table 5.12 Format for Patent Analysis applied to Automatic Shower Control Panel product.

13. Identify Market Needs

Objective: To know more characteristics that might be added to the product based on experience and knowledge of people with similar products.

Logo	**Market Needs Identification**		F-ID-013
Name of Product: Water Temperature and Pressure Panel Control for Shower			
Customer: Casa Hogar Ma. Esperanza Nuestra		**Interviewer**: Guízar, Luis.	
Address: Av. Luis Elizondo #402. Col Altavista, Monterrey, N.L.		**Date**: April 12, 2004	
Would you like to keep informed about the process? Yes			
User type: Old people and people who assists them			
Question	**Customer Answer**	**Interpreted Need**	**Importance**
Do you find it useful?	Yes, is a product that makes easier showering old people	It is a product that will be useful to old people carers.	8
What do you like?	Ease of use	That simplifies the activity of showering the user. Diminishes activity time.	10
What do not you like?	That it might be dangerous	Users think that it is dangerous because of the combination of water and electricity.	10
Suggested Improvements	None	-	

Table 5.13 Format for Market Needs Identification applied to Automatic Shower Control Panel product.

14. QFD Quality Function Deployment

Objective: Determine technical characteristics form customer requirements.

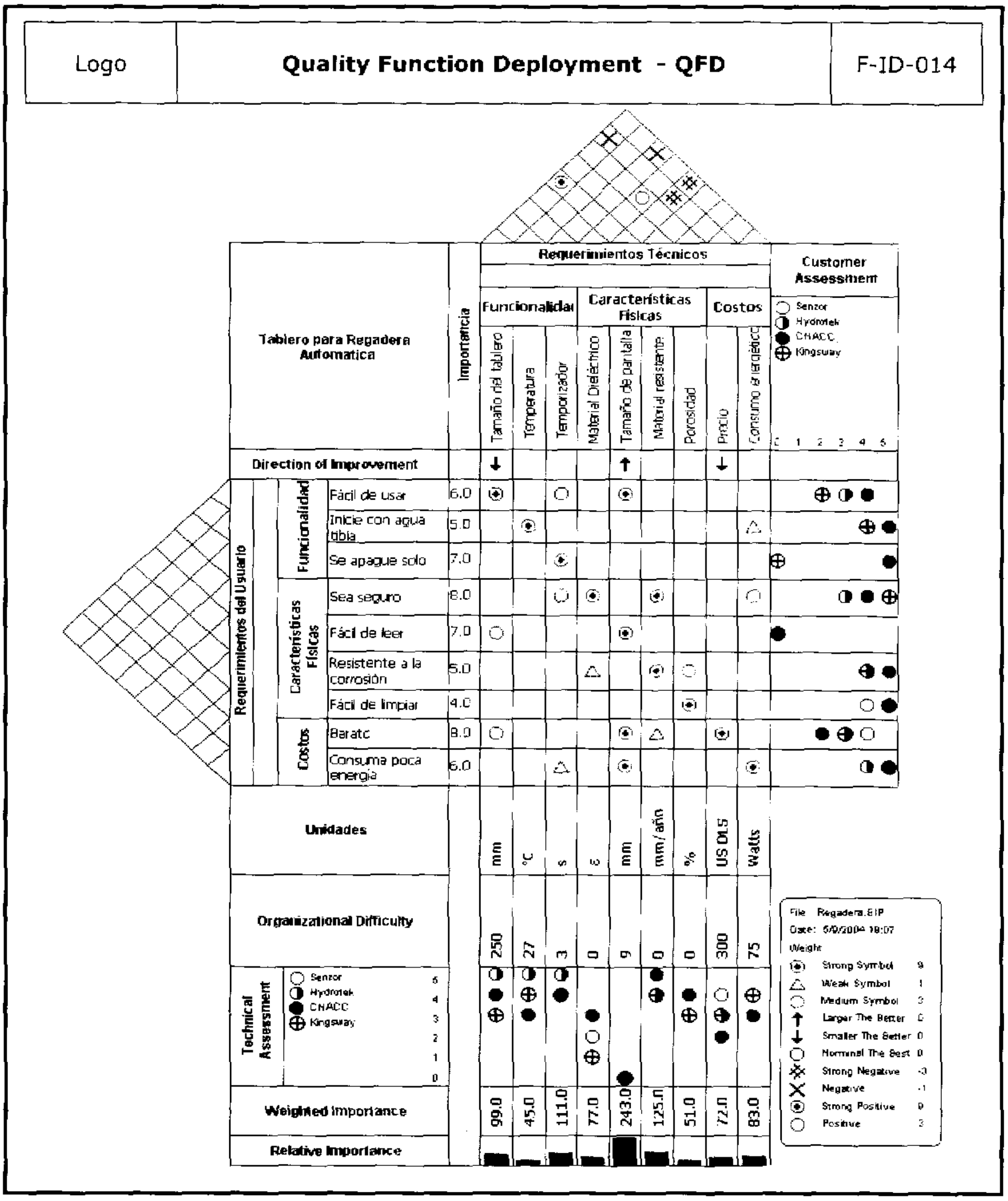


Table 5.14 Format for QFD applied to Automatic Shower Control Panel product.

15. Technical Characteristics of the Product

Objective: Translate the technical characteristics of the product as permanent requirements of the product development; these will be the most important issues to be satisfied with the design.

Logo	**Technical Characteristics of the Product**	F-ID-015
Important Technical Requirement (How)	Objective Value	
Control Panel Dimensions (mm)	250 x 200 x 30	
Display Dimensions (mm)	120 x 90	
Price	USD $300	

Table 5.15 Format for Technical Characteristics applied to Automatic Shower Control Panel product.

16. Functional Decomposition

Objective: Decompose the product into its main functions and sub-functions, in a way that the resultant model shows the relations between functional elements, making it easy to visualize and understand.

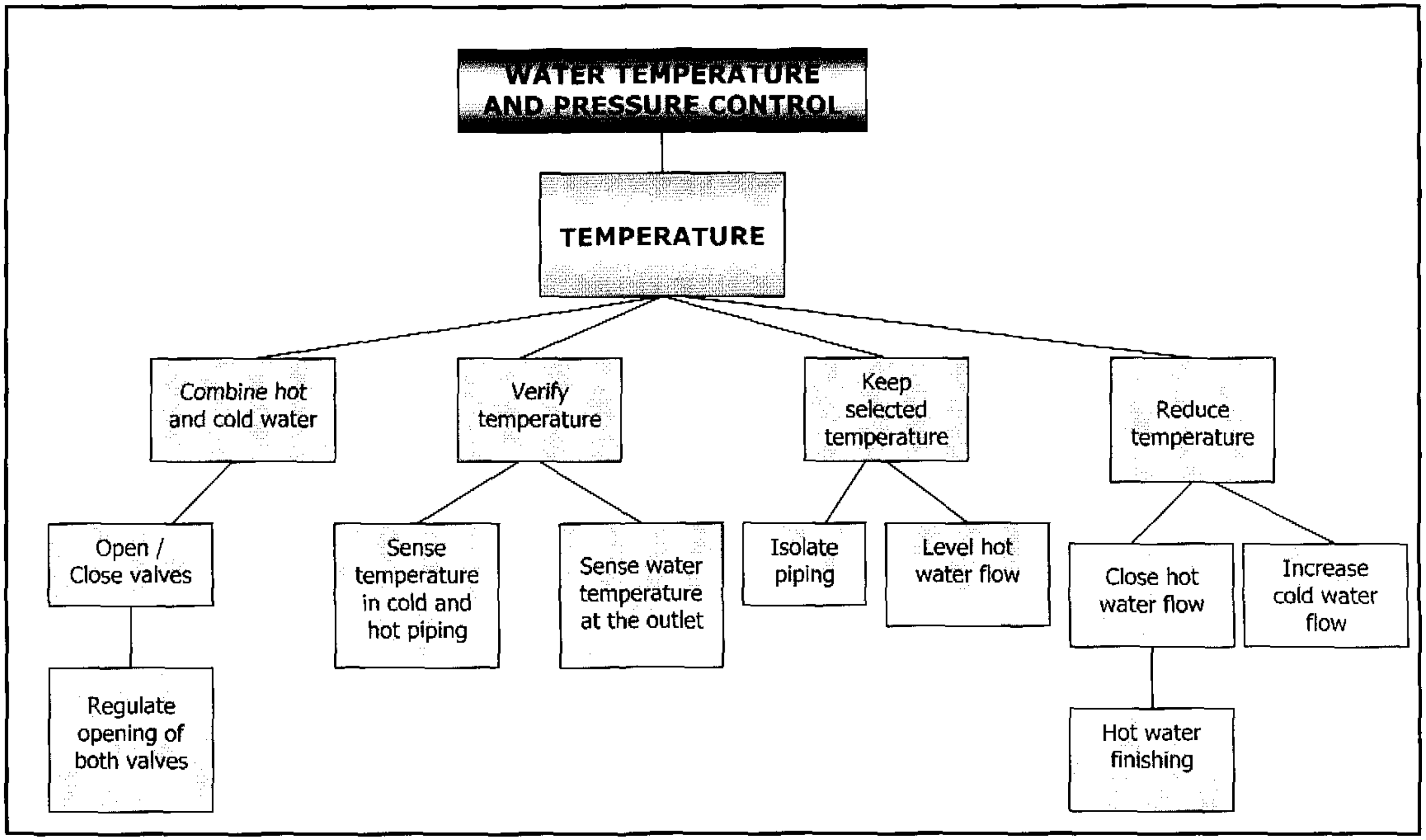


Figure 5.3 (a) Format for Functional Decomposition applied to Automatic Shower Control Panel product.

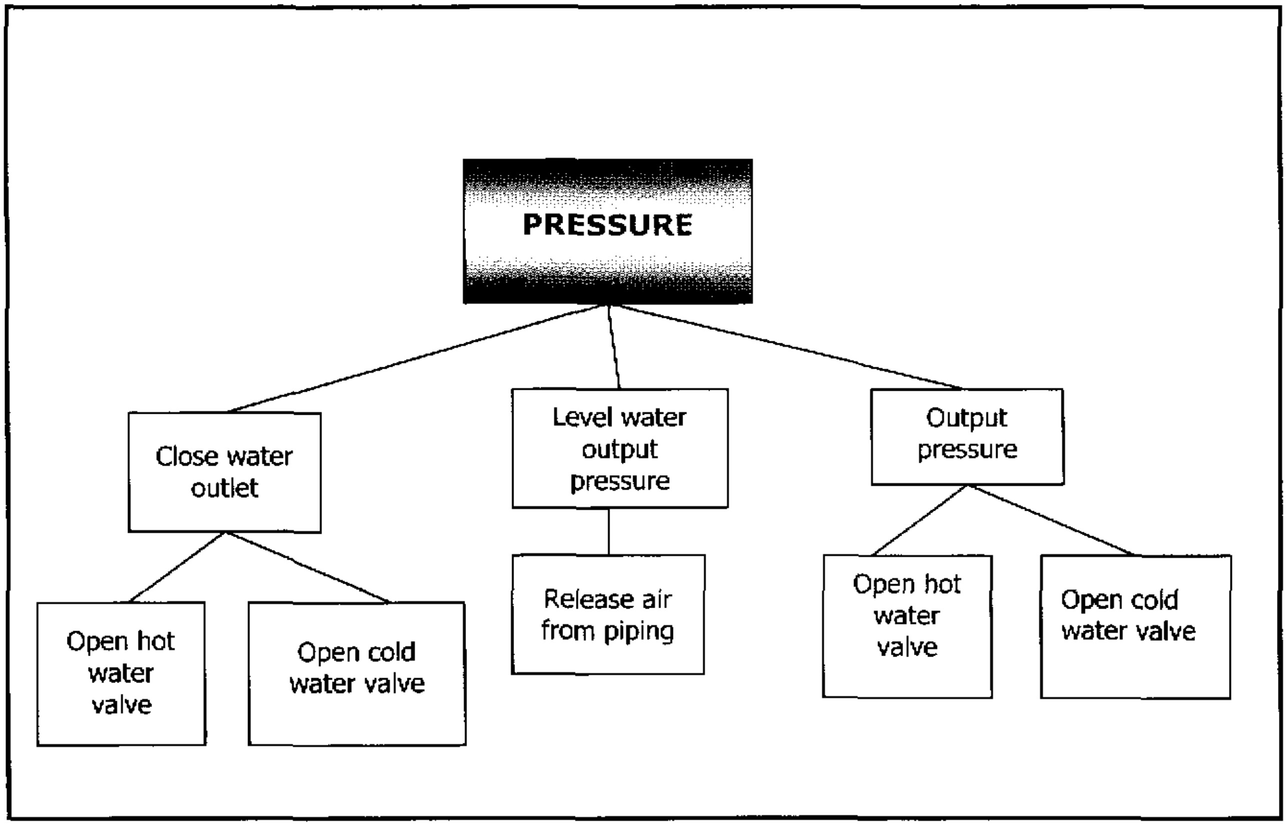


Figure 5.3 (b) Format for Functional Decomposition applied to Automatic Shower Control Panel product.

18. Concept Generation

Objective: Propose solution alternatives for each product sub-function, using the morphological matrix tool.

Function	Sub-function	Option 1	Option 2	Option 4	Option 3
Regulate Pressure (2)	Close water outlet (1)	Close hot and cold water valves	Put a central feed valve before the faucet	Close nozzle with a flood-gate	
	Level pressure of faucet (2)	Free air from pipelines	Put pump to maintain pressure in both pipelines	Open both valves simultaneousl y	Have a deposit with hot and cold water at the top of the installation.
	Output Pressure (3)	Put an asperser with different types of faucets.	Reduce diameter of outlet pipe	Hydro pneumatic system for water feeding to the system	

Table 5.16 Format for Concept Generation applied to Automatic Shower Control Panel product.

19. Concept Selection

Objective: Select the best configuration of the product evaluating the options for each function and physical characteristic of the product with the appropriate criteria.

Selection can be done directly from the morphological matrix pointing out the selected options with a line.

REGULATE TEMPERATURE

1. Combine cold and hot water	2. Verify Temperature	3. Keep indicated temperature	4. Decrease temperature
1.1.1 ; 1.1.2	1.2.5	1.3.3	1.4.1 ; 1.4.3

REGULATE PRESSURE

1. Close water outlet	2. Level pressure of faucet	3. Output pressure
2.1.2	2.2.3	2.3.3

Table 5.17 Format for Concept Selection applied to Automatic Shower Control Panel product.

Product 2
5.3 Kit for Lights and Doors Control

1. User Observation

Objective: To observe the user according to the appropriate approach, so the designer gets closer to user experience, in a way that will be possible to emphatically analyze his/her interaction with the environment.

Logo	User Observation	F-ID-001
Needs	Description	Difficulty Identified
Turn on and off lights	User wants to turn off or turn on the lights in accordance to his/her location in a determined installation.	To reach the light switches. Distance of displacement to control lights from the switch.
Open / Close Doors	Open and close doors according to the path described by the user in a specified installation.	Push or pull door, turn handles.
Lock doors	Lock the doors where privacy is required, besides the doors that are access from outside the building.	Use keys, turn a lock, push locking button.

Table 5.18 Format for User Observation applied to Kit for Lights and Doors Control product.

2. Need Identification

Objective: Determine those needs perceived from the customer that are possible to improve using the top-down, bottom-up or a combination of both approaches, according to the type of user.

Logo	Need Identification	F-ID-002
Difficulty	Type	Description
Reach light switches. Displacement to control the lights.	Motion / Sensory (visual impairment)	Reach light switches is difficult for people in wheelchairs, paraplegics, and others who have any impairment on their upper extremities. Distance for displacement is an obstacle for people who have any difficulty for walking. This indicates that it is necessary to apply a method on a remote control basis.
Push or pull door, turn handles.	Motion	Moving hands or the extension of arms to push or pull a door can be difficult or even impossible for some people. It is required a system that opens and closes the door displacing it from the axis formed by the hinges. Also there is a need of help to pull the door once the user goes through it.
Use keys, turn a lock, push locking button.	Motion	This implies the movement of hands and arms for turning or for applying a pressure over the fingers.

Table 5.19 Format for Need Identification applied to Kit for Lights and Doors Control product.

3. Classification of User Ability – User Pyramid

Objective: Determine user ability according to the user pyramid and to its specifications of users with low functional capability, moderate functional capability or high functional capability.

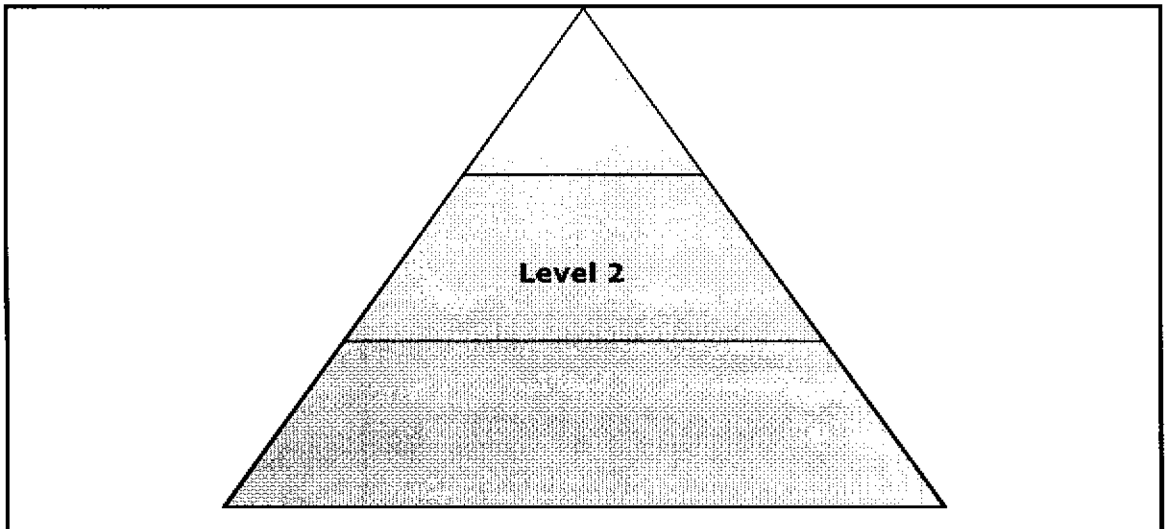


Figure 5.4 User Pyramid applied to Kit for Lights and Doors Control product.

4. Categorize the user according to his/her disability grade

Objective: Utilize the inclusive design cube to determine the capability of the user related to the following factors:

- Motion: Movement of extremities, strength and precision.
- Cognitive: Intellectual capability.
- Sensory: Auditive and visual.

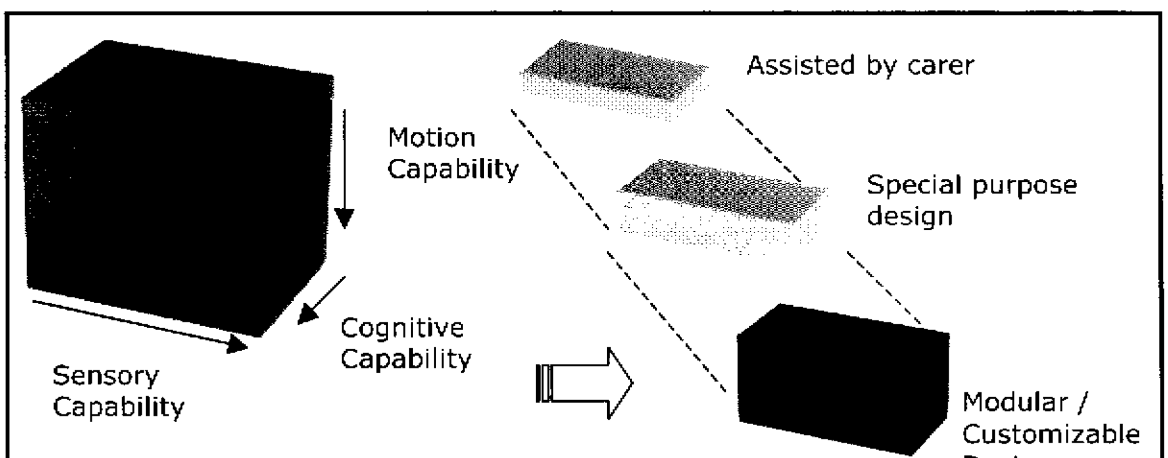


Figure 5.5 Inclusive Design Cube evaluation applied to Kit for Lights and Doors Control product.

Low Motion Capability
Low Sensory Capability
Normal Cognitive Capability } Modular / Customizable Design

Design of this product is flexible to be configured according to the user requirements and needs, and also allows increasing the number of devices installed.

5. Generate Product Specifications

Objective: To establish the product functions and needs to be satisfied, including those functional, sensory, motion, cognitive and capability needs identified.

Logo	**Product Specifications**		F-ID-005
Function	Motion	Cognitive	Sensory
Turn ON / OFF lights	Avoid movement of arms and hands to use the switches.	-	Will help users to turn on/off lights by indicating the location of the light source.
Open / Close Doors	Avoid the effort of displacing and moving upper extremities to perform these actions.	-	Will ensure to the user that the doors are closed.
Lock Doors	Avoid the user from going back to lock doors.	-	Will ensure to the user that the doors are locked.

Table 5.20 Format for Product Specifications applied to Kit for Lights and Doors Control product.

6. Products Proposal

Objective: In proposing products to be developed, it will be presented a table where a brief description of each product has to be done.

Logo	**Products Proposal**	F-ID-006
Product	Description	Image
Remote Control for Doors and Lights	Remote Control for turn on/off lights and to control opening/closing/locking of doors with status indicators for each device controlled. The kit will include timers, pistons for doors, presence sensors, X10 modules, transceivers and other electronic devices. It will use X10 wired and wireless signal.	Image not available
Wire Main Control for Lights and Doors	A control embedded in the wall that will control the turning on/off of lights, as the locking/opening and closing of doors. It needs pistons for doors, transceivers, and receivers. It will work through internal wiring.	Image not available

Table 5.21 Format for Products Proposal applied to Kit for Lights and Doors Control product.

7. Evaluate Products in accordance to user capabilities

Objective: Determine the type of users that are able to use the proposed products; the product will be analyzed using the inclusive design cube to evaluate its practical acceptability.

Logo	**Product Evaluation using the Inclusive Design Cube**		F-ID-007
Qualitative Axis	*Remote Control*	*Main Control*	-
Strength and Coordination Capability	Very Minimum	Minimum	-
Intellectual Capability	Minimum	Minimum	-
Sensory Capability	Visual y tactile minimum	Visual y tactile minimum	-
Type of Design	Modular / Customizable	Modular / Customizable	-

Table 5.22 Format for Product Evaluation using Inclusive Design Cube applied to Kit for Lights and Doors Control product.

8. Product Selection

Objective: Select the product that better fulfill user specifications and motion, cognitive and sensory capabilities.

Logo	**Product Selection**			F-ID-008
		Ideas de Producto		
Criteria	Importance	Remote Control	Main Control	-
Ease of use	10	+	0	-
Safe	9	+	+	-
Technology	5	+	-	-
Modernity	6	+	+	-
Flexible	9	+	-	-
Appearance	8	+	+	-
	Total +	6	3	-
	Total -	0	-2	-
	Sum	6	1	-
	TOTAL	47	23	-

Table 5.23 Format for Product Selection applied to Kit for Lights and Doors Control product.

9. Product Definition

Objective: Describe product operation characteristics such as mechanical, electrical, electronic and interfaces properties. Also it must include the main function to be carried out by the product and other functions that it will be able to perform.

Logo	**Product Definition**	F-ID-009
Remote Control Kit, transmitter-receiver and piston for controlling illumination and doors opening		
Product Description	Kit for turning on/off lights and opening doors using a remote control, transceivers and pistons.	
Key Business Goals	Prototype presentation on November 2004 Launching of product on January 2005 Facilitar el acceso de las personas en el interior de una instalación Approximate cost of product: Control USD $70, two transceivers USD $50 and pneumatic piston USD $280.	
Primary Market	People in wheelchairs Blind people Third age people	
Secondary Market	People who want to install it at their homes for comfort. Companies that sales illumination equipment. People who want to install it at their offices. Control lights and doors for safety at educative installations, public buildings, etc.	
Assumptions	The control is easy to use; it has just a few buttons. Installation of transceivers does not require qualified personal. The installation of pneumatic piston requires highly capacitated personal. The kit is designed for people with motion impairments. The control has visible buttons and of easy tactile perception. The control will use two batteries. Do not require maintenance, just clearing.	
Stakeholders	People with difficulties to move their hands and arms. People in wheelchairs Disabled people assistants People who look for ease of displacement in frequented places.	

Table 5.24 Format for Product Definition applied to Kit for Lights and Doors Control product.

10. Project Planning

Objective: Generate a schedule of the project in a table where all the activities to be done, responsible for each activity, objectives and sequences are to be chronologically specified.

Logo	**Project Planning**						F-ID-010
Name of Product		Time					
	Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week n
Product Planning		*To be defined*	*To be defined*	*To be defined*	*To be defined*	*To be defined*	*To be defined*
Conceptual Design		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined
Detailed Design		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined
Prototype		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined

Table 5.25 Format for Project Planning applied to Kit for Lights and Doors Control product.

11. Market Analysis – Competitive Benchmarking

Logo	**Benchmarking**	F-ID-011

i. Describe general function of Product.

Kit of Remote Control, Transmitter-Receiver and Piston for Illumination and Door Opening Control

ii. Define the most important properties of the Product (at least five).

Property 1	Price
Property 2	Number of buttons in control
Property 3	Luminous intensity control (Dimmer)
Property 4	Number of devices controlable simultaneously
Property 5	Lights control
Property 6	Doors opening control
Property 7	Timer for door opening
Property 8	Compatible with X10

iii. Name of similar products or competence products:

Product 1	X10 PowerHouse Wireless Remote Control System RC5000
Product 2	Automatic Sliding Door System

Table 5.26 Format for Benchmarking applied to Kit for Lights and Doors Control product.

iv. Matrix Analysis

	X10 Powerhouse wireless remote control system RC5000	Automatic sliding door system
Price	US$43	$290
Number of Buttons in Control	8	2
Luminous Intensity Control (Dimmer)	YES	NO
Number of Devices Controlable Simultaneously	8	1
Lights Control	YES	NO
Doors Opening Control	YES	YES
Timer for Door Opening	NO	YES
Compatible with X10	YES	YES

Table 5.27 Format for Matrix Analysis applied to Kit for Lights and Doors Control product.

iv. Correlations

It is not possible to generate any correlations due there is no information about the price of the product, but it is possible to detect characteristics that are missing in the analyzed products in comparison with the proposed product.

12. Patent Analysis

Objective: Search for patents of similar products to avoid copying and to find new ideas to generate a more refined product.

Logo	**Patent Analysis**				F-ID-012
Title					
Patent No.		**Date of registration**		**Date of Issue**	
Assignee			**Inventors**		
Analyzer		**Date of analysis**			
Pages of Interest:					
Functions:					
Results:					
Important Figures:					
Claims:					

Table 5.28 Format for Patent Analysis applied to Kit for Lights and Doors Control product.

13. Identify Market Needs

Objective: To know more characteristics that might be added to the product based on experience and knowledge of people with similar products.

Logo	**Market Needs Identification**	F-ID-013

Name of Product: Kit of Remote Control for Lights and Doors	
Customer: Casa Hogar Ma. Esperanza Nuestra	**Interviewer**: Guízar, Luis.
Address: Av. Luis Elizondo #402. Col Altavista, Monterrey, N.L.	**Date:** April 12th, 2004
Would you like to keep informed about the process? Yes	
User type: Old people and assistants	

Question	Customer Answer	Interpreted Need	Importance
Do you think it is useful?	Yes, it is a device that will help users and patients	It is a product that principally will be useful for people that assist old people for controlling lights and doors when the patient needs it according to their displacement requirements.	10
What do you like?	That it is able to control many doors and all the lights.	Users want to control lights in all the building, and also the more utilized doors.	10
What do not you like?	-	-	-
Suggested Improvements	-	-	

Table 5.29 Format for Market Needs Identification applied to Kit for Lights and Doors Control product.

14. QFD Quality Function Deployment

Objective: Determine technical characteristics form customer requirements.

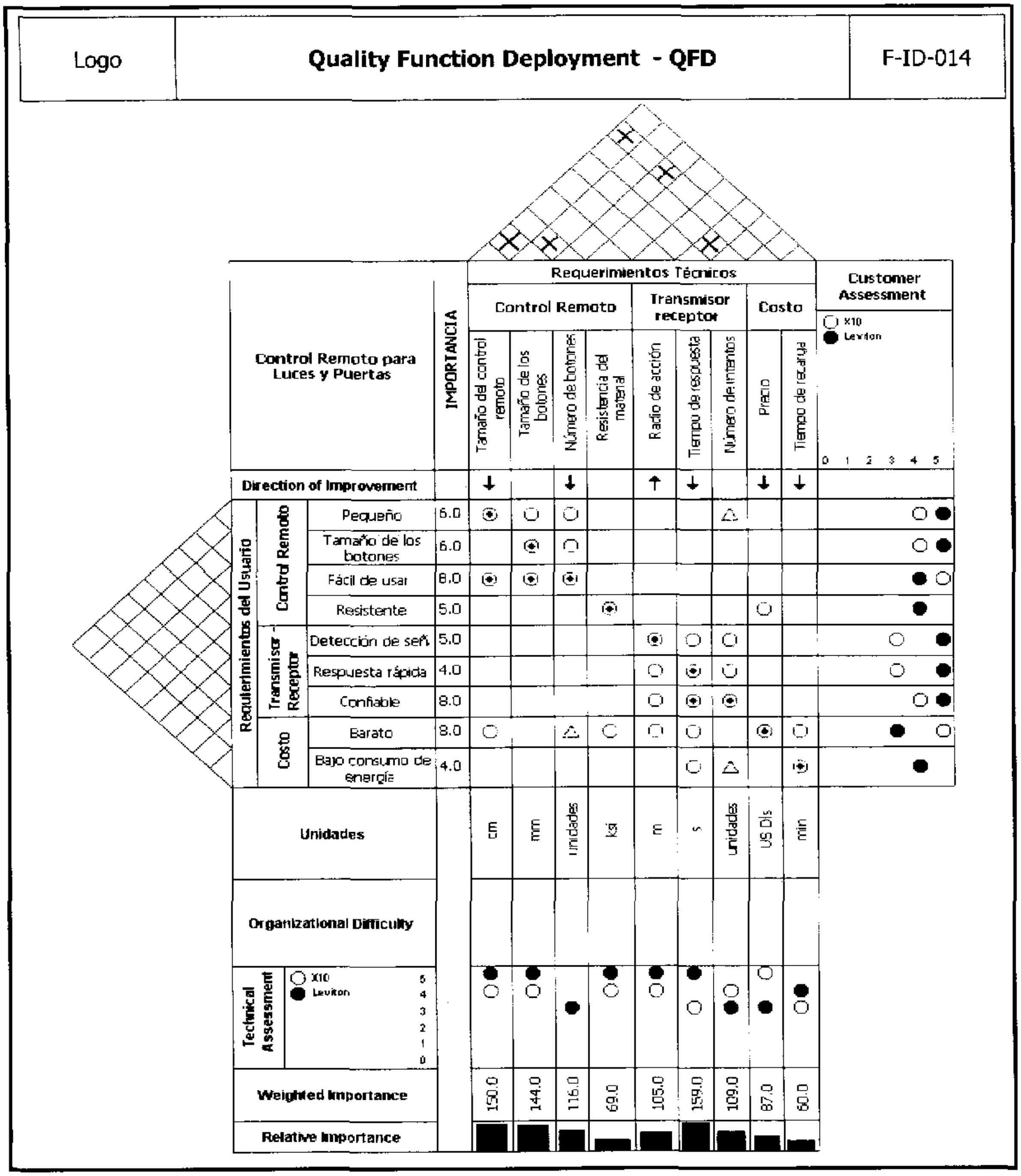


Table 5.30 Format for QFD applied to Kit for Lights and Doors Control product.

15. Technical Characteristics of the Product

Objective: Translate the technical characteristics of the product as permanent requirements of the product development; these will be the most important issues to be satisfied with the design.

Logo	**Technical Characteristics of the Product**	F-ID-015
Important Technical Requirement (How)	Objective Value	
Size of remote control (cm)	12 x 8 x 1.5	
Number of buttons	15	
Action radio (m)	20	
Response time (s)	0.1 s	
Price (USD $)	400	
Recharge time (min)	30	

Table 5.31 Format for Technical Characteristics applied to Kit for Lights and Doors Control product.

16. Functional Decomposition

Objective: Decompose the product into its main functions and sub-functions, in a way that the resultant model shows the relations between functional elements, making it easy to visualize and understand.

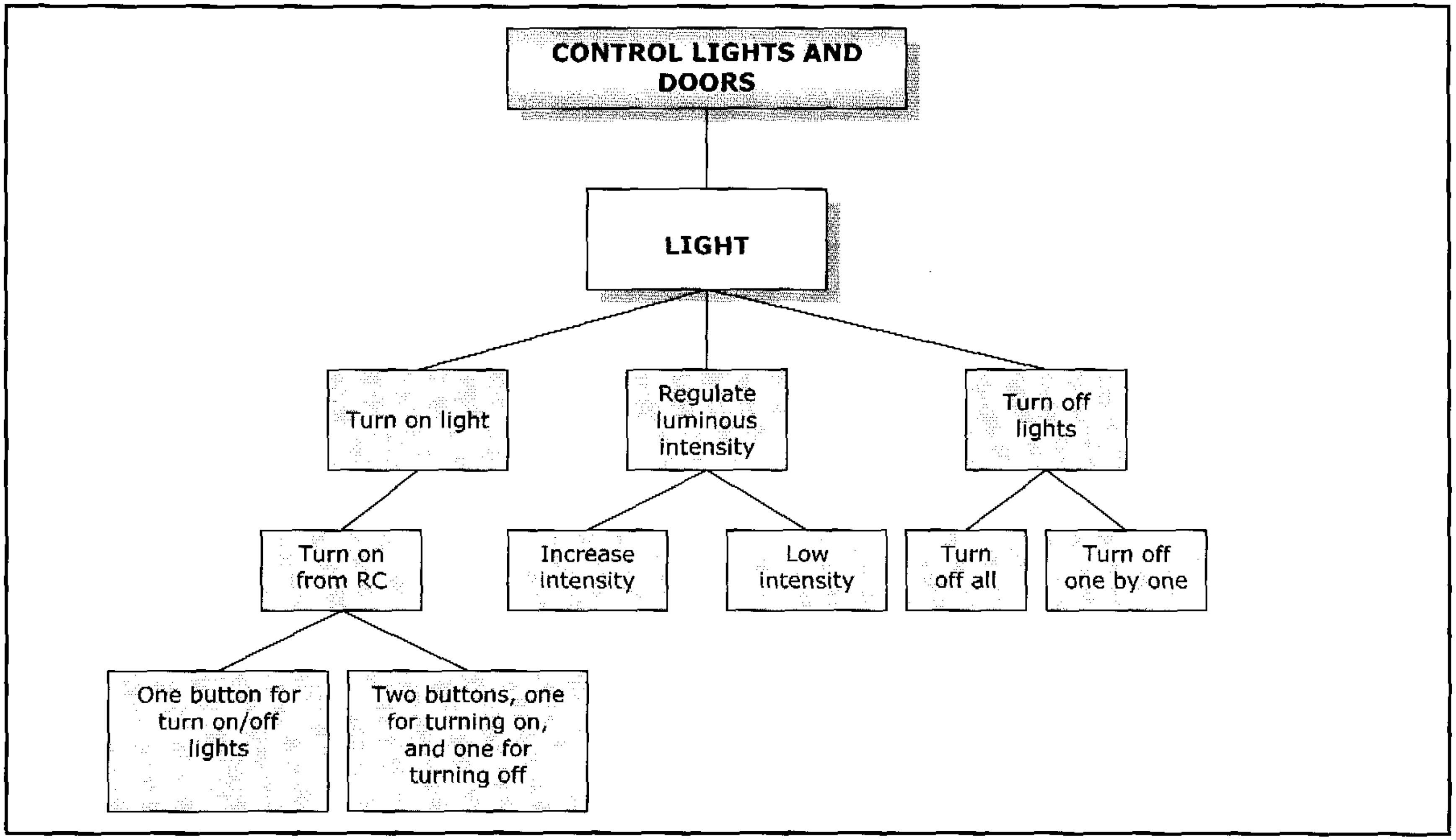


Figure 5.6 (a) Format for Functional Decomposition applied to Kit for Lights and Doors Control product.

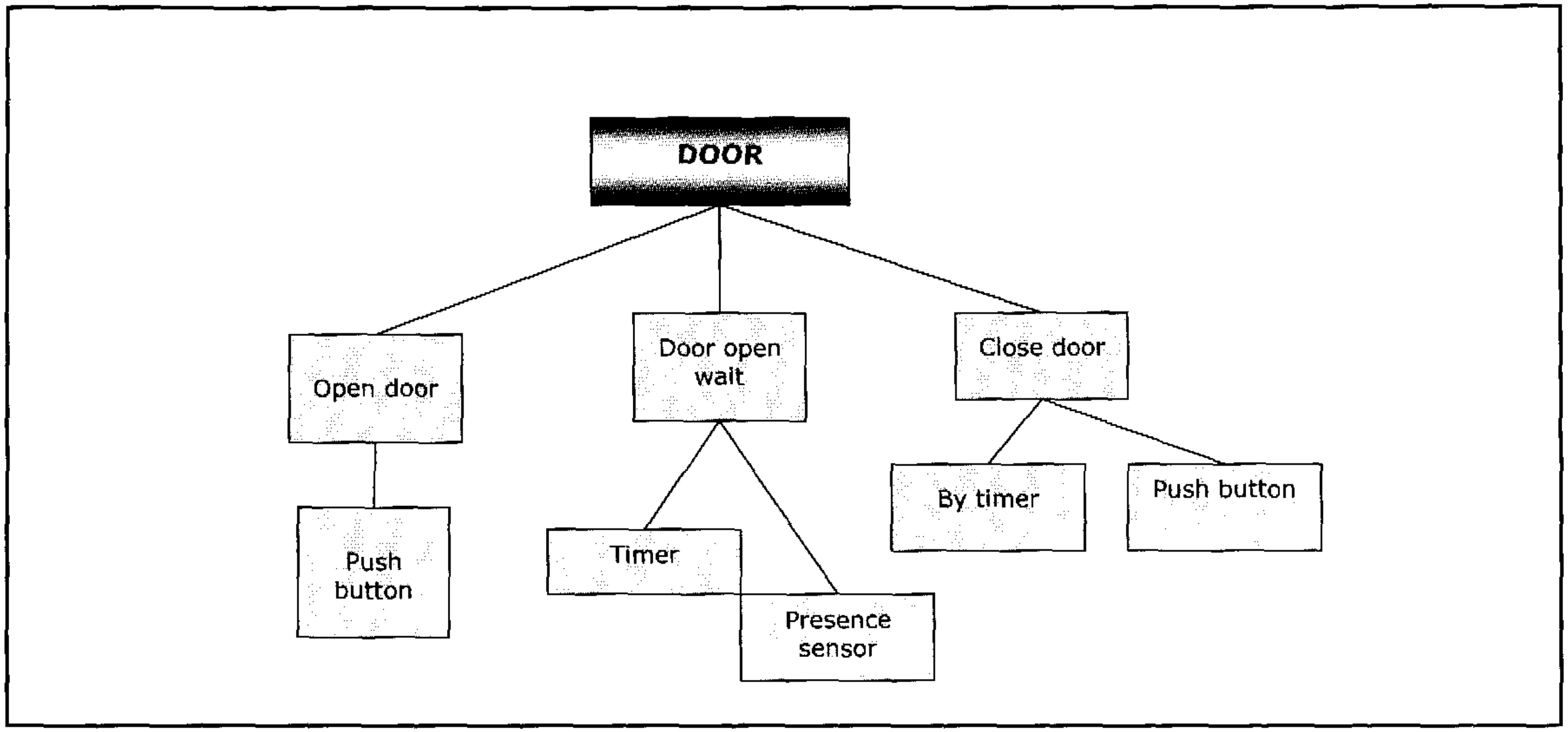


Figure 5.6 (b) Format for Functional Decomposition applied to Kit for Lights and Doors Control product.

18. Concept Generation

Objective: Propose solution alternatives for each product sub-function, using the morphological matrix tool.

Function	Sub-Function	Option 1	Option 2	Option 3	Option 4	Option 5
Door Functions (1)	**Open Door (1)**	With pneumatic piston	With electrical piston	Sliding door	-	-
	Open Door Wait (2)	Timer	Presence Sensor	Sense with MOTES	-	-
	Close Door (3)	Close with spring-damper system	Eliminate pneumatic pressure in piston	Electrical piston	-	-

Function	Sub-Function	Option 1	Option 2	Option 3	Option 4
Light Functions (2)	**Turn on lights (1)**	With X10 transmitter-receiver	With MOTES	-	-
	Regulate luminous intensity (2)	Dimmer X10	Attenuator Leviton X10	Low intensity when there is no people	-
	Turn off lights (3)	Turn off by people absence	Turn off with X10 lamp module	*Turn off with MOTES*	-

Table 5.32 Format for Concept Generation applied to Kit for Lights and Doors Control product.

19. Concept Selection

Objective: Select the best configuration of the product evaluating the options for each function and physical characteristic of the product with the appropriate criteria.

Selection can be done directly from the morphological matrix pointing out the selected options with a line.

DOOR FUNCTIONS

1. Open Door	2. Open door wait	3. Close Door
1.1.1 ; 1.1.3	1.2.3	1.3.3

LIGHT FUNCTIONS

1. Turn on lights	2. Regulate bright intensity	3. Turn off lights
2.1.1	2.2.1	2.3.2

Table 5.33 Format for Concept Selection applied to Kit for Lights and Doors Control product.

Product 3

5.4 Sensor for Lights and Doors Control

1. User Observation

Objective: To observe the user according to the appropriate approach, so the designer gets closer to user experience, in a way that will be possible to emphatically analyze his/her interaction with the environment.

Logo	**User Observation**	F-ID-001
Needs	Description	Difficulty Identified
Turn on/off lights	User wants to turn off or turn on the lights in accordance to his/her location in a determined installation.	To reach the light switches. Distance of displacement to control lights from the switch.
Open / Close doors	Open and close doors according to the path described by the user in a specified installation.	Push or pull door, turn handles.
Look doors	Lock the doors where privacy is required, besides the doors that are access from outside the building.	Use keys, turn a lock, push locking button.

Table 5.34 Format for User Observation applied to Sensor for Lights and Doors Control product.

2. Need Identification

Objective: Determine those needs perceived from the customer that are possible to improve using the top-down, bottom-up or a combination of both approaches, according to the type of user.

Logo	**Need Identification**	F-ID-002
Difficulty	Type	Description
Reach light switches. Requires displacement for controlling lights.	Motion/ Sensory (tactile and visual impairment)	Reach light switches is difficult for people in wheelchairs, paraplegics, and others who have any impairment on their upper extremities. Distance for displacement is an obstacle for people who have any difficulty for walking. This requires an autonomous system adjusted to user needs.
Push or pull door, turn handles.	Motion	Moving hands or the extension of arms to push or pull a door can be difficult or even impossible for some people. It is required an automated system that responds immediately when a person wants to go through the door.
Use keys, turn a lock, push locking button.	Motion	For many people it is impossible to manipulate objects using their hands, and it is necessary a system that locks doors automatically.

Table 5.35 Format for Need Identification applied to Sensor for Lights and Doors Control product.

3. Classification of User Ability – User Pyramid

Objective: Determine user ability according to the user pyramid and to its specifications of users with low functional capability, moderate functional capability or high functional capability.

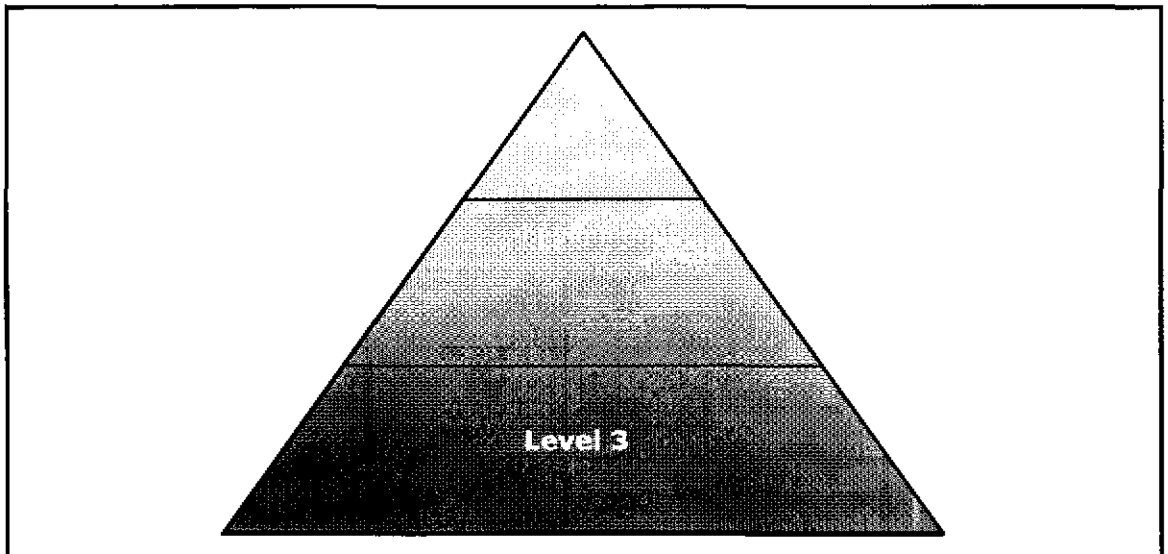


Figure 5.7 User Pyramid applied to Sensor for Lights and Doors Control product.

4. Categorize the user according to his/her disability grade
Objective: Utilize the inclusive design cube to determine the capability of the user related to the following factors:

- Motion: Mobility in their extremities, strength and precision.
- Cognitive: Intellectual capacity.
- Sensory: Auditive and visual.

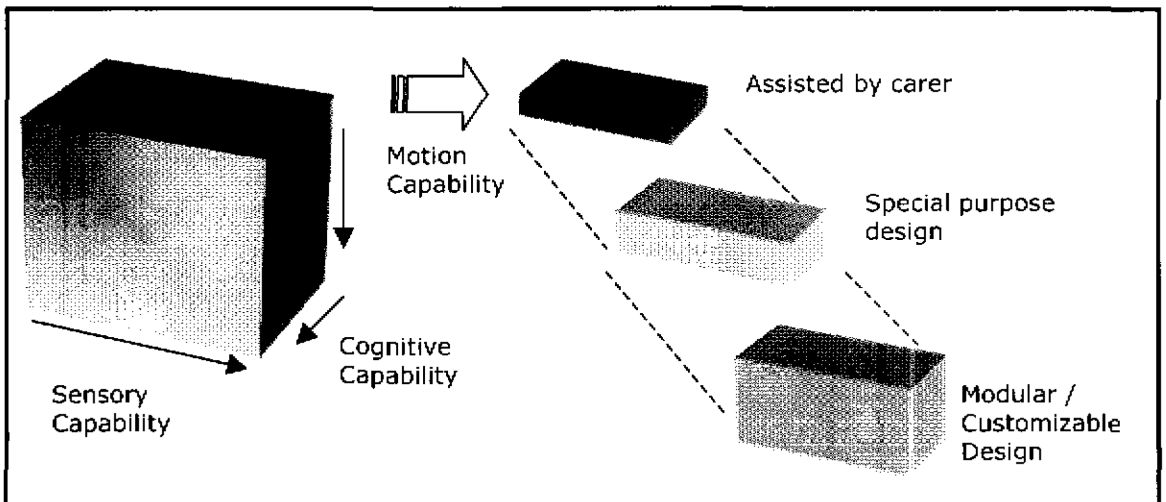


Figure 5.8 Inclusive Design Cube evaluation applied to Sensor for Lights and Doors Control product.

Very Low Motion Capability
Low Sensory Capability
Does Not Require Cognitive Capability
} User Assisted by Carer

Design of this product is flexible to be configured in accordance with the requirements and user needs, and also allow increasing the number of installed devices.

5. Generate Product Specifications

Objective: To establish the product functions and needs to be satisfied, including those functional, sensory, motion, cognitive and capability needs identified.

Logo	**Product Specifications**		F-ID-005
Function	Motion	Cognitive	Sensory
Turn On / Off lights	Will avoid user's displacement and movement of his extremities, doing it automatically when detecting his presence.	-	Will turn on lights (if needed) according to user's displacement, attenuating the areas where the user has passed through.
Open / Close Doors	Will avoid the user the activity of opening and closing doors, doing it automatically.	-	Will open doors when user goes through, and will close them after the user has passed.
Lock Doors	Will avoid the action of locking doors.	-	Lock doors in places that require privacy and outer doors.

Table 5.36 Format for Product Specification applied to Sensor for Lights and Doors Control product.

6. Products Proposal

Objective: In proposing products to be developed, it will be presented a table where a brief description of each product has to be done.

Logo	**Products Proposal**	F-ID-006
Product	Description	Image
Sensors for lights and doors control	Presence, path and velocity sensors to detect user and send on/off signals for doors opening and lights turning on.	Image Not Available
X10 Sensors	Presence and movement sensors for turning on lights and door opening.	Image Not Available

Table 5.37 Format for Products Proposal applied to Sensor for Lights and Doors Control product.

7. Evaluate Products in accordance to user capabilities

Objective: Determine the type of users that are able to use the proposed products; the product will be analyzed using the inclusive design cube to evaluate its practical acceptability.

Logo	**Product Evaluation using the Inclusive Design Cube**		F-ID-007
Qualitative Axis	Sensors for lights and doors control	X10 Sensors	-
Strength and Coordination Capability	Null	Null	-
Intellectual Capability	Null	Null	-
Sensory Capability	Visual minimum	Visual minimum	-
Type of Design	Assisted User	Assisted User	-

Table 5.38 Format for Product evaluation with Inclusive Design Cube
applied to Sensor for Lights and Doors Control product.

8. Product Selection

Objective: Select the product that better fulfill user specifications and motion, cognitive and sensory capabilities.

Logo	**Product Selection**			F-ID-008
		Product Ideas		
Criteria	Importance	Sensor for lights and door control	X10 Sensor	-
Ease of use	7	+	+	-
Safe	10	+	-	-
Technology	9	+	+	-
Modernity	7	+	o	-
Flexible	8	+	-	-
Appearance	9	+	+	-
	Total +	6	3	-
	Total -	0	-2	-
	Sum	6	1	-
	TOTAL	50	7	-

Table 5.39 Format for Product Selection applied to Sensor for Lights and Doors Control product.

9. Product Definition

Objective: Describe product operation characteristics such as mechanical, electrical, electronic and interfaces properties. Also it must include the main function to be carried out by the product and other functions that it will be able to perform.

Logo	**Product Definition**	F-ID-009
Presence, movement and path sensors for automatic doors opening and lights control		
Product Description	Presence, movement and path sensors that detect when a person walks nearby and that will send signals to turn on lights and open doors automatically.	
Key Business Goals	Prototype presentation in September 2004 Launching of product on December 2004 Facilitate access of people to buildings and homes. Approximate cost of product USD$450	
Primary Market	Disabled population (visual, intellectual and motion) Third age people People in wheelchairs	
Secondary Market	Homes Hospitals Offices Restricted access places	
Assumptions	The system is designed to avoid action lights and opening of doors. Does not require physical interaction to be used, just programming the opening doors and turning on of lights times. Does not require maintenance, just cleaning and do not block the sensors.	
Stakeholders	Automation products producers. Producers of domestic electronic devices.	

Table 5.40 Format for Product Definition applied to Sensor for Lights and Doors Control product.

10. Project Planning

Objective: Generate a schedule of the project in a table where all the activities to be done, responsible for each activity, objectives and sequences are to be chronologically specified.

Logo		**Project Planning**					F-ID-010
Name of Product		Time					
	Activities	Week 1	Week 2	Week 3	Week 4	Week 5	Week n
Product Planning		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined
Conceptual Design		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined
Detailed Design		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined
Prototype		To be defined	To be defined	To be defined	To be defined	To be defined	To be defined

Table 5.41 Format for Project Planning applied to Sensor for Lights and Doors Control product.

11. Market Analysis – Competitive Benchmarking

Logo	**Benchmarking**	F-ID-011

i. Describe general function of Product.

Presence, movement and path sensors (MOTES) for automatic doors opening and turning on lights

ii. Define the most important properties of the Product (at least five).

Property 1	Price
Property 2	Ease of changing to manual mode. (turn off system)
Property 3	Detection distance
Property 4	Time of doors opening
Property 5	Time of lights turning on
Property 6	Times programming
Property 7	Lights intensity control
Property 8	Programmable according to illumination characteristics
Property 9	Works even in darkness
Property 10	Compatible with X10
Property 11	Utilizable in the open

Property 12	Has an option to open doors
Property 13	Electrical energy save
Property 14	Expansion capability (number of lights and doors)

iii. Name of similar products or competence products:

Product 1	Leviton - wall mounted occupancy sensor
Product 2	200 Series Wireless PIR Motion Detector
Product 3	Decora-Style Temperature and Light Sensor
Product 4	Version II Wireless X10 Motion Sensor
Product 5	Automatic Sliding Door System with Proximity Sensor

Table 5.42 Format for Benchmarking applied to Sensor for Lights and Doors Control product.

iv. Matrix Analysis.

	Leviton wall mounted occupancy sensor	200 Series wireless PIR Motion Detector	Decora Style Temperature and Light Sensor	Version II Wireless X10 Motion Sensor	Automatic Sliding Door System with Proximity Sensor
Price	US$60	US$110	US$120	US$21	US$310
Ease of changing to manual mode. (turn off system)	YES	YES	YES	YES	YES
Detection distance	40 ft	60 ft	N/A	30 ft	10 ft
Time of doors opening	N/A	N/A	N/A	N/A	NO
Time of lights turning on	Up to 30 mins	NO	NO	Up to 256 mins	NO
Times programming	YES	YES	NO	YES	YES
Lights intensity control	NO	NO	NO	NO	N/A
Programmable according to illumination characteristics	NO	NO	YES	NO	N/A
Works even in darkness	YES	YES	YES	YES	N/A
Compatible with X10	YES	YES	YES	YES	YES
Utilizable in the open	NO	YES	NO	NO	YES
Has an option to open doors	NO	NO	NO	YES	YES
Electrical energy save	YES	YES	YES	YES	N/A
Expansion capability (number of lights and doors)	YES	YES	YES	YES	NO

Table 5.43 Format for Matrix Analysis applied to Sensor for Lights and Doors Control product.

V. Correlations

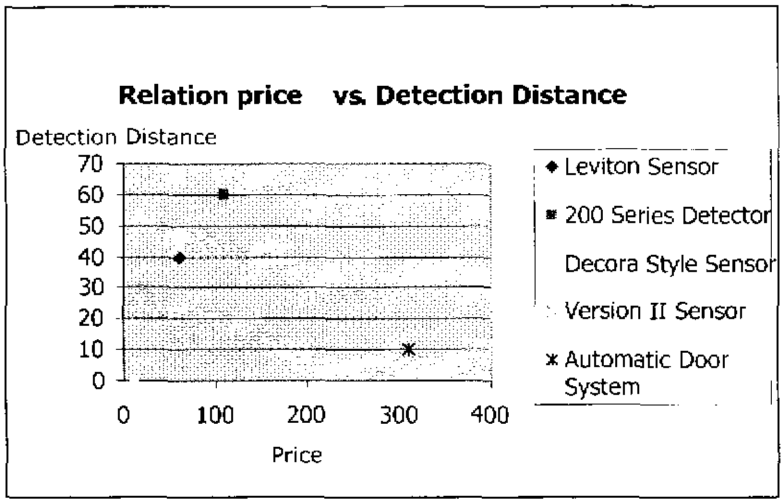


Figure 5.9 Relation between price and detection distance for different suppliers of electronic devices for controlling doors and lights.

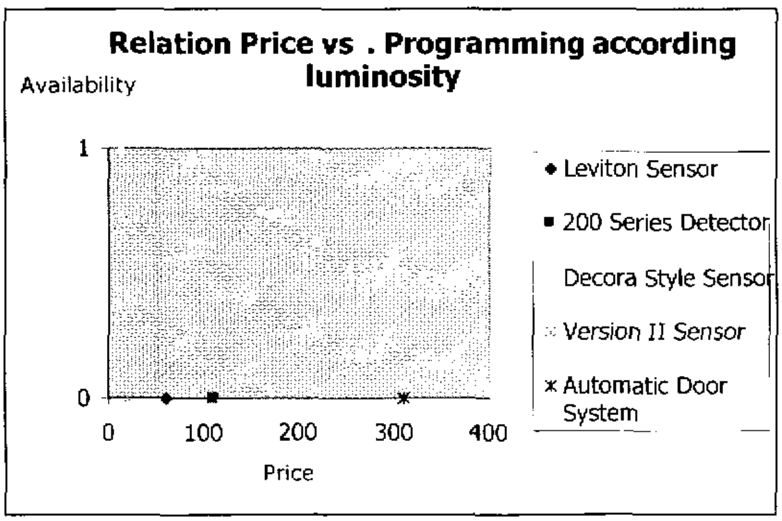


Figure 5.10 Relation between price and programming according luminosity f or different suppliers of electronic devices for controlling doors and lights.

13. Patent Analysis

Objective: Search for patents of similar products to avoid copying and to find new ideas to generate a more refined product.

Logo	**Patent Analysis**				F-ID-012
Title					
Patent No.		**Date of Registration**		**Date of Issue**	
Assignee			**Inventors**		
Analyzer		**Date of analysis**			
Pages of Interest:					
Functions:					
Results:					
Important Figures:					
Claims:					

Table 5.44 Format for Patent Analysis applied to Sensor for Lights and Doors Control product.

14. Identify Market Needs

Objective: To know more characteristics that might be added to the product based on experience and knowledge of people with similar products.

Logo	**Market Needs Identification**		F-ID-013
Name of Product: *Remote Control Sensors for Lights and Doors*			
Customer: Casa Hogar Ma. Esperanza Nuestra		**Interviewer:** Guízar, Luis.	
Address: Av. Luis Elizondo #402. Col Altavista, Monterrey, N.L.		**Date**: April 12th, 2004	
Would you like to keep informed about the process? Yes			
Type of User: Old people and carers			
Question	**Customer Answer**	**Interpreted Need**	**Importance**
Do you find it useful?	Yes, it is a system that will eliminate the time invested in routine tasks.	Eliminate the time of attention to continuous activities that demand too much time to the personal.	10
What do you like?	That the system would work by itself	Wish that the system works automatically and to be totally autonomous	10
What do not you like?	That it can fail and do not comply with its tasks	Provide safety about the system accuracy	10
Suggested Improvements	*That it is possible to add more lights and doors*	Expansion Capability	8

Table 5.45 Format for Market Needs Identification applied to Sensor for Lights and Doors Control product.

15. QFD - Quality Function Deployment

Objective: Determine technical specifications from information gathered in the customer and experts interviews, competitive benchmarking and patent analysis.

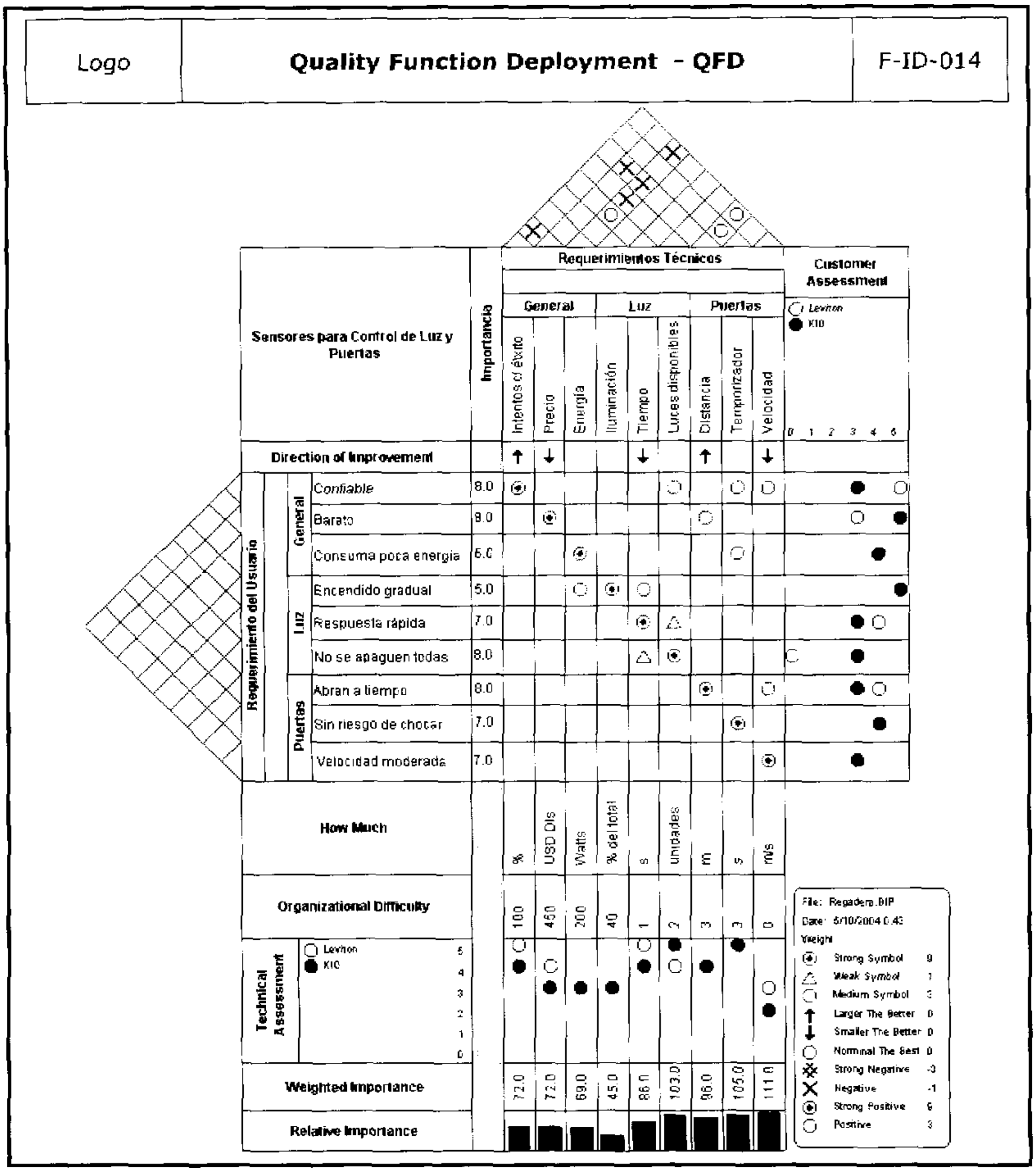


Table 5.46 Format for QFD applied to Sensor for Lights and Doors Control product.

16. Technical Characteristics

Objective: Translate the technical characteristics of the product as permanent requirements of the product development; these will be the most important issues to be satisfied with the design.

Logo	**Product Technical Characteristics**	F-ID-015
Important Technical Requirement (How)	Objective Value	
Successful trials (%)	100	
Price	400	
Lights Response Time (s)	0.1	
Response Distance (m)	2.5	
Velocity (m/s)	0.3	

Table 5.47 Format for Technical Characteristics applied to Sensor for Lights and Doors Control product.

17. Functional Decomposition

Objective: Decompose the product into its main functions and sub-functions, in a way that the resultant model shows the relations between functional elements, making it easy to visualize and understand.

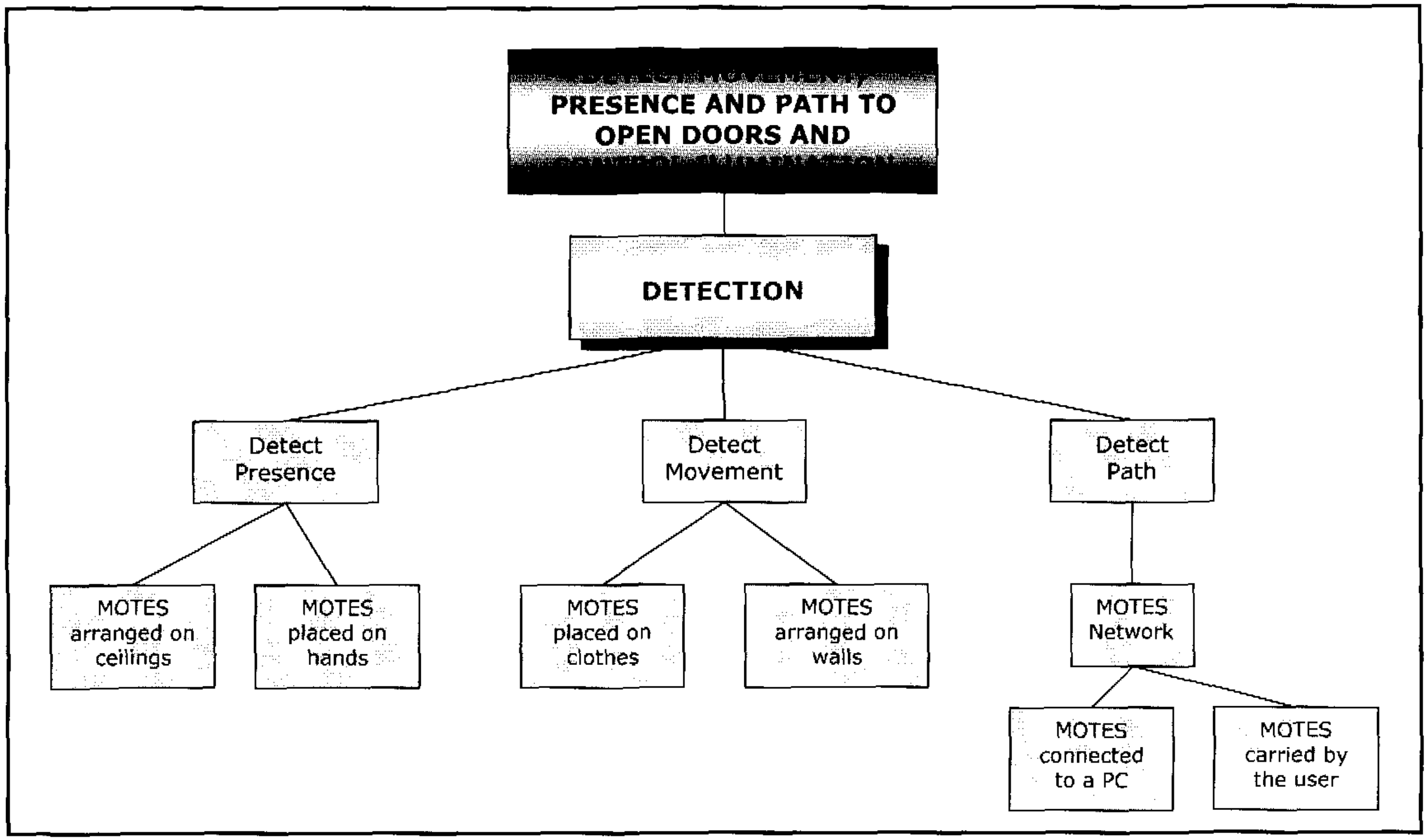


Figure 5.11 (a) Format for Functional Decomposition applied to Sensor for Lights and Doors Control product.

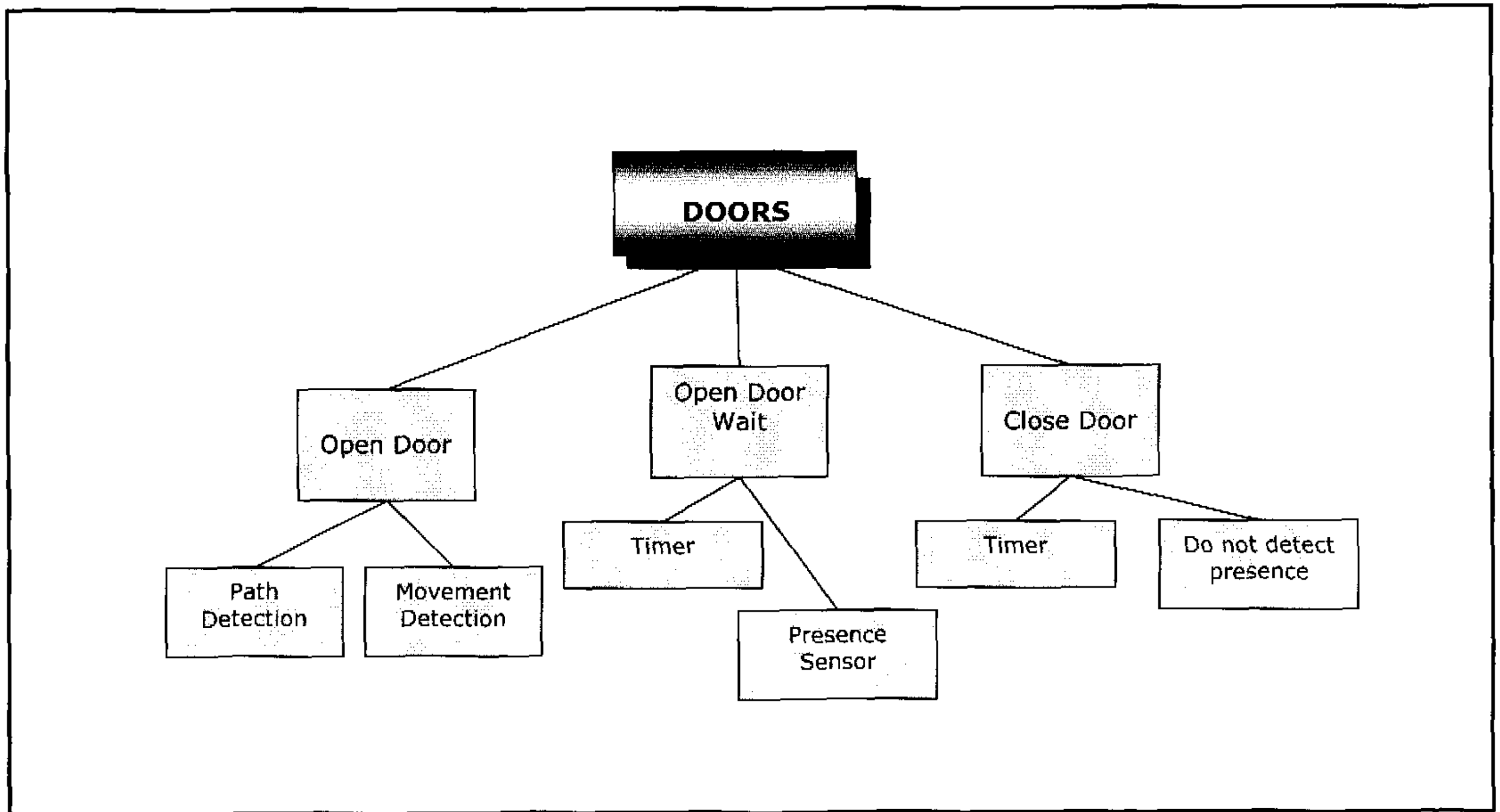


Figure 5.11 (b) Format for Functional Decomposition applied to Sensor for Lights and Doors Control product.

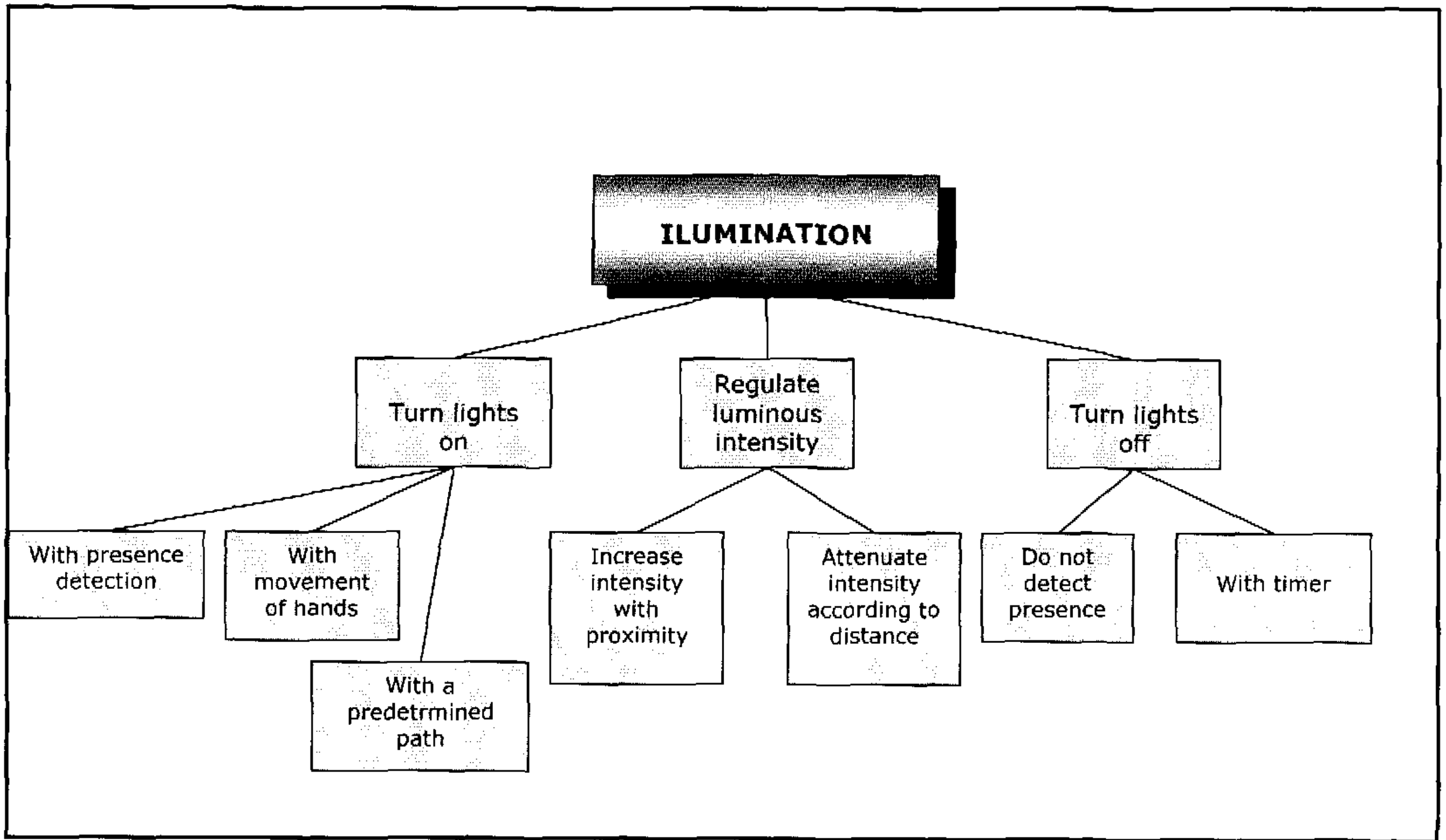


Figure 5.11 (c) Format for Functional Decomposition applied to Sensor for Lights and Doors Control product.

18. Concept Generation

Objective: Propose solution alternatives for each product sub-function, using the morphological matrix tool.

Function	Sub-Function	Option 1	Option 2	Option 3	Option 4	Option 5
Door Functions (1)	**Open Door (1)**	With pneumatic piston	With electric piston	Sliding Doors	-	-
	Open Door Wait (2)	Timer	With X10 Movement Sensor	Sense with MOTES	-	-
	Close Door (3)	Close with spring-damper system	Eliminate pneumatic pressure in piston	Electric Piston	-	-

Function	Sub-Function	Option 1	Option 2	Option 3	Option 4
Light Functions (2)	**Turn On Lights (1)**	With X10 transmitter- receiver	With MOTES	-	-
	Regulate Luminous Intensity (2)	X10 Dimmer	Attenuator Leviton X10	Attenuation of lights when turning on and off	-
	Turn Off Lights (3)	Presence Sensor, turning off by absence of people	Turns off with a X10 lamp module	Turning off with a MOTES signal of user path indicator	-

Function	Sub-Function	Option 1	Option 2	Option 3	Option 4
Detection Functions (3)	**Detect Presence (1)**	X10 Sensors	MOTES	-	-
	Detect Movement (2)	X10 Sensor	MOTES	-	-
	Detect Path (3)	Series of X10 Sensors	MOTES Network	-	-

Table 5.48 Format for Concept Generation applied to Sensor for Lights and Doors Control product.

19. Concept Selection

Objective: Select the best configuration of the product evaluating the options for each function and physical characteristic of the product with the appropriate criteria.

Selection can be done directly from the morphological matrix pointing out the selected options with a line.

DOOR FUNCTIONS

1. Open Door	2. Open Door Wait	3. Close Door
1.1.1 ; 1.1.3	1.2.3	1.3.3

LIGHT FUNCTIONS

1. Turn On Lights	2. Regulate luminous intensity	3. Turn Off Lights
2.1.1	2.2.1	2.3.3

DETECTION FUNCTIONS

1. Detect Presence	2. Detect Movement	3. Detect Path
3.1.2	3.2.2	3.3.2

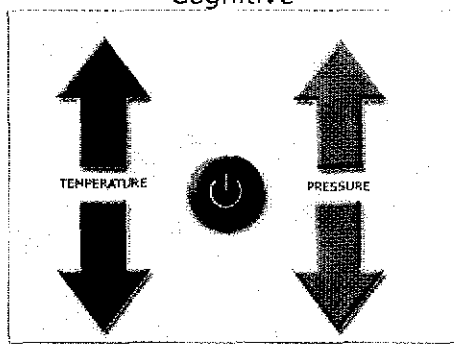
Table 5.49 Format for Concept Selection applied to Sensor for Lights and Doors Control product.

5.5 EVOLUTION OF PRODUCTS WITH INCLUSIVE DESIGN APPROACH

5.5.1 Automatic Shower

The concept is an automatic shower that is easy to use by the suppression of handles; it has buttons that represents the elemental functions that the product performs.

Cognitive



Improvement with Inclusive Design in the Cognitive Axis

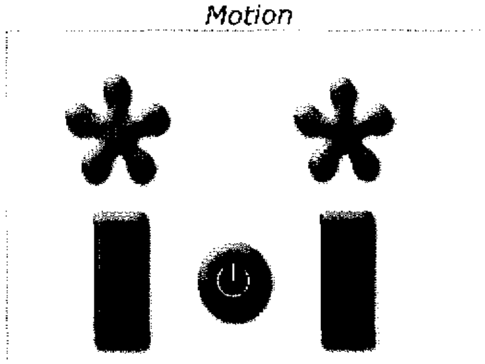
- Know how it works.
- Ease to recognize functions.
- The user knows how to regulate water temperature and pressure.

Wireless Technology Functions adding functional capability

- Distance: The product has a wireless sensor that determines the distance between user and shower control panel.

When the user gets closer the shower works normally, but when user gets far the shower turns off and the user is ready to soap up.

Motion



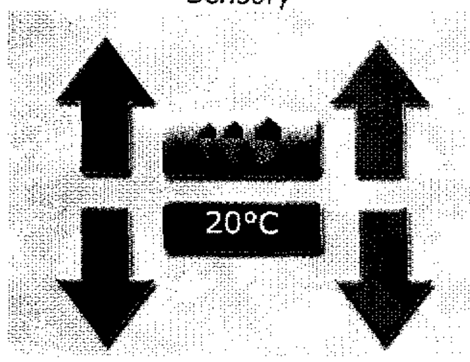
Improvement with Inclusive Design in the Motion Axis

- Know how to use the product
- Simplification of use (from handles to buttons)

Wireless Technology Functions adding functional capability

- Presence: The shower begins its operation after detecting person presence during ten seconds. This can happen if the user cannot push buttons.
- Position: The shower can detect the presence of a child if he is to short to reach the buttons.

Sensory



Improvement with Inclusive Design in the Sensory Axis

- Know how to identify and measure functional parameters

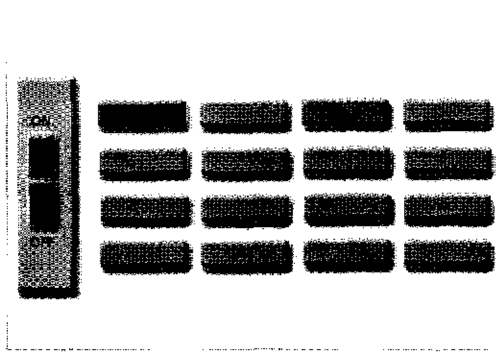
Wireless Technology Functions adding functional capability

- Temperature: Detect the output temperature to determine the regulation of internal water temperature (tactile).
- Sound alarm: To notify user that hot water is getting finished.
- Visual Display: Display visual numbers and icons that represents water temperature and pressure respectively.

5.5.2 Control for Lights and Doors

The concept is that the user can open/close doors and turn on/off lights of his home or another place. The design comprehends a control that is easy to interpret its functions and easy to use.

Cognitive



Improvement with Inclusive Design in the Cognitive Axis

The product represents:

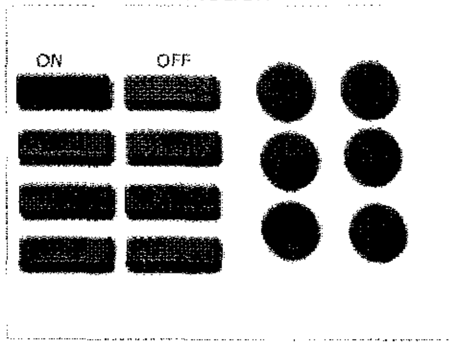
- Lights buttons
- Door buttons
- ON/OFF Button
- Large size control
- The lights buttons have an icon that represents an opened door and another icon with a closed door
- The door buttons have an icon that represents a lamp turned on and another icon to represent a lamp turned off.

Wireless Technology Functions adding functional capability

Powered by X10

- It sends the signal frequency to each module integrated with lights and doors, and each has a unique address that is activated by the user when he presses the particular button.

Motion



Improvement with Inclusive Design in the Motion Axis

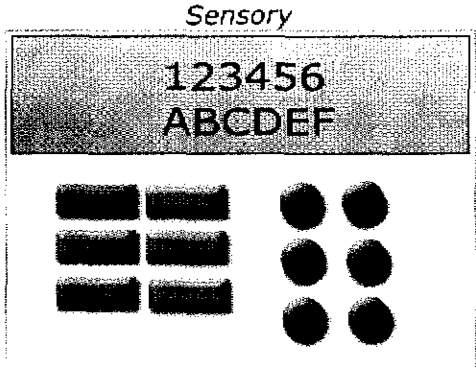
- *Soft buttons*
- Handy size control
- Elimination of switches
- *Braille language*

Wireless Technology Functions adding functional capability

Powered by X10

- The system opens/close a door when the user presses a door button
- The system turns on/off a light when the user presses a light button

Sensory



Improvement with Inclusive Design in the Sensory Axis

- Visual: Display to show activated lights and doors, larger buttons.
- Auditive: Sound alarm to confirm open/close on/off actions.
- Tactile: To differentiate between door buttons and light buttons.

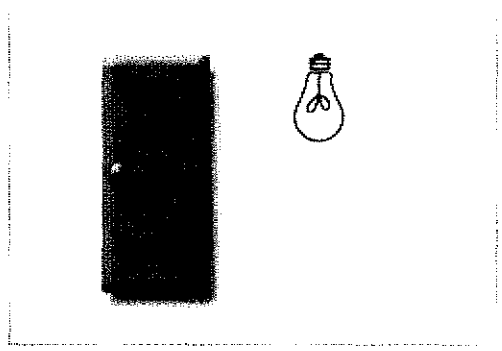
Wireless Technology Functions adding functional capability

Powered by X10

- The system confirms to the user when a door is opened/closed and when a light is turned on/off.

5.5.3 Automatic Control for Lights and Doors

Cognitive



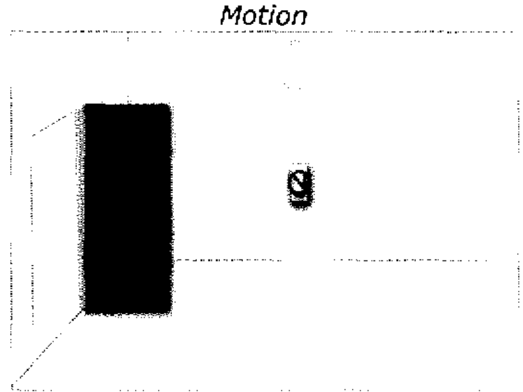
Improvement with Inclusive Design in the Cognitive Axis

- Do not require previous knowledge to use both the doors and lights.
- It does not require understanding of functions.

Wireless Technology Functions adding functional capability

- Distance: Dimming the lights (turning on) while the user is getting closer and turning off (dimming) while the user is getting far

Motion



Improvement with Inclusive Design in the Motion Axis

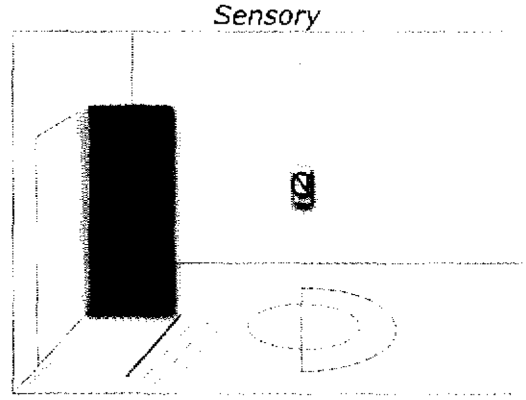
- Allow the use of doors and lights with hands-free operation.

Wireless Technology Functions adding functional capability

- Presence: Detect the presence of the user to turn on lights and open doors
- Path: Detect the user walking path to prevent mistakes with activating the elements unnecessarily.

- Monitor (duration on door opening and lights on): The wireless sensors detect while the user is using the system.

Sensory



Improvement with Inclusive Design in the Sensory Axis

- Visual: Display the range of detection of sensors.
- Auditive: To confirm that the light or door has been activated

Wireless Technology Functions adding functional capability

- Presence: Wireless sensors detect the user presence to maintain the devices activated when the user does not move.
- Distance: Wireless sensors detect the user proximity to the system to determine the lights intensity and anticipated door opening.

5.6 ACTION RESEARCH CYCLE FOR MECHATRONIC CONCEPTUAL PRODUCT DESIGN

The steps followed by the author during the Action Research process applied in this case study for Mechatronic Product Design, are:

Plan

Incorporate the inclusive design approach to a product design methodology with the use of wireless technology in order to add assistive characteristics to accomplish specific user requirements/disabilities.

Act & Observe

- Creation of a Product Design Methodology that involves Inclusive Design
- Development of Product planning and Conceptual Design of three assistive mechatronic products
- Evaluation of mechatronic products according to users' requirements, inclusive design cube and user pyramid.

Observe: These products fulfill a range of needs, and they cover some impairments as following described:

Product 1 - Automatic shower: People who cannot twist a wrench - People with motion impairment such arthritis, paralysis, visual impairment.

Product 2 - Automatic control for lights: People with age related effects, wheelchair users with a severe impairment such quadriplegia.

Product 3 – Control for lights and doors: Wheelchair users (with low severity impairment), arthritis, etc.

Reflect

- The more disabled people, the more automatic products required
- Products must be designed considering three ways: motion, sensory and cognitive as Inclusive Design Cube explains.
- Wireless technology must automate products according to the user mobility level.
- Wireless technology has many applications in mechatronic products that could be used to add more functions
- With the addition of Wireless Technology, products can be more or less assistive by carrying out simple or complex tasks.

Once developed the conceptual phases of product design with the inclusive design approach, the author consecutively reflected over other applications that can be developed in other products or systems.

Now, the application of inclusive design in reconfigurable manufacturing systems, as the user can understand and interact with it quickly and effectively.

The author's reflection about inclusive design is given here:

Products must be designed to cover the inclusive design motion axis to make them easy to drive with hands, complying with minimum requirements of force and coordination to use them. For those people who are severely disabled, product design must be easier, including hands-free operation by detecting approximation of user to the product, interpretation of user's desire of moving from one place to another, and attending user special needs as hand twisting, lifting, and other concerning diseases such arthritis, motion disability and old age impairments.

About visual and auditive aids, products where designed in order to help and allow those people who have visual and auditive impairments, by providing big displays, large buttons, easy-to-understand signals, etc.; in the other hand, these products have auditive alarms to report operations carried out, to confirm entered instructions and to warn when problems occur.

In the cognitive issue, the author learned that products must be easy to understand about their functions, status and usability. Also, the product must have an active error prevention, to prevent user to do an unexpected task. For disabled people, products must interact by facilitating the usability and having interpretation of user disability through offering customized configurations.

CHAPTER 6 – METHODOLOGY FOR INTEGRATING INCLUSIVE DESIGN IN THE DEVELOPMENT OF RECONFIGURABLE MANUFACTURING SYSTEMS

6.1 Methodology of Inclusive Design Incorporated in a RMS

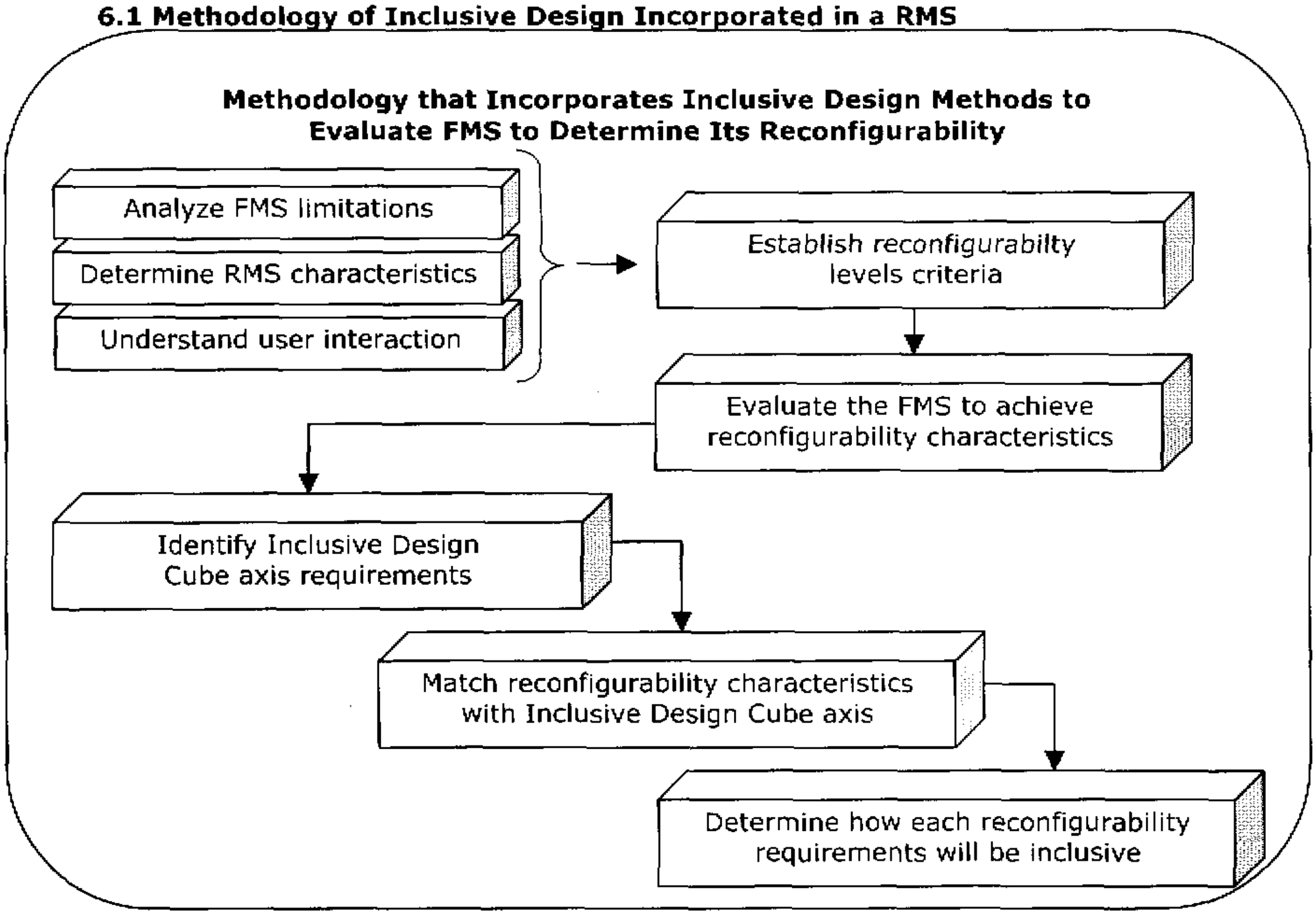


Figure 6.1 – Methodology of RMS with Inclusive Design

6.1.1 LIMITATIONS IN FLEXIBLE MANUFACTURING SYSTEMS

Even though a flexible manufacturing system has a lot of advantages to improve the manufacturing of products in low time rates and medium throughput compared to other manufacturing systems. The characteristics of representative flexible cells are represented in the following table.

Machines are laid out in a predetermined layout to simplify and minimize material movement
Cell has assembly or production sequences and routes for all components. All relevant engineering, design work, and support is done by the group of operators in the cell.
Cell does its own inspection and work scheduling.
Cell produces a family of similar components that requires similar machines, or workstations in the cell.

Table 6.1 Characteristics of a representative cell (Irani, 1999)

Many machines need to be duplicated to create independent cells. A FMS may lack the ability to completely process a new part within any single cell due to the nonavailability of equipment. It is totally recognized that a FMS fails to deal with long-term changes in part demand. Another potential disadvantage of FMS is its lower machine and labor utilization compared to a functional or process layout. (Irani, 1999). Also a load imbalance of machines may occur when some machines types must be duplicated among several cells. This may result in low utilization rates on certain machine types. Finally, when machine breakdowns occur, the production rate of a cell may be hindered because it lacks more machines of similar function to replace the disabled machine. (Burbidge, 1979).

Some other disadvantages arise due to the methods available for design and evaluation of cells, some of the disadvantages are listed in the following table.

Disadvantages of cells
Need for high investment in machine installation and relayout
Lack of flexibility in handling demand changes, product mix changes, infrequent ordering of parts, variable lot sizes, changes in part designs and process plans, improvements in manufacturing technology, etc.
Imbalance of utilization of machines and labor
Implementation problems associated with methods used for cell formation
Lack of a comprehensive cell formation method
Data collection and analysis is time-consuming
Significant difficulty in incorporating the impact of dynamic operational factors into the cell design process.

Table 6.2 Disadvantages of flexible manufacturing cells, (Irani, 1999)

Flexible Manufacturing Systems (FMS) can produce a variety of products, with changeable volume and mix, on the same system. FMSs consist of expensive, general-purpose computer numerically controlled (CNC) machines. The combination of high equipment cost and low throughput makes the cost per part relatively high. (Koren et. al., 1999)

Koren says that the high cost of FMS is one of the major reasons for the low level of acceptance or satisfaction with FMS. Its CNC machines are not designed around the part. Rather, general-purpose CNCs are built before the manufacturer selects machines and before process planning is undertaken to adapt the machines and the process to the part. The flexible systems and machines are constructed with all possible functionality built in. It is also a common assumption that FMS should be able to produce (1) any part (within the machine envelope), (2) at any mix of parts, and (3) in any sequence. This approach increases cost since it requires a parallel system structure for FMS that utilizes high-power, general-purpose multi-axis CNCs with a very large tool magazine and multiple sets of tools, this is a very expensive solution.

Three coordinates – capacity, functionality, and cost – define the difference between RMS and the traditional FMS approach. (Koren et. al., 1999)

6.1.2 DETERMINATION OF RMS CHARACTERISTICS

Reconfigurable systems must be designed at the outset to be reconfigurable, and must be created by using hardware and software modules that can be integrated quickly and reliably; otherwise, the reconfiguration process will be both lengthy and impractical. Achieving this design goal requires a RMS that has the several key characteristics listed below:

Modularity: *In a RMS all major components are modular (e.g. structural elements,* axes, controls, software and tooling). Those can be transacted between alternate production schemes to achieve the optimal arrangement to fit a given set of needs.

Integrability: The ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that enable integration and communication.

Convertibility: The ability to easily transform the functionality of existing systems, machines, and controls to suit new production requirements.

Diagnosability: The ability to automatically read the current state of a system and controls so as to detect and diagnose the root-cause of defects, and subsequently correct operational defects quickly.

Customization: The ability to adapt the customized flexibility of production systems and machines to meet new requirements with a family of similar products.

Reconfigurable Manufacturing Systems are systems capable of being quickly adapted to changing capacity and variability requirements by providing exactly the needed functionality and capacity at any time.

6.1.3 UNDERSTANDING USER INTERACTION

The major approach in the development of reconfigurable manufacturing systems is the variations that can occur in variety and amount of product demand. With the evaluation of flexible manufacturing system in order to achieve reconfigurability, user centered approach must be considered to develop RMS with compatibility and usability oriented to user interaction, understanding and comprehension of the five key characteristics of the reconfigurable system. (see Figure 6.2)

Having considered designing for the goal of social acceptability, the next step is to consider practical acceptability. Jakob Nielsen's (1993) definition of practical acceptability divided it into:

- Cost
- Compatibility
- Reliability
- Usefulness

Of these, *usefulness is subdivided further into utility and usability, where utility is* the provision of the necessary functionality by the product or service to perform the desired task.

Usability is defined as including:

- Ease of learning

- Efficiency of use
- Ease of remembering
- Low (user) error rates

With the consideration of user interaction, the objective of the Methodology described in this chapter is to prepare a Flexible Manufacturing System with the characteristics of a Reconfigurable Manufacturing System in order to improve the user learning, understanding, perception and interaction with the support of Inclusive Design Methods.

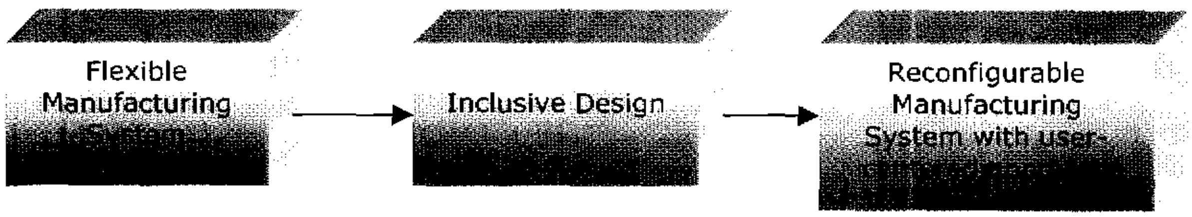


Figure 6.2 - Flexible Manufacturing System with the addition of inclusive design concepts toward Reconfigurable Manufacturing System

The Flexible Manufacturing System that achieves reconfigurability characteristics, *with the application of Inclusive Design Concepts turns the system into a* reconfigurable manufacturing system with a user-centered approach.

The system must be assessed with the consideration of the reconfigurability levels proposed by the author and the capabilities that the system own in order to verify it possibility to achieve reconfigurability.

The reconfigurability levels page comprehends the assessment of the five key characteristics of RMS in terms of provided support by hardware and software.

6.1.4 RECONFIGURABILITY LEVELS

Table 6.3 : Reconfigurability levels to assess a system reconfigurability

	Hardware	**Software**
Modularity	Number of modules and variety of operations covered (functions) 1. All functions required 2. Some functions required exist. 3. Single module working or limited functions covered.	Software compatibility to allow a combination of modules with own functions 1. Highly compatible 2. Only certain types of functions 3. Limited to one function at a time
Integrability	Number of modules allowed to integrate on cell 1. All type of modules (CNC machines, robots, actuators) 2. Some modules are allowed 3. Confined system	Software reconfigurability to allow integration of modules 1. All type of programs supported (CNC, vision, robot) 2. Some programs are allowed 3. Non upgradeable software.
Convertibility	Number of components, tools and sub-modules available 1. All necessary components to changeover 2. Some components exist to perform some operations 3. Very limited components.	Software flexibility to support configuration on changeovers 1. Fully able software to support all changeovers 2. Some changeovers are allowed by the software 3. No flexibility allowed to perform changeovers
Diagnosability	The system count with product tracking and error identification. 1. All Modules have accurate capacities to detect quality problems. 2. Not all modules detect quality issues.	Software has a sub-module for detection and prevention of errors 1. Software can detect quality problems in each process stage 2. Software depends on machine responding concerning quality reporting 3. Software does not perform the diagnosing task.
Customization	Modules are arranged within cell layout to perform a variety of processes 1. All modules have the ability to be moved. 2. Some modules are fixed some others are movable. 3. All modules are fixed.	Software is customizable for each process required 1. Software can be adjusted to all types of processes. 2. Software is limited to allow some configurations. 3. Software is not able to perform changes during cell customization.

The scale used in each cell of the reconfigurability table is given to assess a system and to determine its reconfiguration capabilities to have an idea of how the designer can propose an improvement regarding the system limitations.

6.2 - IDENTIFICATION OF INCLUSIVE DESIGN CUBE AXIS REQUIREMENTS IN RECONFIGURABILITY CHARACTERISTICS

Modularity

In order to be inclusive must fulfill the IDC axis requirements.

• In the Motion axis	Modules have to be easily inter-connectable, with distinctive geometries; light, easy to grasp with a minimum of force and coordination.
• In the Sensory axis	User must identify how modules interconnect through visual aids such as colors, icons, labels or numbers.
• In the Cognitive axis	Facilitate the understanding of modules integration with a process flow with a logic sequence.

Figure 6.3 Modularity fulfills the requirements of the Inclusive Design Cube

6.2.1 MODULARITY

The major components can contribute to make the cell more flexible when allowing configuration changes due to functional requirements in a short setup time, for example, a machining system can easily be reconfigured by simply removing, adding or changing the constituent units.

The modules can also contribute to reduce the product development lead time, translated into parallel development activities that are possible once the interfaces between the modules have been considered.

Modules have the advantage of having easy service and upgrading because their ability to be easily added or replaced.

Modules are grouped into the following functions:

- Move: Robot
- Operate: Robot, ASRS,
- Assemble: Robot, Assembly table
- Transport: Conveyor, Robot
- Inspect: Inspection Station
- Load: All
- Unload: All
- Machine: Mill
- Store: ASRS
- Control: Main computer and PLCs

Also the modules can be subdivided into:

- Components- tools, clamping devices, containers, shells, etc.
- Sub-modules- Machining: Milling, Turning, Shearing, Drilling, etc.

The objective of modularity applied to cell is to provide users exchangeability, flexibility and variety of functions given by each module.

To make the FMS modular and inclusive it has to achieve the three qualitative axis of the Inclusive Design Cube (IDC), as described in the table.

Integrability

In order to be inclusive must fulfill the IDC axis requirements.

• In the Motion axis	Modules have to be easily interconnectable, with distinctive geometries; light, easy to grasp with a minimum of force and coordination.
• In the Sensory axis	User must identify how modules interconnect through visual aids such as colors, icons, labels or numbers.
• In the Cognitive axis	Facilitate the understanding of modules integration with a process flow with a logic sequence.

Figure 6.4 Integrability fulfills the requirements of the Inclusive Design Cube

6.2.2 INTEGRABILITY

To know how many modules can be interconnected with which modules, which are compatible according to their functions and capabilities. For example, placing a robot between a machining station and a conveyor, because their functions are: for the conveyor, transport; for the robot, unload, transport and load; and for the machine, to operate. The purpose is to integrate. There is a product and control flow among the modules. This flow of information makes possible that each element in the process knows what part of it is being carried out.
This is a basic example of virtual integrability for a manufacturing cell.

An example of wrong virtual integrability would be to place ASRS, robot and machine, because the robot cannot take the work piece directly from the ASRS and bring it to the machine.

To make the FMS integrable and inclusive it has to achieve three qualitative axis of the Inclusive Design Cube (IDC), as described in the table.

Convertibility

In order to be inclusive must fulfill the IDC axis requirements.

• In the Motion axis	The machining, assembling and control modules must be reachable, easy to fit and connect using geometric forms in the matching outputs and inputs in order to reduce changeover time.
• In the Sensory axis	Components (tools) must be identifiable and easy to interpret their interconnectivity and functionality with colors and codes to differentiate tools belonging to each module.
• In the Cognitive axis	Modules, components and sub-modules must be identifiable in geometric forms, colors and codes in a way to UNDERSTAND the matching functionality of each component within their corresponding module or sub-module.

Figure 6.5 Convertibility fulfills the requirements of the Inclusive Design Cube

6.2.3 CONVERTIBILITY

In a reconfigurable system it may be necessary to make manual adjustments to the components such as connecting them to the control module, changing tools, part-programs or machining modules (for example: milling or turning) and short conversion times are required. Due to this, user must do theses changes precisely, quickly and error free. To get these results, user needs to understand, identify and skillfully handle machining, assembly and control modules, which are the ones that require more adjustments during each conversion.

For example, in the case of a process that requires a tool different from those commonly used by the robot, the new tool can be added in the assembling table without causing any delays in the conversion time; only by a quick adjustment of robots software module to integrate and convert the new tool.

To make the FMS convertible and inclusive it has to achieve the three qualitative axis of the Inclusive Design Cube (IDC), as described in the table.

Diagnosability

In order to be inclusive must fulfill the IDC axis requirements.

• In the Motion axis	User will be able of modify the components position, like tools, clamping devices, etc. with accuracy.
• In the Sensory axis	System must have a screen that displays in real-time the spatial distribution of products, components, modules and submodules, to notify the user the activity of the system with an acoustic alarm.
• In the Cognitive axis	By means of monitoring the status of process, user will identify the most common problems that happen during each process, and will know how to prevent and correct unexpected problems in the process.

Figure 6.6 Diagnosability fulfills the requirements of the Inclusive Design Cube

6.2.4 DIAGNOSABILITY

User will know the system status, by monitoring the cell with sensors by means of information obtained in real-time of product flow, position of components, modules and submodules, in order to diagnose the system functionality, coupling and behavior, also including the prevention and correction of problems regarding parts quality.

The information displayed that user will be up-to-date is about the application of each component as is used during the process within the cell, also will be notified about the product status, if this is been machined, transported, assembled or stored.

Machine application software as from machine or robot will be capable of finding quality problems concerning to programming errors, sequence, and logic procedures introduced by user.

To make the FMS diagnosable and inclusive it has to achieve the three qualitative axis of the Inclusive Design Cube (IDC), as described in the table.

Customization

In order to be inclusive must fulfill the IDC axis requirements.

• In the Motion axis	The control modules with an open-architecture technology would be upgradeable and customizable to the flexibility, facilitating the user to configure the control modules easily.
• In the Sensory axis	The control module would have a visual label to indicate what PLCs are working and supporting each module (machining, transporting, etc.)
• In the Cognitive axis	The user will know the amount of options to configure the cell, it means, selecting and distributing the modules according to the processes and product flow.

Figure 6.7 Customization fulfills the requirements of the Inclusive Design Cube

6.2.5 CUSTOMIZATION

The arrangement of cell modules, sub-modules and components when they are needed will be oriented to the parts family and the control modules that will be modified to achieve those changes in cell distribution. According to the user inclusion, user will be able to configure the cell based on his knowledge to take modules and arrange them in order to provide the necessary flexibility to specific parts.

User will have many options to configure the cell, using machining, assembly, inspection, transporting and storing modules regarding the software modules necessary to do any process. The customization process will be further demonstrated on Chapter 4.

To make the FMS customizable and inclusive it has to achieve the three qualitative axis of the Inclusive Design Cube (IDC), as described in the table.

6.3 - APPLICATION OF THE EVALUATION METHODOLOGY TO A FMS IN ORDER TO IDENTIFY ITS OPPORTUNITIES

6.3.1 MODULARITY

Motion

- Force: Modules are light, easy to grasp and handle
    - Are Modules light, easy to grasp, easy to handle?, do they require force to move and join with others?.
- Speed: Module with easy mobility (lightweight) to move, push and pull them quickly.
- Coordination: Modules with geometric forms to couple with others.
    - Are Modules easy to connect with others?
    - Is the Manufacturing system easily reconfigured by simply removing, adding or changing the constituents units or modules of the system?

RMS-ID Modularity-Motion

Enhance modules mobility and handling within the cell by minimizing the use of force and coordination in short time.

Sensory

- Visual: Modules are easy to identify and recognize by their functions.
    - Do the modules have a visual ID to know what functions they cover?
- Auditive: Modules have and identification device to coupling properly.
    - Do the modules have an auditive warning for coupling tasks?

RMS-ID Modularity-Sensory

Are the Modules easy to identify with an identification tag that describes their functions and show coupling capability with other modules?

Cognitive

- Intellectual: Modules are simple to interpret about their functions, forms and fitting.
    - Does the organization and categorization of modules allow the user to understand and learn quickly about how to integrate them?

RMS-ID Modularity-Cognitive

Evaluate the user knowledge about modules and components in function of his dominion of an amount of modules.

Control Software

- How many modules does the control module support?
- Does the control module have an easy user interface to reconfigure it?

6.3.2 INTEGRABILITY

Motion

- Force: Machine and control modules do not require too much force to move and interconnect them.
  - Does the user require too much force to move modules in the way of matching them?
- Coordination: Machine and control modules easily place, connect and fit with other family components. Also, software is easy to understand and shows a easy configuration interface for each application.
  - Does the placing of machine and control modules require a high coordination skill?
  - Do the modules have a handy interface with user?
  - Does the software have a friendly interface that allow user configure it quickly and correctly?

RMS Integrability-Motion

All the modules, sub-modules and components are easy to integrate without requiring user's extreme force and accurate coordination.

Sensory

- Visual: User is able to rapidly visualize connections with colors, icons and geometric forms of modules in order to interconnect them and setup the proper software as fast as possible.
  - Does the user identify the integrability of modules by perceiving visual identification and differentiation of each module, sub-module and component?
  - Does the user can identify the suitable software for each module and process configuration?
- Auditive: The coupling of modules, sub-modules and components is confirmed with a sound alarm that indicates if the devices are placed in a correct reaching distance for operation purposes.
  - Do the system count with a notifying alarm that confirms the correct coupling of modules, sub-modules and components corresponding to their spatial distribution, height, orientation, declination, and other 3D constraints?
  - Are the system, machine and control modules designed with interfaces for integration purposes allowing user to efficiently integrate hardware and software?

RMS-ID Modularity-Sensory

The system must be easy to integrate modules, sub-modules and components by the proper directions displayed to user.

Cognitive

- Intellectual: The user is prevented of connecting modules that do not have functional relationship.

  The user understands the modules integration by means of operation flow with a logical sequence.

  - Is the system able to inform user about wrong settings and configuration of each module?
  - Does the user understand what possible configurations of cell can be done in order to satisfy his planned processes?

RMS Integrability-Cognitive

The user understands the functionality given by the integration of the modules in a configuration according to their functions.

Control Software

o Does the control module support exchangeability of modules?

o How much time does the control module takes to reconfigure it in order to perform a module exchange? The least 1 2 3 4 5 The most (days)

o Does the integration is stable in terms of software and hardware?

6.3.3 CONVERTIBILITY

Motion

- Force: User can changeover the modules with light components and sub-modules that do not require much force to couple, assembly, adjust, screw on, etc.
    - Do the modules and components require force in order to fit and connect them?
    - Can user make the proper adjustments, screwing up, clinch and other with a minimum force?
- Coordination: Modules, Sub-modules and components have a margin of safety in the connection interface that facilitates the user coordination during the changeover process.
    - Do the modules have a proper interface that allows the correct modification and prevent to users of errors during the work?
    - Can user make the proper adjustments by quickly changing, removing and modifying components in machining modules with a little accuracy and precision?

RMS Convertibility-Motion

Facilitate to user the handling, connecting and matching of modules, sub-modules and components by requiring the least force and coordination.

Sensory

- Visual: The identification of tooling, components and sub-modules is required by having visual aids in each element to relate them to a group of modules.
    - Do the machine, assembly and control elements have a visual attach to make them identifiable when changeover is required?
    - Can user identify the belonging components and sub-modules of each major module by a visual tag or a screen that displays in real-time the position of each module pointing out if they are well or wrong placed?
- Auditive: If a component or sub-module is placed in a wrong module (i.e. a clamping device in the conveyor), it can be detected and notified to user by means of a sound alarm avoiding the continuing process.
    - Does the system counts with sound alarms to prevent of errors during the setup and changeover time?

RMS Convertibility-Sensory

System will be prepared for facilitate to user the changeover and setup of machines, while showing visual and auditive aids to make these operations faster.

Cognitive

- Intellectual: the objective of this convertibility concerning is that user can understand and learn how the modifications can be done when problems raise in a determined process for each major module. This imply, that user will know how to use the correct tools, clamping devices and other elements to their corresponding machines in terms of place and time.
    - Can user understand and learn how wrong settings are put right?
    - Does the user know what component or sub-module corresponds to a determined major module?
    - If a failure happens, is the user able to identify what is the concerning of system halting and correct the problem adequately?

RMS Convertibility-Cognitive

System must enable user to make the proper modifications and changeovers with minimum effort and allowing them to learn quickly the changeover procedure of each module.

Control Software

o How many components are allowed to change by each module?.

o Is it the software easy to reconfigure in order to recognize new components added to modules?

6.3.4 DIAGNOSABILITY

Motion

- Force: System will detect whether a human error on placing elements or information introduced wrongly has tempted a system halt.
    - Is the system able to identify quality problems attributing them to human error?
- Coordination: User is able to access the control module to know the system status by simply clicking on a screen the section of cell that has trouble.
    - Is the system able to notify user the problems concerning to product flow, machine operation and modules arrangement?

RMS Diagnosability-Motion

System must prevent of errors by pointing out the physical settings done by the user.

Sensory

- Visual: Cell must own a sensor map on a screen that displays the position of product, components, and sub-modules within the layout.
    - Does the cell have a scanning system that provides status information of each cell element?
- Auditive: The same sensor map screen must show to user what errors are going on with a beep.
    - Does the cell diagnose its own system with an alarm during the machine, assembly or inspecting operation?

RMS Diagnosability-Sensory

System must show in real time the system functionality and behavior through a interface with visual and auditive aids.

Cognitive

- Intellectual: User is able to know what problems due to human errors like configuration of software and hardware, placing of components, etc. are happening in the cell and how he can interpret each indicator shown in a screen.
    - Does the user know what is happening on the cell in real time when a problem occurs?
    - Is the user able to detect quality problems during the process?
    - Can the user assign a quality problem to a specific operation by knowing what machine failed due to human error?

RMS Diagnosability-Cognitive

The objective of this Diagnosability-cognitive issue is to help user to understand when a quality problem occurs, and enable him through the identification of errors during the configuration of cell.

Control Software
o Is the software able to detect programming errors?
o Is the software able to detect product quality fails?
o Is the software able to prevent mistakes of user during programming or by product out of specification?

6.3.5CUSTOMIZATION

Motion

Customized flexibility: Arranging modules around family parts

Customized control: Setting up control modules to accomplish process

- Force: Modules must be easily moved and adjusted with others by user (*flexibility*)

  Control modules can be configured according to the process by moving few switches, buttons or clicks.

  - Are the modules capable of moving through the cell?

Do the modules have levels of height, distance and orientation?

- Coordination: Modules are easy to place according to orientation, reach range, with low accuracy demanding.
  - Do the modules have a default measure to couple each other?

RMS Customization-Motion

Enable user to arrange modules with ease, by the minimum requirement of force and coordination due to incorporated measures and levels to arrange them.

Sensory

- Visual: System shows to user what modules, components and sub-modules are activated during the distribution arrangement of cell.
  - Is the system able to detect what components are used in a determined process?
- *Auditive: System help to user by preventing him to connect incompatible* modules or components with modules, facilitating the configuration.
  - Is the system able to detect errors in the cell configuration about matching incompatible modules or placing sub-modules in other non corresponding modules?

RMS Customization-Sensory

System has an intelligent interface with user that displays the real-time arrangement of cell and prevents of wrong configurations in control modules to users.

Cognitive

- Intellectual: User can learn quickly about how to accommodate modules, configure control modules in a little time with the prevention of errors that cause the spent of time and resources.
  - Does the user understand the logic arrangement of cell modules, components and sub-modules in order to achieve a correct and functional cell configuration?

RMS Customization-Cognitive

User is able to accommodate modules and configure control modules, by taking advantage of the cell flexibility and customization to the process requirements.

The assessment is applied regarding the hardware and software issues, also with the information of control module to evaluate the customization and adapting capabilities of the system to perform the changes required by each of the five key characteristics of RMSs.

6.4 Inclusive Design applied to a Reconfigurable Manufacturing Cell

The reconfigurable manufacturing systems are focused on functionality and capacity demanded, they require a quick adaptation to the market needs, but also a quick adaptation of their internal components. This adaptation is translated into changeover of machines that must be tasked by cells users. That is why people play an important role in the reconfigurable manufacturing systems arranging them in short times, accurate movements and in a low learning curve process.

The Inclusive Design apply to this type of manufacturing systems because its main objective is to adapt products to the functional needs of people, facilitating the interpretation, driving and evaluation of the designed product used by a user with predetermined skills.

The elements of the Inclusive Design Cube Axis that are Cognitive, Sensory and Motion make a complement with the five key characteristics of RMS. The cube axis represents all the functionality given by each modularity, integrability, etc. given to such ergonomic characteristics of users by implementing an adaptable system to achieve both machine (products) and user requirements.

The motion axis represents such factors as strength and co-ordination capability; the sensory axis covers audio and visual capability; while the cognitive axis recognizes the range of intellectual capability. The characteristics of reconfigurable manufacturing systems will have a complementary functionality by introducing the inclusive design tools to adapt products and systems to user.

6.5 Matching the Inclusive Design Cube Axes with the Characteristics of Reconfigurable Manufacturing Systems to determine how the reconfigurability characteristics can be inclusive.

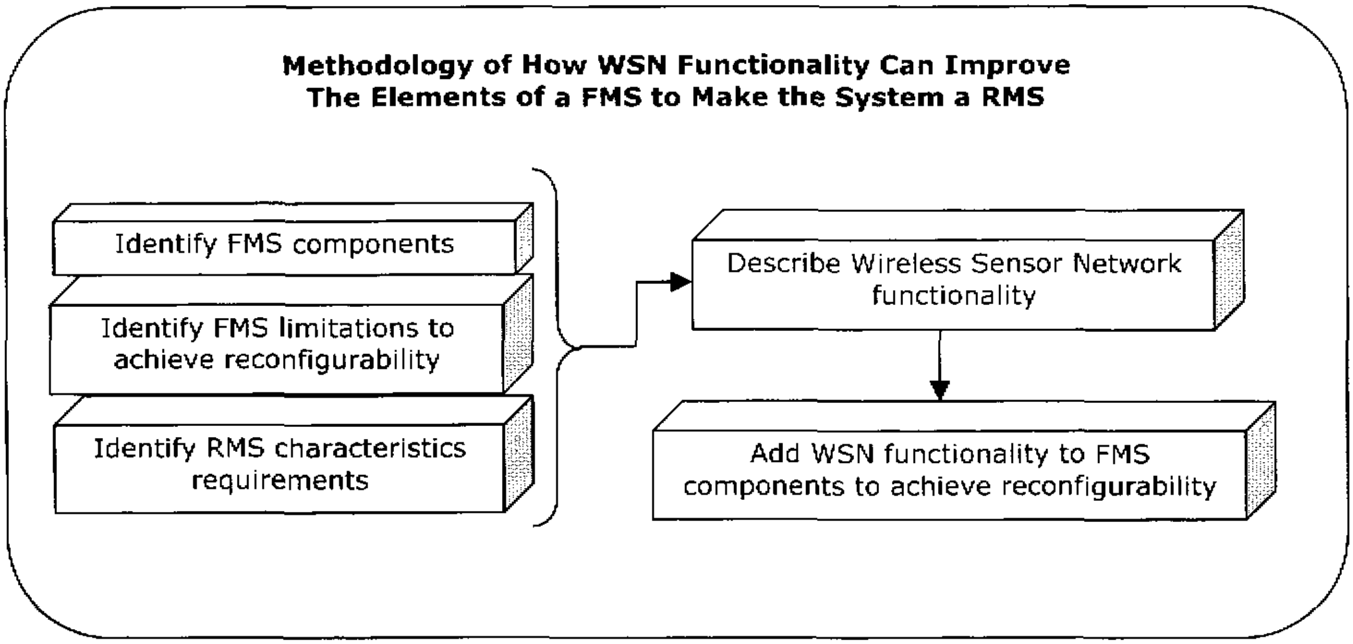
Characteristics of Reconfigurable Manufacturing Systems	Inclusive Design Cube Axis		
	Motion	**Sensory**	**Cognitive**
Modularity	Design components easy to grasp and move, light and easy to plug each other.	Major modules must be identifiable in groups by using visual, auditive and tactile indicators.	Learn the functionality of each component and modules.
Integrability	Modules with interfaces that allow easy interconnection and	Capable of identify compatible modules to integrate them	The user will know how to integrate different modules with some

	upgradeability.	according to their functions and visual id tags. Using visual and auditive signals to recognize interconnection.	restrictions and capabilities. System must help to understand quickly its integration and configuration modes
Convertibility	Facilitate the inter-connectivity between components and modules by designing them easy to match and changeover.	User must identify each component according to its own module, by means of visual and auditive in the order to facilitate changeover.	Allow the user to make changes to machines by the quick understanding of modifications required when problems arise.
Diagnosability	System must be able to prevent of mistakes to user.	Place sensors to diagnose the system functionality and workpiece tracking by displaying visual and auditive signals.	Understand the status of process while the user observes the sensors signals in the software module.
Customization	Enable the user to configure the system (hardware and software) according to his requirements and preventing mistakes of connecting some non-compatible components	Allow and facilitate the configuration of hardware through visual and auditive aids that indicate successful connections and display the new control configuration of system that support new arrangement.	Know how to select different modules and components for specific processes and arrange them within the cell layout.
Results	A highly ergonomic system designed to satisfy customer work on a RMS.	Easy perception and understanding of modules and components functions	Low learning curve and easy reconfiguration of cell.

Table 6.4 – Match between characteristics of RMS and Inclusive Design Cube Axis

For understanding the different capabilities of each user or group of users, it is necessary to observe and analyze students of each laboratory's group; each group accomplish the "fully able user", but the skill needed to use the equipment would be based on the criteria of the inclusive design cube.

6.6 A METHODOLOGY OF HOW WIRELESS SENSOR NETWORKS (WSN) FUNCTIONALITY CAN IMPROVE THE ELEMENTS OF A FMS TO MAKE THE SYSTEM A RMS



6.7 Description of how Wireless Sensor Network functionality improves the operation of a RMS.

6.7.1 WSN supporting Modularity

1. RFID Tags attached to each module (machining, assembly,...) to know the position and proximity of each other.
2. RFID Tags will help to count how many items of each module are going to be used in the cell arrangement.
3. RFID can be used to track components of a particular module to know its current position.
4. A Receiver with its RFID Tag can display the position of each module within the cell, to know its presence.
5. On each pallet a RFID Tag can be placed to track the product and to know its current operation.

6.7.2 WSN supporting Integrability

1. When ordering physically the cell modules to do a particular operation, based on unitary functions of each module to avoid mistakes in the physical configuration.
2. Sensors will send information about the setup status of the modules so the control system recognizes the process to be carried out, as it can be assembly, machining or inspection.

3. Sensors can detect errors in the spatial distribution of the modules, for example, operation distance.
4. User can learn to interconnect the modules correctly when getting a feedback or when having to comply certain constrains to start the process. For this, it is proposed to have a display that shows the layout of the modules in the cell with warnings when any component is out of the action range and an approval signal when the configuration is fully constrained and then the control module activates the setup to the execution of the process.
5. The software must be connected to the control module, which will get the information from the WSN, this in order to predict in some way the process to be done, it means that the software will activate the functions for machining when the WSN detects that this operation is integrated in the process or that activates the robot controller when it is included to any process.

6.7.3 WSN supporting Convertibility

1. Components will have sensors to know their position, integration with any module and availability.
2. Sensors will prevent users from setting components in a wrong module, example, a clamping device for assembly set in conveyor pallet.
3. Sensors will indicate to the user the proper software application for each machine change. For example, if the machining module it is being used a milling tool the software has to indicate that the process to be done is one of milling; and when another tool change is done, now to a turning tool, the system has to identify the change in the process and activate the turning functions.

6.7.4 WSN supporting Diagnosability

1. Sensors will monitor and approve the modifications done to the components and modules during the process by helping users to do this with accuracy.
2. Sensors will track the parts during the whole process, while notifying to the control module about the status of parts.

6.7.5 WSN supporting Customization

1. Sensors will interpret the type of process by the arrangement of modules and notify this to the control module.
2. Sensors will predict the necessary software according to the integration of modules.
3. The logic of process programming can be detected by sensors to setup the flow of functions on each module.
4. Sensors will detect what process is going to be done, as regards to the logic of functions performed by modules according to their arrangement.
   Functions are described as: Move, Transport, Operate, Load, Unload.
   Logic: Connect multiple conveyors to a robot
   Non logic: Connect an ASRS with robot

As the attributes of Wireless Sensor Networks, such corresponding MOTES and RFID, they can match the characteristics of Reconfigurable Manufacturing Systems, as shown in the following table:

6.8 Application of Wireless Sensor Networks functions to Reconfigurable Manufacturing Systems

Functional Characteristics	Monitoring	Distance	Path	Presence	Position	[illegible]entation
Modularity	Detect current status of machines	-	-	Detect and confirm presence of modules to software module	Detect position of modules to [illegible]ne [illegible]tions to be [illegible]rformed	
Integrability	Monitor the integration status of [illegible] each [illegible]dule with [illegible]er	[illegible]ch of [illegible] mod[illegible] Prox[illegible] of mod[illegible]ith each[illegible]		Detect the presence of new modules to determine the new process to be performed	Detect to determine appropriate position of modules	Detect orientation of modules to determine joint functions
Convertibility	[illegible]ents [illegible]sed	Detect distance of components from their modules	Tracking of components and containers	Detect the presence of components in their modules	Verify components position in their modules	Detect orientation of components that are ready to use
[illegible]gnosability	[illegible]ted curre[illegible] statu[illegible]f work[illegible]ces and [illegible]chines	Detect the distance traveled by the workpiece	Detect proximity of workpieces to use the advanced planning feature	Workpiece tracking	Detect position of workpiece to know its transformation	Detect workpiece orientation during process
Customization	Detect the process that will be performed by the selection of modules	Detect the effective distance between modules to add more	Detect the path traveled by the workpiece	Detect presence of modules necessary to perform a process	Detect position of modules to determine the desired process	-

The Functional characteristics of wireless sensor networks, both MOTES and RFID, can deliver sensing applications that work together with the functions of each module with the objective of improve the tracking of product, components and the modules current status.

Once integrating wireless sensor networks with reconfigurable manufacturing systems characteristics, it is important to consider the functionality that can be added with the application of wireless technology.

Characteristics of RMS	Wireless Sensor Networks
Modularity	• Each sensor in a module with a RFID to identify used and available components.
Integrability	• Each sensor in a module with a RFID to identify compatibility with other modules.
Convertibility	• Sensors will provide information about the status of components adjustment in order to improve the conversion time.
Diagnosability	• Sensors will provide information about connectivity of modules, status of product flow and status of machines. Also will guide to interconnect modules easily and error free.
Customization	• Sensors will determine whether a group of modules is working and provide this information to the control system in order to activate the proper control software.

Table 6.5: Wireless sensor networks improving characteristics of RMS

6.8.1 RFID applicability

RFID can be used for Advanced Planning, while detecting a new product or process required to be done, it can send a signal to control module in order to prepare the modules and components according to the new process executed. RFID can be mainly used to add this Advanced Planning feature to the convertibility characteristic.

Chapter 7 – Case study for the application of Inclusive Design Concepts in a Flexible Manufacturing Cell to convert it into a Reconfigurable Manufacturing System

7.1 Overview

Reconfigurable systems must be designed at the outset to be reconfigurable, and must be created by using hardware and software modules that can be integrated quickly and reliably; otherwise, the reconfiguration process will be both lengthy and impractical. Achieving this design goal requires a RMS that has the several key characteristics listed below:

Modularity: In a RMS all major components are modular (e.g. structural elements, axes, controls, software and tooling). Those can be transacted between alternate production schemes to achieve the optimal arrangement to fit a given set of needs.

Integrability: The ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that enable integration and communication.

Convertibility: The ability to easily transform the functionality of existing systems, machines, and controls to suit new production requirements.

Diagnosability: The ability to automatically read the current state of a system and controls so as to detect and diagnose the root-cause of defects, and subsequently correct operational defects quickly.

Customization: The ability to adapt the customized flexibility of production systems and machines to meet new requirements with a family of similar products.

Reconfigurable Manufacturing Systems are systems capable of being quickly adapted to changing capacity and variability requirements by providing exactly the needed functionality and capacity at any time.

Advances in reconfigurable manufacturing will not occur without machine tools that have the modular structures to provide the necessary characteristic of quick reconfiguration. The modular design of machine tools is a key enabling technology to reconfigurability, as the machining system can easily be reconfigured by simply removing, adding or changing the constituent units or modules of the system or the machine. Reconfigurable Manufacturing Systems need a modular structure to meet the requirements for changeability, which is provided by a modular system structure. The primary goal in developing reconfigurable manufacturing systems is to develop machine modules, which can be quickly exchanged between different manufacturing systems. This exchangeability can be accomplished by equal structure of the machines and the control systems and the standardization of the interfaces combining the modules.

To make easy reconfigurability not only the physical system must be updated, but also the management and control software must take into account the new characteristics, because this is needed to ensure the proper flow of materials, tools, and information.

7.1.1 The Mechatronic Manufacturing Cell of Mechatronics Department at Monterrey Tech.

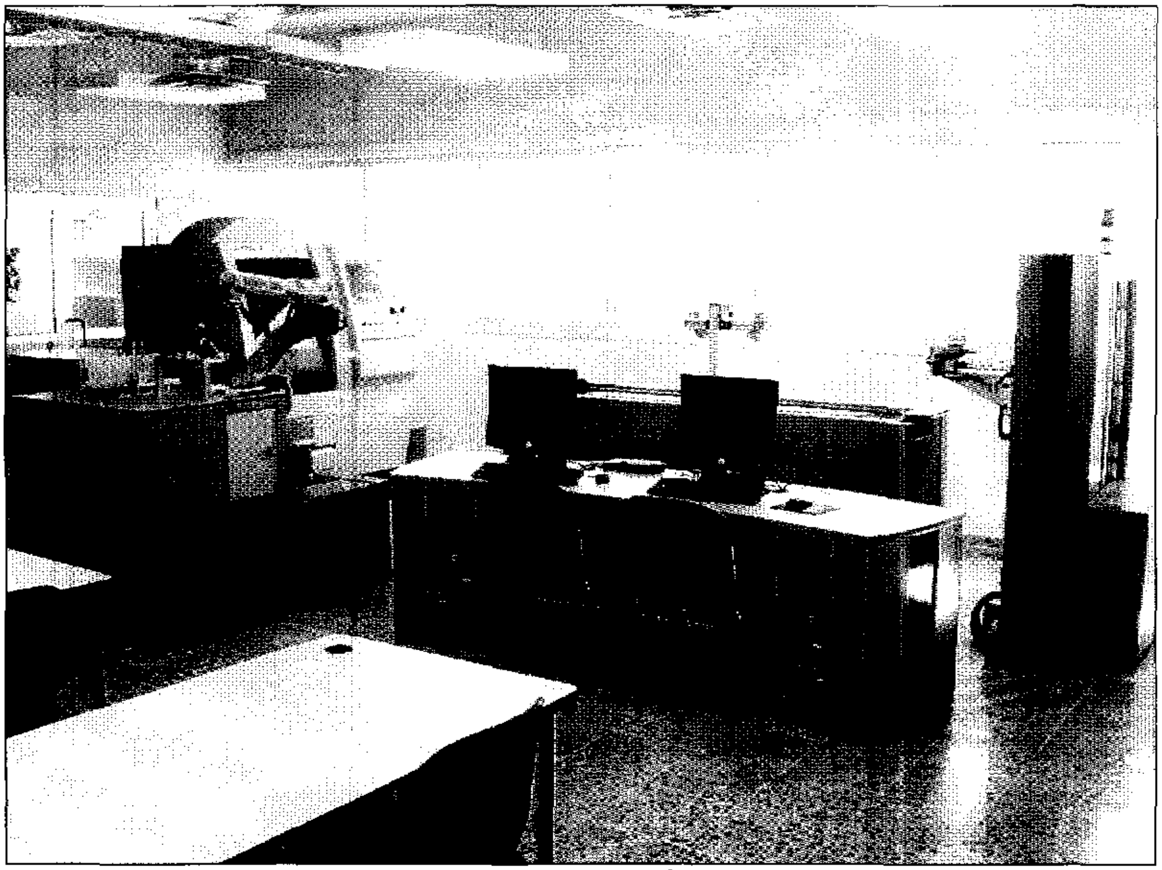


Figure 7.1 Mechatronic Manufacturing Cell

The objective of this work is to apply inclusive design in this cell briefly explained

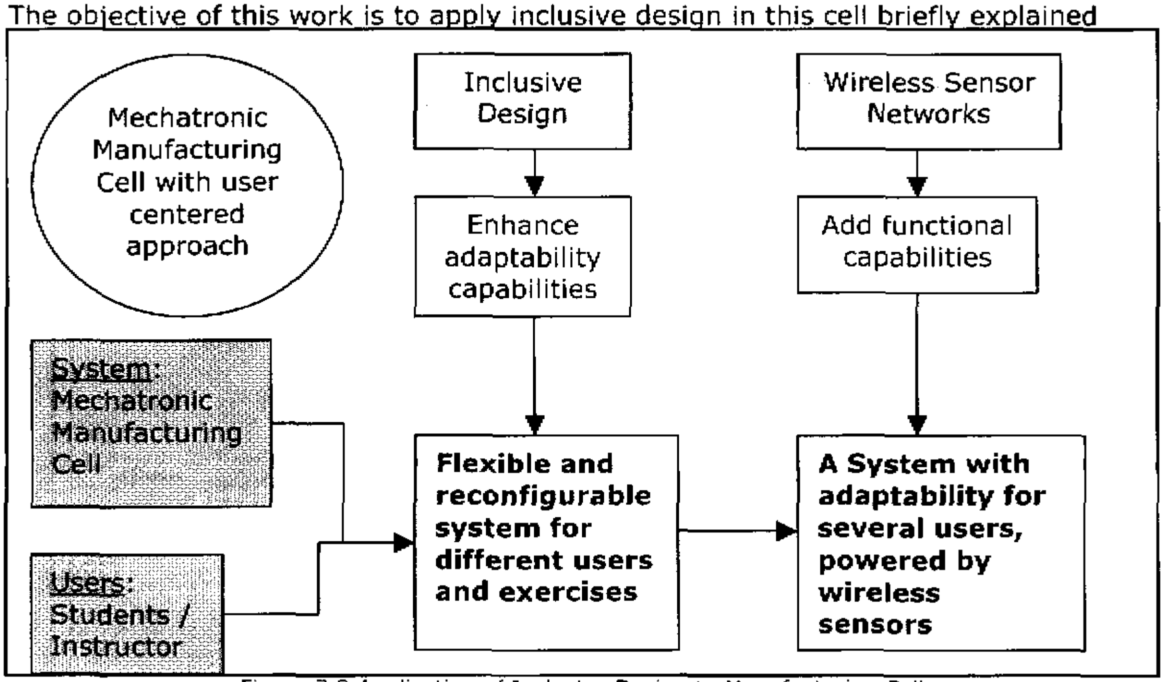


Figure 7.2 Application of Inclusive Design to Manufacturing Cell

The case study is based on the Monterrey Tech, Campus Monterrey mechatronic laboratory facility; the activities developed on this work are described here:

The objective is to improve a mechatronic manufacturing cell with user centered approach. A system is given, the mechatronic cell, and the users are defined as students and instructors whose utilize the cell to perform exercises.

The application of inclusive design approach is to improve the cell capabilities by adapting them to the user understanding, interaction and visualization. The result is a flexible and reconfigurable system for several users and also adaptable for different exercises.

The incorporation of wireless sensor networks allow the addition of functional capabilities to facilitate the user interaction, cell diagnosing and the physical arrangement of cell, also in the proposed application the WSN delivers improving on control configuration to support physical modifications, and allow changes in software to adjust the interface to users.

7.2 Scope of the Methodology Application

When a reconfiguring proposal is given, some aspects must be considered due to a scope level of application, in this case, the reconfiguring proposal only applies to a Cell Controller Level.

The cell controller level includes certain control types that are inherent to their own machines. All the modules are subjected to redistribution and reprogramming to achieve virtual and physical configurations that will be described later.

The configurations mentioned during the development of the methodology, will include functions and attributes of modules, also the positioning of them within the cell to comply with assembly, machining or other related configurations.

The virtual and physical configurations will be displayed in Unified Model Language diagrams with both functional and control descriptions for each configuration.

The current cell controller level scheme is shown in the following figure:

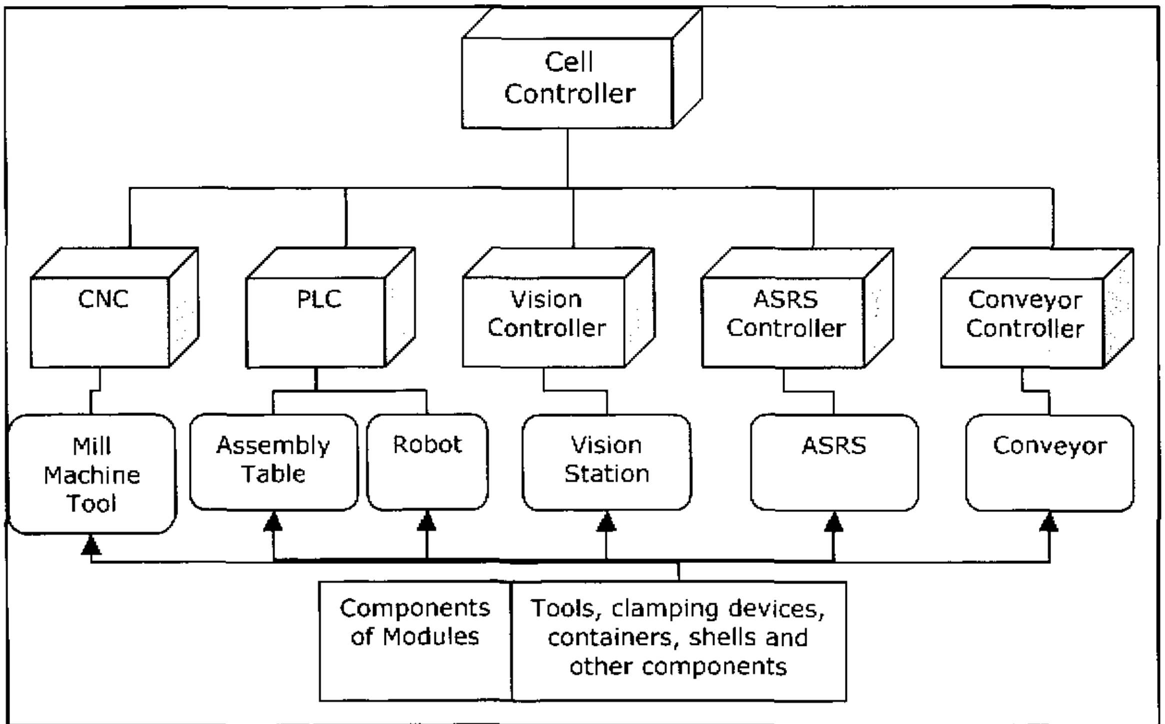


Figure 7.3 : Map of the controller level of the current cell

Physical configurations can be carried out regarding flexible control and software that support positional and functional changes. To facilitate the rapid configuration of cell, some assumptions must be considered.

7.3 Assumptions to be considered to perform the proper configurations

The physical modifications made to the cell can be done under the following assumptions:

- Control Module is reconfigurable; it can be adjusted to the different physical configurations.
- Software is adaptable and modifiable in order to enable cell capabilities
- Cell Modules (Robot, ASRS, Conveyor, CNC Machine Tool, Vision Station, Assembly Table) are able to move through the physical space.

The assumptions described above are current cell constraints that do not allow the physical movement of equipment. Due to this, it is necessary to make further research about the flexibility and reprogramming of control and software modules. The further research can be better described on the last chapter.

7.4 Evaluation of FMS to achieve reconfigurability characteristics.

7.4.1 Does the Cell have RMS Characteristics?

Actual Manufacturing Cell does not comply with the Reconfigurable Manufacturing System characteristics, as is explained here:

Modularity: It only has one component of each type, like one Storage system that only can be connected with one Conveyor. The number of components of the Cell is not enough to form groups by functional characteristics.

Integrability: The system only can be integrated in one way, with a flow shop layout from storage system to assembly and finally to the mill.

Convertibility: The components of this cell are fixed to the floor, they can not be moved, and it would take a lot of time changing the cell distribution to do a different task.

Diagnosability: The system is unable for detecting process quality, as product assembled or manufactured, neither can track products through processes.

Customization: It cannot be customized due to limited components of each type, the machines cannot be built around parts and does not provide the flexibility required.

A system that possesses these key characteristics has a high level of reconfigurability.

In order to have a reconfigurable cell, it would be necessary to take major components into modules. This rapid adaptability is possible by the use of mechanical modules, control modules, hydraulic and electric modules. Modules that can be exchanged and integrated represent a modular set.

7.5 Assessment of Flexible Manufacturing Cell

7.5.1 MODULARITY

Motion

- Are Modules light, easy to grasp, easy to handle?, do they require force to move and join with others?.
- *No, they do not have handles, and are fixed to the floor.*
- Are Modules easy to connect with others?
- *The interfaces are difficult to interconnect, and they require some adjustments*
- Is the Manufacturing system easily reconfigured by simply removing, adding or changing the constituents units or modules of the system?
- *No, the software and hardware is already predetermined and do not allow changes*

Sensory

- Do the modules have a visual identification to know what functions they cover?
- *No, they do not have icons neither other type of functions descriptions.*
- Do the modules have an auditive warning for coupling tasks?
- *No, they do not have auditive aids of coupling confirmation*

Cognitive

- Does the organization and categorization of modules allow the user to understand and learn quickly about how to integrate them?
- *Yes, they are capable of be understood.*

Control Software

- How many modules does the control module support?
- *It only supports the current capacity of modules it is designed to fit this system, the software supports more modules.*
- Does the control module have an easy user interface to reconfigure it?
- *No, the programming of control module require advanced knowledge*

7.5.2 *INTEGRABILITY*

Motion

- Does the user require too much force to move modules in the way of matching them?
- *All modules are fixed.*
- Does the placing of machine and control modules require a high coordination skill?
- *No, it does not require a high coordination skill, it is easy to perform.*
- Do the modules have a handy interface with user?
- *Yes, all modules have it.*
- Does the software have a friendly interface that allow user configure it quickly and correctly?
- *It requires advanced knowledge.*

Sensory

- Does the user identify the integrability of modules by perceiving visual identification and differentiation of each module, sub-module and component?
- *Yes, they identify the modules, sub-modules and components quickly.*
- Does the user can identify the suitable software for each module and process configuration?
- *Yes, the user know what software corresponds for each module and process*
- Do the system count with a notifying alarm that confirms the correct coupling of modules, sub-modules and components corresponding to their spatial distribution, height, orientation, declination, and other 3D constraints?
- *No, the system does not have this type of system.*
- Are the system, machine and control modules designed with interfaces for integration purposes allowing user to efficiently integrate hardware and software?
- *Yes, it is easy to reconfigure it virtually.*

Cognitive

- Is the system able to inform user about wrong settings and configuration of each module? *Only Robot and CNC Machine.*
- Does the user understand what possible configurations of cell can be done in order to satisfy his planned processes?
- *Yes, it is easy to understand.*

Control Software

- Does the control module support exchangeability of modules?
- *Yes, it allows the exchangeability.*
- How much time does the control module takes to reconfigure it in order to perform a module exchange? The least 1 2 **3** 4 5 The most (days)
- Does the integration is stable in terms of software and hardware?
- *It is not stable in the current cell configuration, but there is not a new configuration proved.*

7.5.3 CONVERTIBILITY

Motion

- Do the modules and components require force in order to fit and connect them?
- *They are easy to fit in their own modules*
- Can user make the proper adjustments, screwing up, clinch and other with a minimum force?
- *Yes, with minimum force.*
- Do the modules have a proper interface that allows the correct modification and prevent to users of errors during the work?
- *It does not have mistake prevention features.*
- Can user make the proper adjustments by quickly changing, removing and modifying components in machining modules with a little accuracy and precision?
- *Yes, it is easy, vertically only.*

Sensory

- Do the machine, assembly and control elements have a visual attach to make them identifiable when changeover is required?
- *Only id labels in the two cells*
- Can user identify the belonging components and sub-modules of each major module by a visual tag or a screen that displays in real-time the position of each module pointing out if they are well or wrong placed?
- *This is a future plan*
- Does the system counts with sound alarms to prevent of errors during the setup and changeover time?
- *No, the modules does not have any alarm to prevent errors.*

Cognitive

- Can user understand and learn how wrong settings are put right?
- *Only on zero of workpiece and tooling compensation.*
- Does the user know what component or sub-module corresponds to a determined major module?
- *The user determines what components are going to be placed on each module.*
- If a failure happens, is the user able to identify what is the concerning of system halting and correct the problem adequately?
- *Yes*

Control Software

- How many components are allowed to change by each module?. There is not limit on components allowed by module
- Is it the software easy to reconfigure in order to recognize new components added to modules? Yes, the software can be reconfigured to recognize more components.

7.5.4 DIAGNOSABILITY

Motion

- Is the system able to identify quality problems attributing them to human error?
- *No, it only uses control variables that identifies product quality.*
- Is the system able to notify user the problems concerning to product flow, machine operation and modules arrangement?
- *No, only detects product tracking.*

Sensory

- Does the cell have a scanning system that provides status information of each cell element?
- *Yes, through industrial network with PLCs*
- Does the cell diagnose its own system with an alarm during the machine, assembly or inspecting operation?
- *Robot has auditive/visual alarms, CNC machine has visual alarm, Vision station has a visual alarm.*

Cognitive

- Does the user know what is happening on the cell in real time when a problem occurs?
- *Not with accuracy, the user does not why occurs.*
- Is the user able to detect quality problems during the process?
- *Only on vision station.*
- Can the user assign a quality problem to a specific operation by knowing what machine failed due to human error?
- *Only with user experience, the machining process could be done but the user does not know if it is well done.*

Control Software

- Is the software able to detect programming errors?
- *Yes, during the compilation process.*
- Is the software able to detect product quality fails?
- *No, it does not detect fails on product quality during the process, but only detects on vision station on final product.*
- Is the software able to prevent mistakes of user during programming or by product out of specification?
- *Yes, it has that capacity.*

7.5.5 CUSTOMIZATION

Motion

- Are the modules capable of moving through the cell?
- *No, but the control is capable.*
- Do the modules have levels of height, distance and orientation?
- *The modules does not have these features*
- Do the modules have a default measure to couple each other?
- *Yes, but only the robot can displace in a rail.*

Sensory

- Is the system able to detect what components are used in a determined process?
- *Yes, it detects the components immediately.*
- Is the system able to detect errors in the cell configuration about matching incompatible modules or placing sub-modules in other non corresponding modules?
- *It does not detect any errors, i.e. a container can be placed anywhere.*

Cognitive

- Does the user understand the logic arrangement of cell modules, components and sub-modules in order to achieve a correct and functional cell configuration?
- *Yes, the user understand what arrangement of modules are correct and functional.*

Control Software

- Is the software able to detect changes in the distribution of modules within the physical space?
- *No, it does not detect those changes.*
- Is the software able to determine what processes are going to be undertaken (i.e. assembly, machining, etc) according to the arrangement of modules?
- *No, it is not able to interpret the purpose of arrangements, only related to communication issues.*

7.6 Reconfiguring Proposal

The author proposes the joint of the two manufacturing cells, once having this, there will be more choices to mix cells components and to accomplish with the reconfigurable manufacturing systems characteristics.

According to the RMS, they are implemented on large manufacturing systems, due to this, cells must own two or more components of the same type (i.e. 2 mill machines) to be reconfigured and distributed within a given layout. The objective of unification of both cells is the ability to swap the cell components with different purposes oriented to requisites of exercises, processes, customization, etc.

The challenge in this case is to design an optimum reconfigurable cell in terms of productivity, functionality and reconfiguration time.

Once having the joined cells, they would have the following assumptions given by RMS key characteristics:

Modularity: Considering Modularity, it comprises the sectioning of cell components into groups, to adjust them in certain types of configuration. Groups could be of machining, assembling, transporting, storing, controlling, and more. By combining this, the cell could be configured to work as a job shop, by adapting the components according to the different jobs required.

Integrability: With different work configurations, cell components would have the connectivity each other to combine functionalities (i.e. robot with conveyor to remove products out of specifications) also the cell could be prepared to interconnect more components as is required for capacity and variability of processes, it would have the upgradeability to support more machines, conveyors, robots, etc.
Example:

Convertibility: The system must have the easiness to reconfigure the modules, interconnect in few minutes and rearrange them to fulfill the several processes as components are needed.

Diagnosability: The control system will provide timely information about the process flow, detecting the flow of product, adjustability of components, errors and

Customization: Configure the layout and components according to the user requirements, the user will know how to use the available components.

The proposal is better viewed on the demonstration of the concept that shows the modeling and simulation of the different configurations that can be carried out in the single cell and in an integrated cell as the reconfiguration proposal determines.

7.7 Demonstration of the Concept and Simulation

7.7.1 PHYSICAL AND VIRTUAL CONFIGURATIONS

The present demonstration of the concept is divided into two approaches; the first one is described by physical and virtual configurations that can be carried out by the users and laboratory instructors. In the other hand, there is a simulation procedure to demonstrate the RMS characteristics and the user interaction with a reconfigured manufacturing cell.

Thus, in a first order, the descriptions of both configurations physical & virtual are represented in Unified Model Language (UML) to show the functions and attributes of modules and components, demonstrating a product flow sequence and operations of cell elements. Also the state diagrams used in this phase, determine the logic sequence of control module that has to be performed to integrate elements and deliver the required exercise in both assembly and machining configurations. There were developed activity and state diagrams. The activity diagrams describe the functions carried out by each module and describe the flow of workpiece through the cell modules.

Furthermore, the arrangement of modules of both physical and virtual configurations can be visualized on the simulation with DELMIA® software, a brief description of reconfigurability achieving and user interaction will be written after each display image.

- **Physical Configuration**

  A physical arrangement, the sum of resources, integrated to work on simultaneous and complementary operations using all the modules or some of them.

  Objective: Demonstrate that the configurations based on redistribution of cell layout can be deployed by the user, complying with the inclusive design approach.

  Development: The proper description of the physical configuration can be observed in the next UML activity diagram.

- **Virtual Configuration**

  Consider the current cell, in a first phase machine and assemble from the original product from ASRS. Finished product is stored again in the ASRS. In a second phase, the ASRS works together with the conveyor, which has an inspection station to verify the assembly. The second phase, the Robot interacts with the machining station without using assembly operation (assembly table)

  Objective: Determine how to have different work configurations for a fixed configuration in the manufacturing cell.

  Development: The proper description of the virtual configuration can be observed in the next UML diagram.

VIRTUAL CONFIGURATIONS

7.7.2 UML Activity Diagram for Virtual Assembly Configuration - Functional

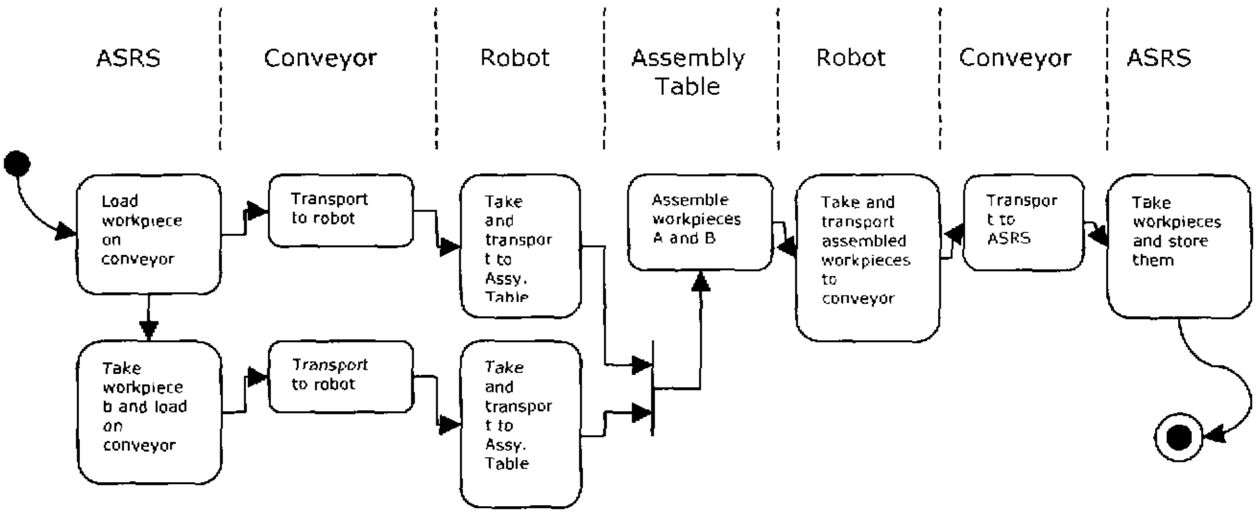


Figure 7.4

7.7.3 UML Activity Diagram for Virtual Machining Configuration - Functional

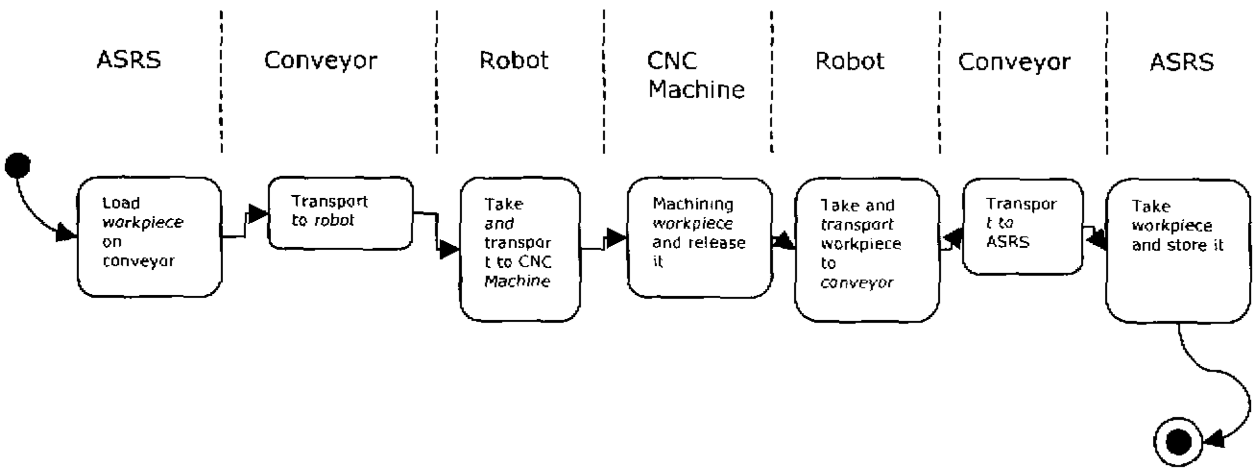


Figure 7.5

7.7.4 UML State Diagram for Virtual Assembly Configuration - Control

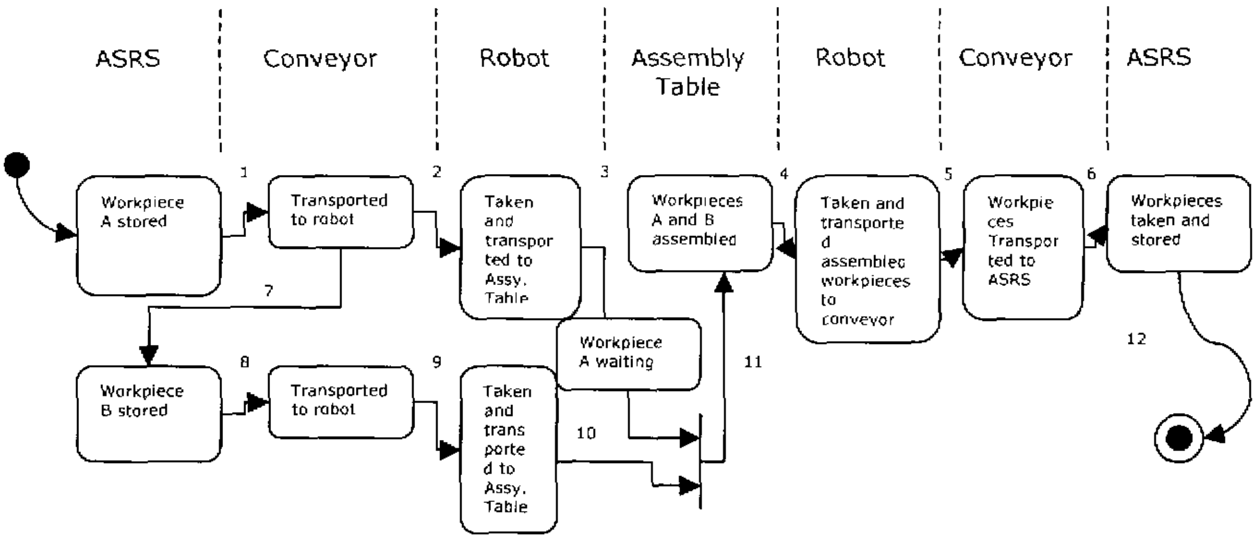


Figure 7.8

Control Instructions

1. Activated by user
2. Conveyor sends signal to PLC and Robot performs its operation
3. Robot gets ready and wait for next workpiece
4. Robot finish its assemble operation and performs the next
5. Robot executes the transporting operation
6. Robot sends signal to conveyor
7. Conveyor sends signal to PLC and ASRS delivers the next workpiece
8. ASRS sends signal to PLC and Conveyor begins its transporting operation
9. Conveyor sends signal to PLC and Robot take and transport workpiece
10. Robot finishes its operation to begin the assembly operation
11. Robot performs the assembly operation
12. ASRS stores the assembled workpieces and send a signal to PLC to confirm finished operation

7.7.5 UML State Diagram for Virtual Machining Configuration - Control

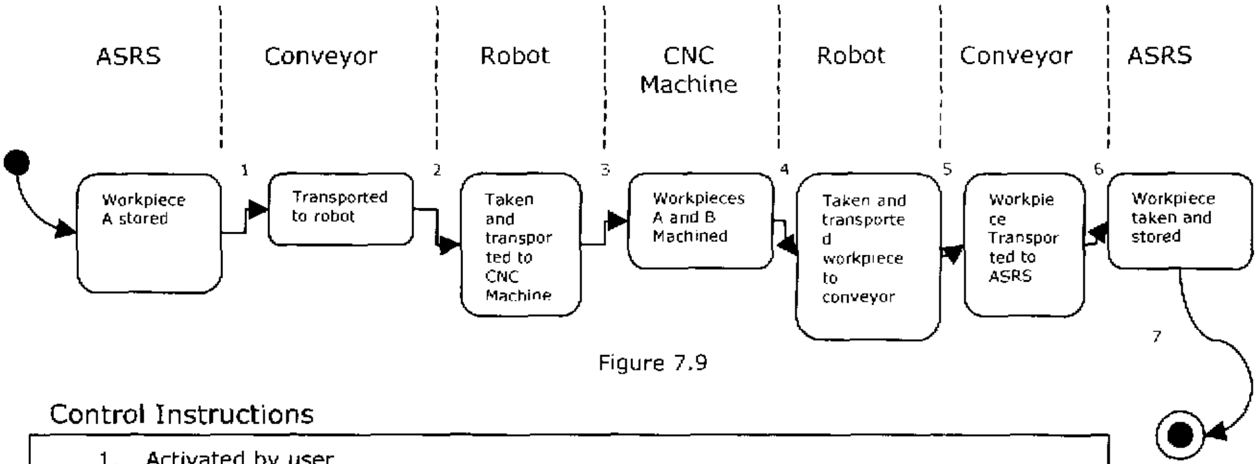


Figure 7.9

Control Instructions

1. Activated by user
2. Conveyor sends signal to PLC and Robot performs transporting operation
3. Robot delivers workpiece and sends signal to PLC when Robot gets away from CNC Machine, and CNC Machine begins the machining operation
4. CNC Machine finishes its operation and sends signal to PLC and then Robot take the workpiece to deliver on conveyor.
5. Robot delivers workpiece on conveyor and sends a signal to PLC and then Conveyor transports the workpiece to the ASRS
6. Conveyor transports the workpiece and sends a signal to PLC and then ASRS takes the workpiece to store it.
7. ASRS sends signal to PLC to confirm finished operation

PHYSICAL CONFIGURATIONS

7.7.6 UML Activity Diagram for Physical Assembly Configuration - Functional

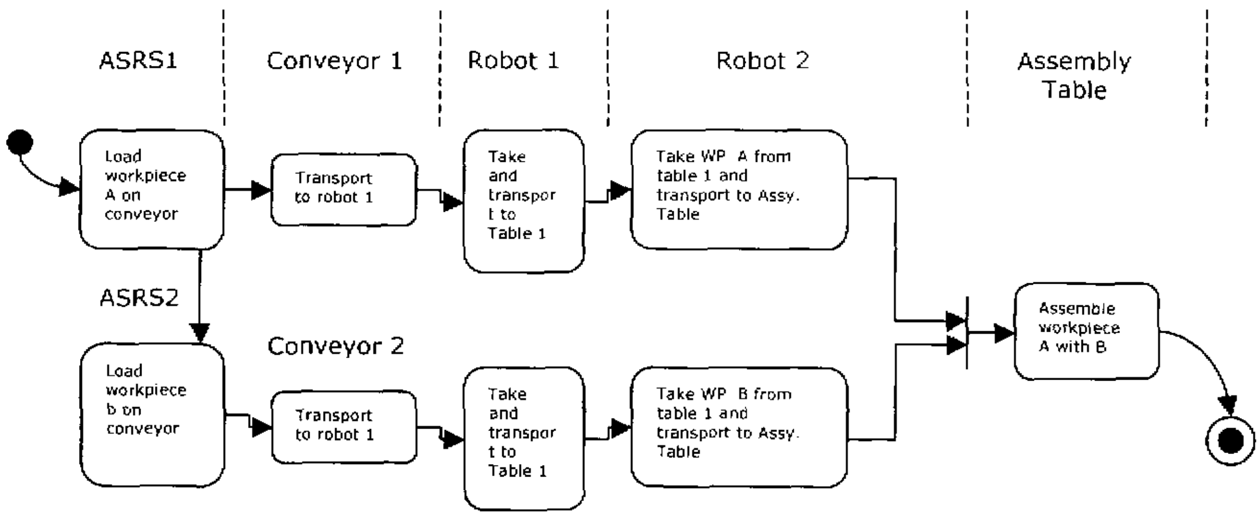


Figure 7.10

7.7.7 UML Activity Diagram for Physical Machining Configuration - Functional

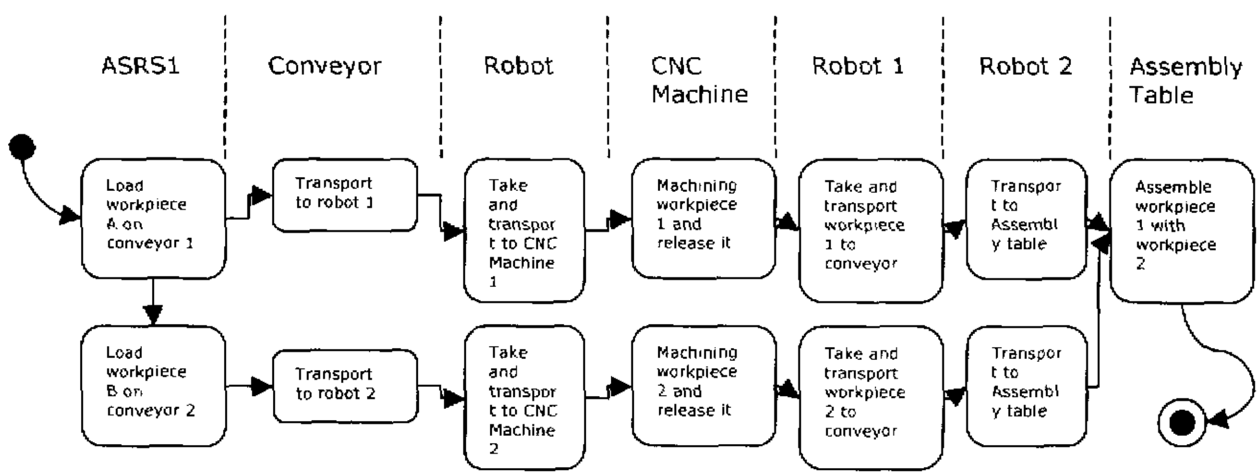


Figure 7.11

7.7.8 UML State Diagram for Physical Assembly Configuration - Control

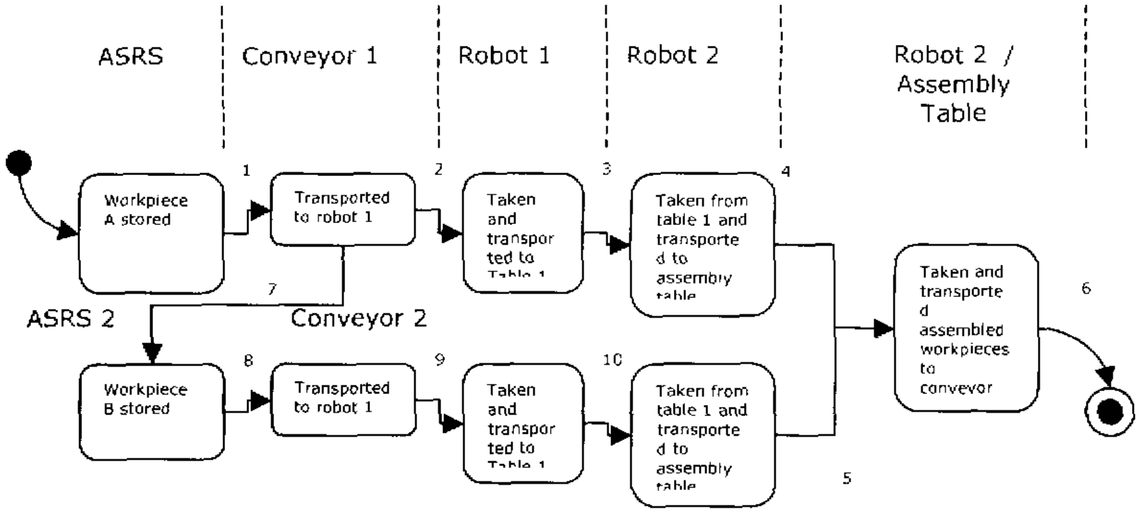


Figure 7.12

Control Instructions

1. Activated by user
2. When Conveyor 1 finishes the transporting operation, it sends a signal to PLC and Robot 1 takes the workpiece
3. Robot 1 places the workpiece on table 1 and sends a signal to PLC and Robot 2 takes the workpiece and place it on assembly table
4. Robot 2 sends a signal to PLC and Robot to confirm waiting for workpiece
5. Robot 2 sends a signal to PLC to confirm that the workpiece B is already placed on Assembly table to begin assembly operation
6. Robot 2 sends a signal to PLC to confirm finished operation
7. Conveyor 1 sends a signal to PLC and ASRS2 unloads workpiece B to deliver it in Conveyor 2.
8. ASRS2 sends a signal to PLC and Conveyor 2 begins the transporting operation
9. Conveyor 2 finishes transporting operation and sends a signal to Robot 1 to take the workpiece
10. Robot 1 sends a signal to PLC and Robot 2 takes the workpiece B from table 1

7.7.9 UML State Diagram for Physical Machining Configuration - Control

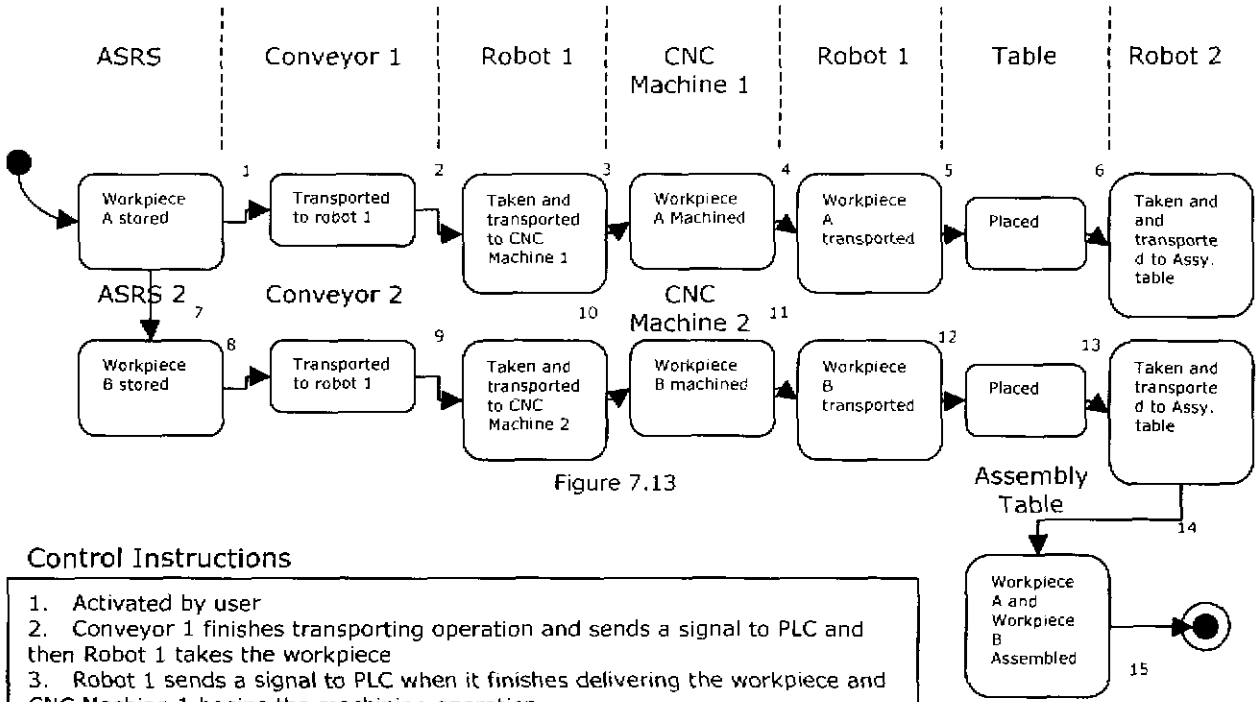


Figure 7.13

Control Instructions

1. Activated by user
2. Conveyor 1 finishes transporting operation and sends a signal to PLC and then Robot 1 takes the workpiece
3. Robot 1 sends a signal to PLC when it finishes delivering the workpiece and CNC Machine 1 begins the machining operation
4. CNC Machine 1 sends a signal to PLC and Robot 1 takes machined workpiece
5. Robot 1 places the workpiece A on table and sends a signal to PLC to confirm workpiece positioning
6. PLC sends a signal to Robot 2 to begin its transporting operation to assembly table
7. ASRS 1 sends a signal to PLC and ASRS 2 begins the unload of workpiece
8. ASRS 2 finishes delivering workpiece and then sends a signal to Conveyor 2 to begin the transporting operation
9. Conveyor 2 sends a signal to PLC and Robot 1 takes the workpiece from conveyor
10. Robot 1 sends a signal to PLC and then CNC Machine 2 begins the machining operation
11. CNC Machine 2 finishes its operation and sends a signal to Robot 1 to take the workpiece
12. Robot 1 places the workpiece B on table and sends a signal to PLC to confirm workpiece positioning
13. PLC sends a signal to Robot 2 to begin its transporting operation to assembly table
14. PLC sends a signal to Robot 2 to perform the assembly operation of both workpieces

7.8 SIMULATION

7.8.1 VIRTUAL CONFIGURATION

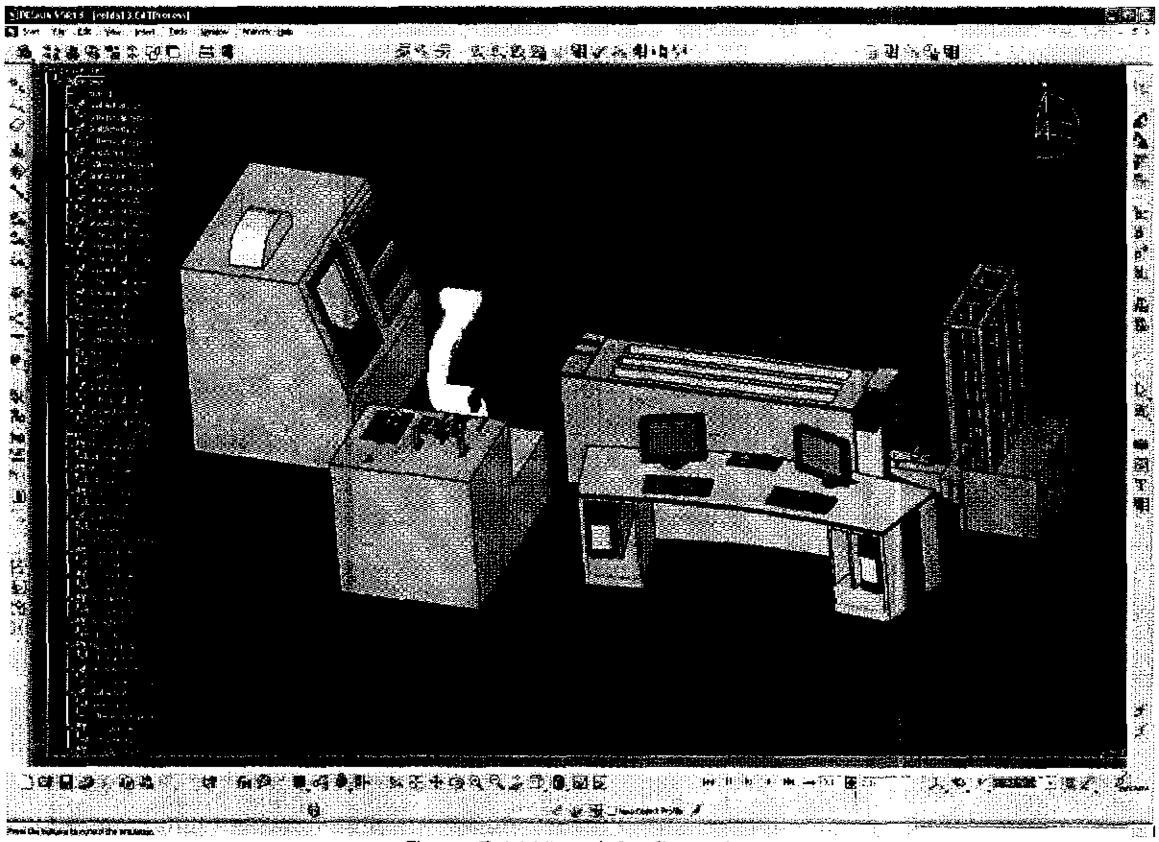


Figure 7.14 Virtual Configuration

DESCRIPTION OF VIRTUAL CONFIGURATION

Fixed components: As can be seen, in this virtual configuration all modules are fixed in their original positions, no physical changes can be made.

Product flow: Product flow can be done in one way, this is coming from the ASRS, transported through the conveyor and taken by the robot to do assembly of machining processes.

Modules utilized: Modules can be utilized by selecting them from the software module, this is, if an assembly configuration is required, all modules will be selected to work with exception of CNC Machine.

Functions and attributes utilized: The functions and attributes that must be carried out, the user will be responsible of using them

Contribution to Inclusive Design

Users can interact with the cell, by selecting modules in the software module and know each function that are required to be performed in the cell, and his sensory capability can be aided by quickly identification of modules, operations and components.

FUNCTIONS AND ATTRIBUTES OF VIRTUAL ASSEMBLY CONFIGURATION

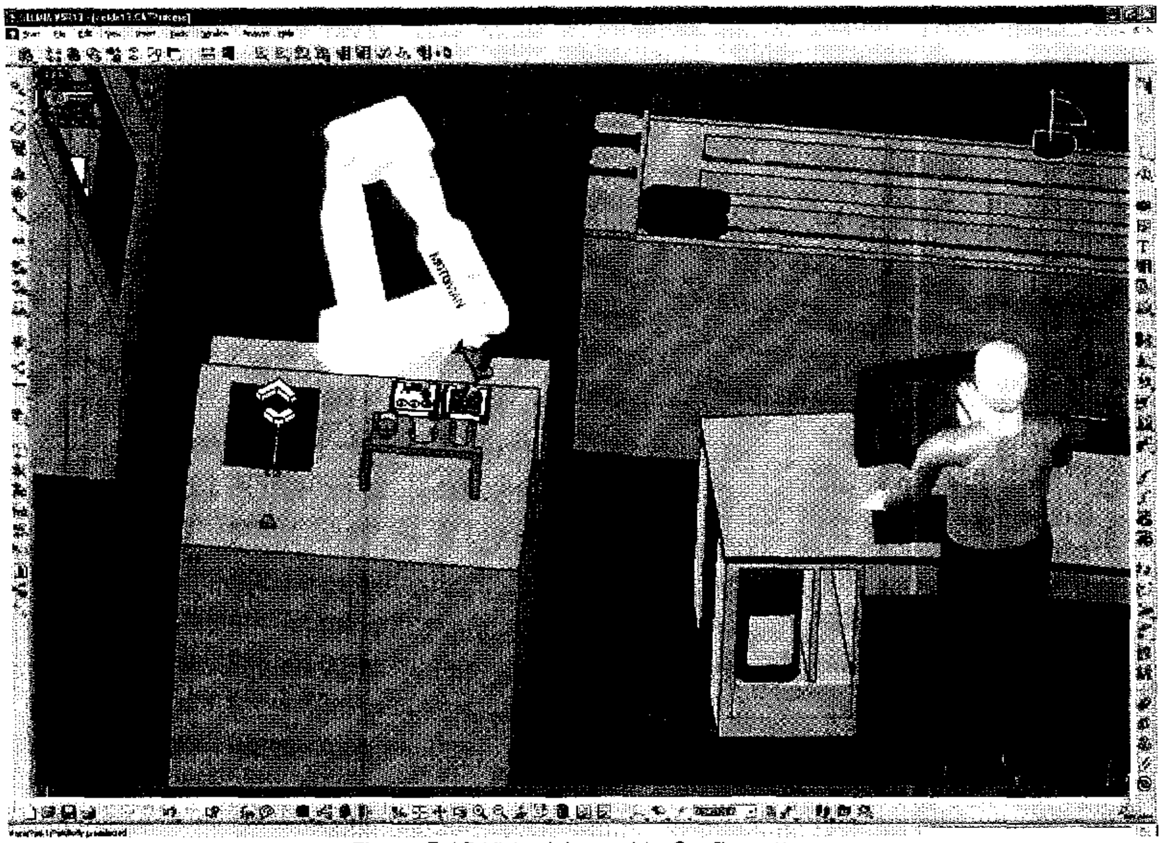


Figure 7.15 Virtual Assembly Configuration

Contribution to Inclusive Design

User selects in the software module the modules and components required to assemble by simply clicking on the easy-to-use program.

User can visualize what tools are necessary to perform the assembly operation and can make the tool change

User understands what effects are those of programming all modules, and the operations that can be carried out by the robot (transport and assembly).

Contribution to Reconfigurable Manufacturing System

Convertibility: User can make changes to the programming and robot's components to do a different assembly operation.

Modularity: User can interact and demonstrate how some minimum modules can perform the process required.

Customization: It is demonstrated that the user can select and configure the necessary modules for any operation with fixed modules.

FUNCTIONS AND ATTRIBUTES OF VIRTUAL MACHINING CONFIGURATION

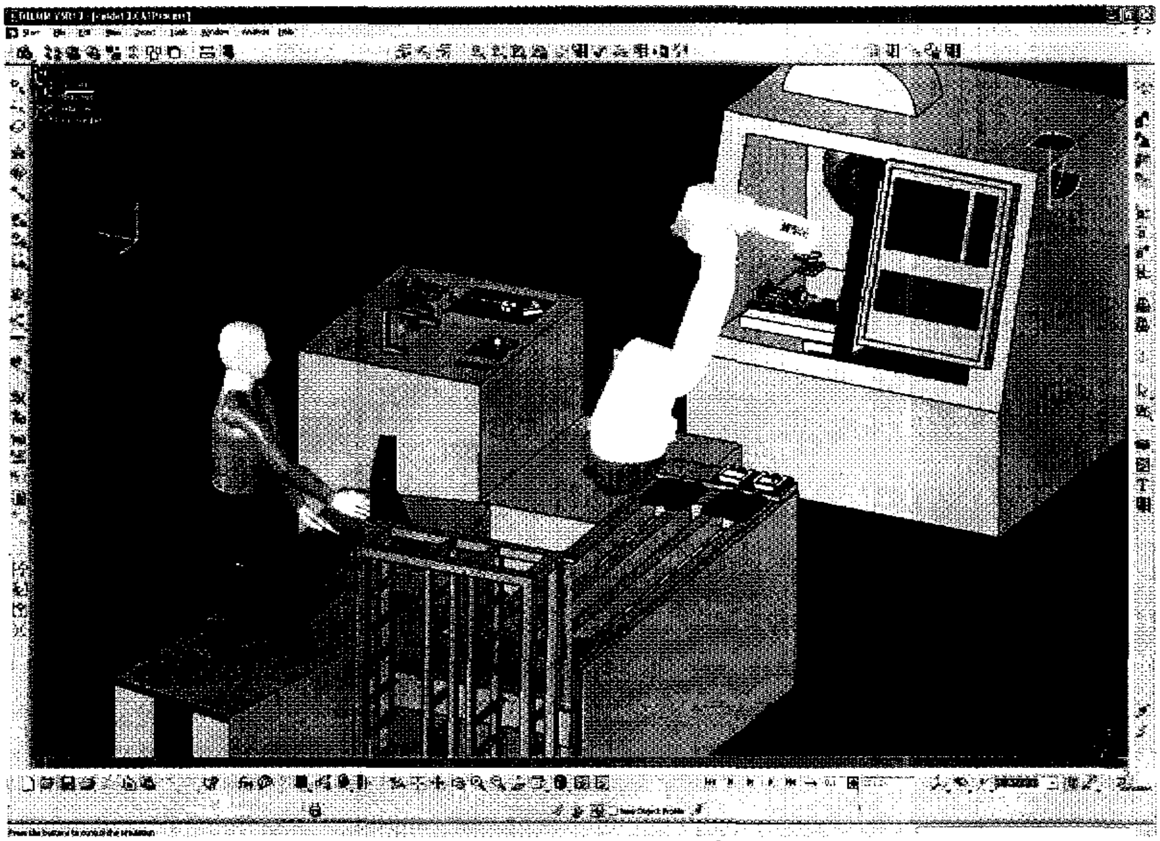


Figure 7.16 Virtual Machining Configuration

Contribution to Inclusive Design

User selects in the software module the modules and components required to assemble by simply clicking on the easy-to-use program.

User can visualize what tools are necessary to perform the machining operation and can change a tool or clamping device in the CNC Machine.

User understands what effects are those of programming and integrating all modules to execute a machining process, from storing to machining and to storing again.

Contribution to Reconfigurable Manufacturing System

Convertibility: User can setup the machine because of the addition of a new tool and *introducing a new CNC program.*

Diagnosability: User can diagnose the current machining status and track the product from the storing state until the machining process.

Customization: Here the user can add a new component, this is the CNC Machine that is necessary (and well selected) by the user to perform machining operation.

7.8.2 PHYSICAL CONFIGURATIONS

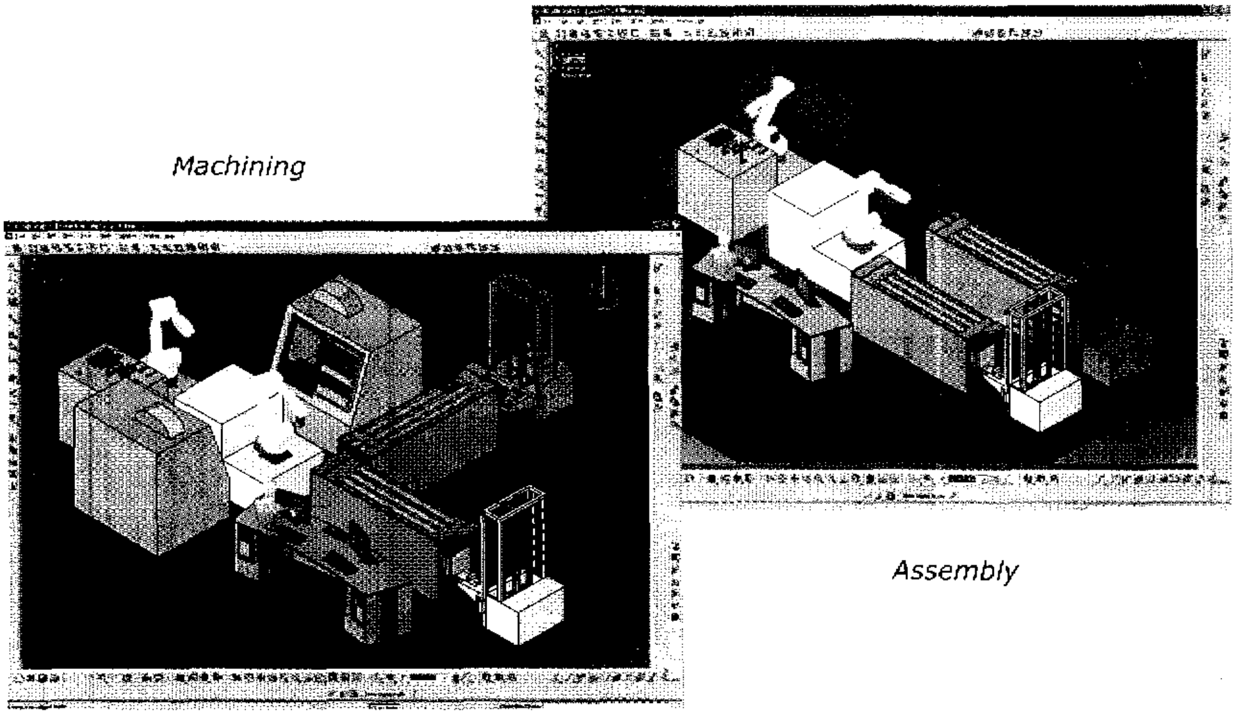


Figure 7.17 Physical configurations

Contribution to Inclusive Design

User can redistribute the layout according to the required operations; the physical moving of modules can be performed easily with minimum force.

User can integrate and visualize each module according to their functions and distribution in the layout.

According to the required process, user is able to select the proper modules and reconfigure the software for a determined exercise.

Contribution to Reconfigurable Manufacturing System

Modularity: Modules are selected according to the functions needed.

Integrability: All modules with their respective components are integrated and interconnected to the layout.

Convertibility: Some changeovers to modules are performed for redistributing cell.

Diagnosability: The software allows to track the product and to detect quality problems.

Customization: The modules are grouped into a predetermined layout to perform one or more activities.

PHYSICAL CONFIGURATIONS

7.8.3 ASSEMBLY

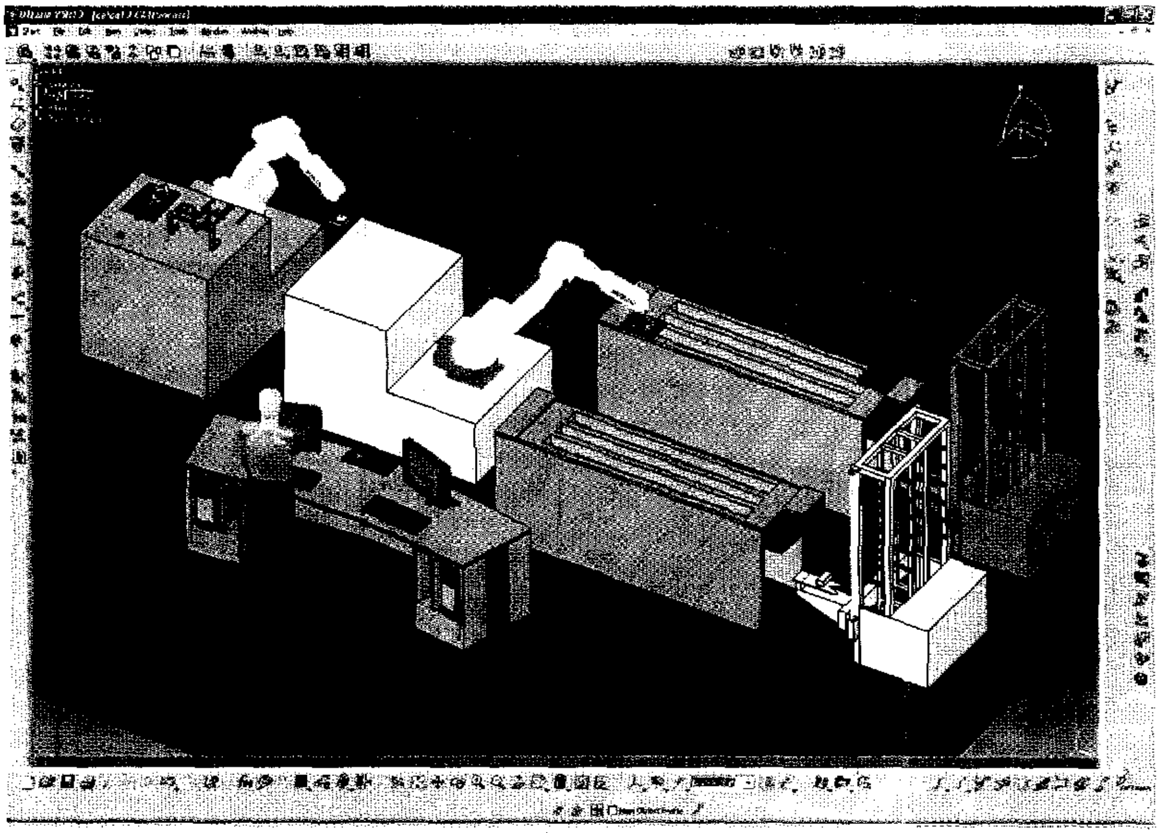


Figure 7.18 Physical Configuration - Assembly

DESCRIPTION OF ARRANGEMENT:

In this cell arrangement, there are three different workpieces that are going to be assembled, the conditions are:
Cell must have the following modules:
(2) Robots
(2) ASRS

User must know the following obligatory actions:

⇒ Configure the control module to support the new arrangement
⇒ Place at least one workpiece in one ASRS
⇒ One robot is for transporting and the other one is for transporting and assembly
⇒ Two conveyors must be oriented towards the transporting robot.
⇒ Transporting robot is necessary to balance the product flow speed of conveyor and ASRS.

7.8.4 PHYSICAL MACHINING CONFIGURATION

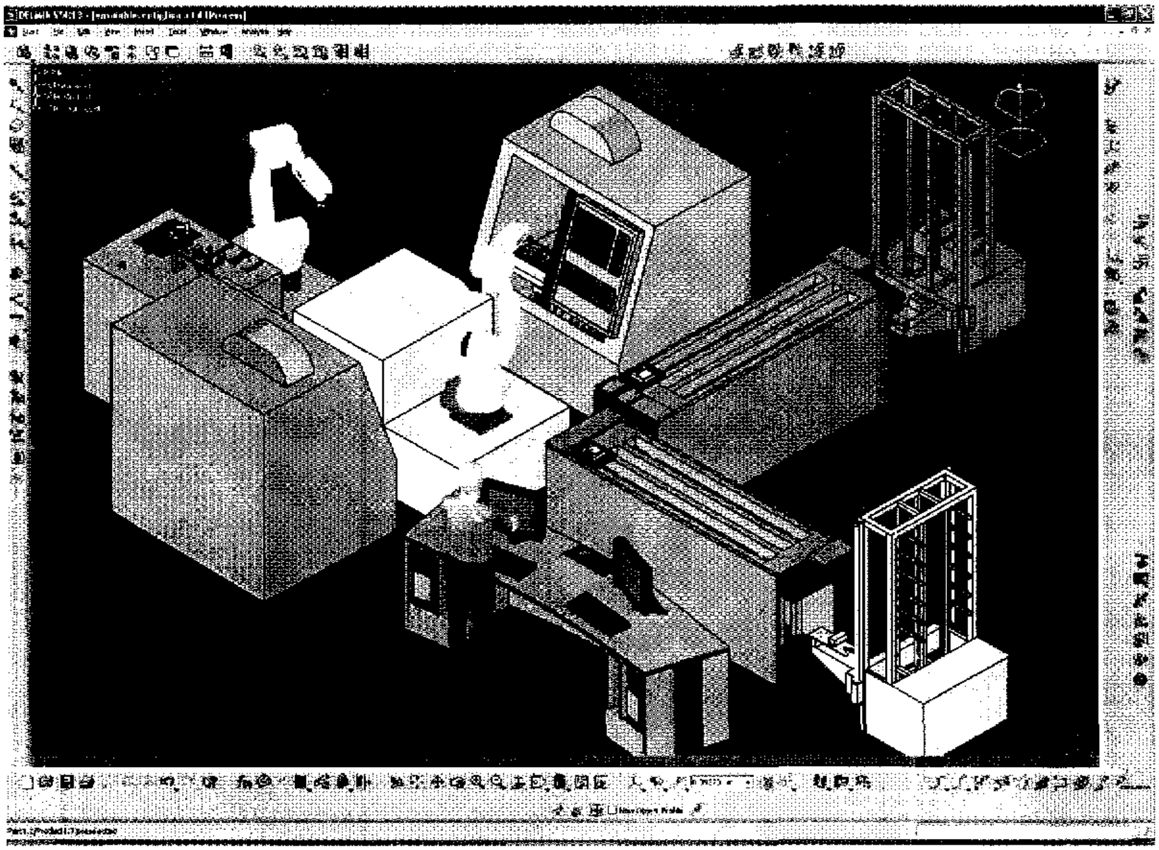


Figure 7.19 Physical Machining Configuration

DESCRIPTION OF ARRANGEMENT:

In this cell arrangement, there are four different workpieces (A,B,C & D) that will be machined and then assembled.

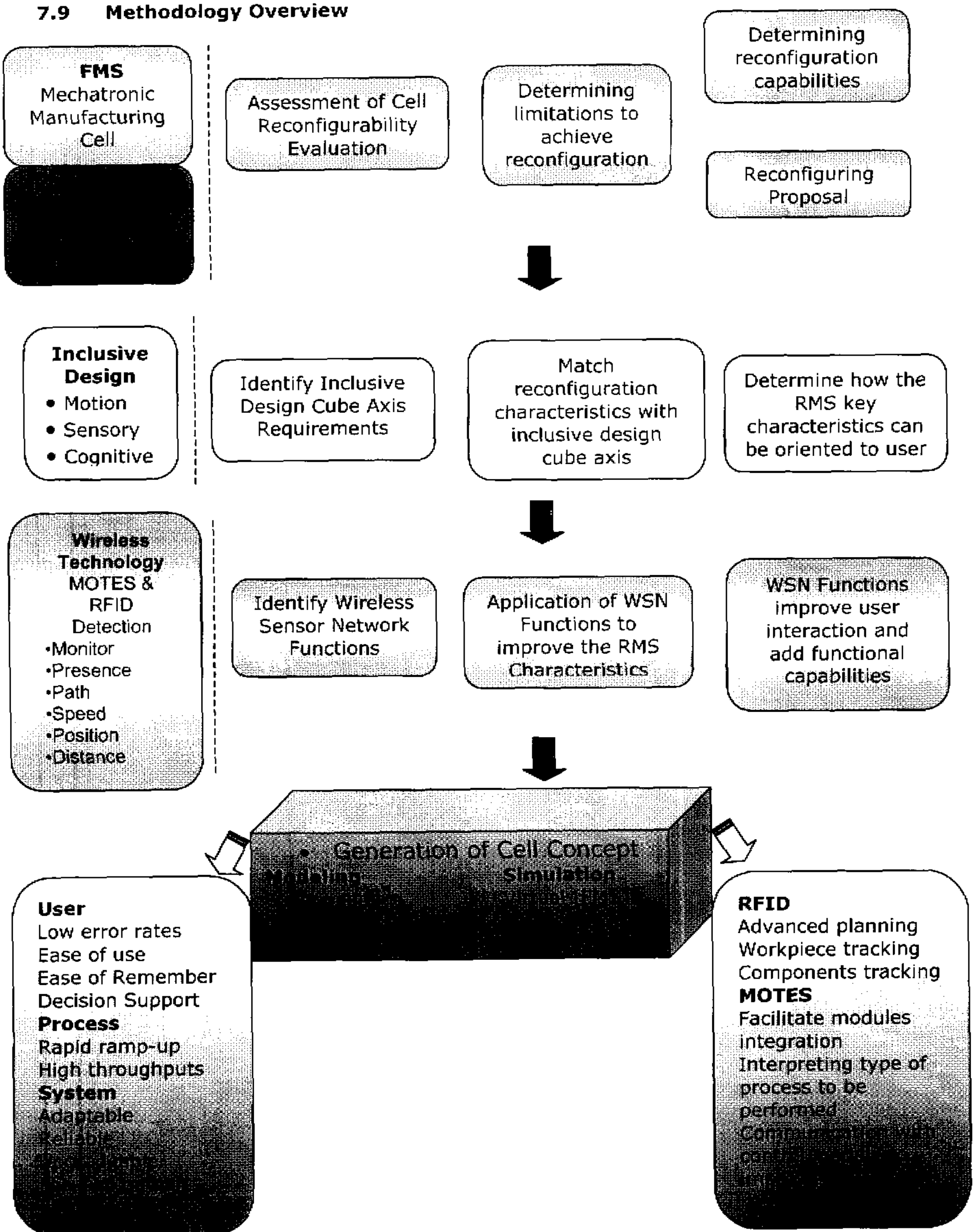
The process consists of first machining the workpiece C and workpiece D, then the workpieces A and B arrive to the Robot 1 to be transported to the Robot 2 and wait for the workpiece C and D until their machining is finished. Then, Robot 1 takes both pieces (C & D) and transported to the Robot 2 to perform the assembly operation and deliver the finished product.

Arrangement conditions
Cell must have the following modules:
(2) Robots
(2) CNC Machines
(2) ASRS

User must know the following obligatory actions:

⇒ Configure the control module to support the new arrangement
⇒ Place two workpieces in one ASRS 1 and the other ones in the ASRS 2
⇒ Robot 1 is for taking the workpieces from the conveyors, supply workpieces to machines, and extract and deliver workpieces to robot 2. Robot 2 must only take workpieces from Robot 1 and assemble.
⇒ One workpiece per CNC machine
⇒ Transporting robot is necessary to balance the product flow speed of conveyor and ASRS.

7.9 Methodology Overview



7.10 Action Research Cycle in RMS

The steps followed by the author during the Action Research process applied in this case study of Reconfigurable Manufacturing Systems, are:

RECONFIGURABLE MANUFACTURING SYSTEM

Revised Plan

Create a Methodology for a Flexible Manufacturing Cell in order to achieve reconfigurability (RMS) with the integration of Inclusive Design to add characteristics (motion, cognitive, sensory) for users;

The integration of WSN to add functionality and support for Reconfigurability (Modularity, Integrability, Convertibility, Diagnosability, Customization), and facilitating the user interaction with the RMS.

Also, the plan contemplates the following tasks:

- A Methodology that incorporates Inclusive Design methods to evaluate FMS to determine its Reconfigurability.
- Application of the Evaluation Methodology to a FMS in order to identify
- Demonstrate how the methodology can be applied to a Mechatronics Cell

Act & Observe

- Development of a Methodology for a FMC to convert it into RMS achieving Inclusive Design goals.
- Development of a Methodology that incorporates WSN to add functionality to a existing FMC.
- Development of a Evaluation Methodology to assess the reconfiguration capability of for a cell.
- Application of such evaluation methodology to determine Reconfigurability Levels.
- Determinate critical factors and key characteristics of RMS, which can be improved by WSN and consequently the adaptation of a FMC to the inclusive design approach.

Reflect

- A RMS with its key characteristics (Modularity, Convertibility,...) can be oriented to satisfy the three qualitative axis of the Inclusive Design Cube: Motion, Cognitive and Sensory.
- The use of WSN can facilitate to the user the correct interaction with an RMS.
- Inclusive Design approach makes a FMC adaptable to users, as it is actually adaptable to a variety of products.
- Any user can understand and interact with the RMS key characteristics through making them easily identifiable and manageable.
- Most of the tools used in this research cycle can be implemented in other projects to enhance their characteristics with inclusive design approach.

CHAPTER 8 - RESULTS AND CONCLUSIONS

8.1 Results

The following results were achieved in the development of this research job:

- Development of a methodology to design assistive mechatronic products with the improvement of inclusive design approach.
- Demonstration of the methodology with the conceptual design of three products.
- Development of a methodology to evaluate Flexible Manufacturing System in order to determine its reconfigurability capabilities using Inclusive Design concepts.
- Use of Inclusive Design concepts to enhance reconfigurability issues in flexible manufacturing system.
- Identification of how wireless technology functionalities are applied to a Reconfigurable Manufacturing System in order to improve and support its key characteristics.
- Case study of manufacturing cell with the modeling of functional and control behavior.

8.2 Conclusions

The application of Inclusive Design concepts in the development of Mechatronic Products contributed to:

- The Inclusive Design is a very useful tool that can and should be integrated into all design processes, whether for products or services, with the responding to the needs and wants of the widest possible range of users.
- The inclusive design cube and users pyramid are tools that provide useful information about user to determine his needs and to provide technical specifications related to the product to be designed.
- The Action Research methodology helped the author to apply the inclusive design concepts in the product conceptual design and generate a reflection of this application to refine a plan of inclusive design study that was applied later in a flexible manufacturing system.
- The development of the case study was important due to the opportunity of considering the user limitations that restrict the usability and acceptability, and to provide effective responses with products that achieve his special needs.
- When developing a product concept, the author noticed that if a product covers the more severely disabled user needs, consequently it is more automated and it can cover the needs and wants of other users.

- The application of inclusive design concepts is not limited only to satisfy disabled people needs, but also is conceived to assist fully able people.
- Wireless technology is a tool that improves product functionality with sensing and then responding to predetermined actions, expected and unexpected events.
- The sensibility of the more disabled people, the more automatic products are required. And the more assistive the product is, it can be used by a wider range of population, in other words, it is more inclusive!

The application of Inclusive Design concepts in the development of Reconfigurable Manufacturing Systems contributed to:

- The Inclusive Design is a very useful tool that can be integrated in the cell reconfiguration through the addition of Inclusive Design Cube axis in the five key characteristics of reconfigurable manufacturing systems, to determine how each RMS characteristic could be oriented focusing on user interaction.
- The Action Research methodology helped to apply the reflection based on the primary application of inclusive design concepts in mechatronic product design and next to refine the plan in order to apply the ID concepts in the reconfiguration of flexible manufacturing system.
- The application of inclusive design cube in the analysis of the flexible manufacturing system determined the major limitations involved in modules to carry out a proposal based on inclusive design benefits oriented to user.
- The author highlights that Inclusive Design concepts were applied in the cell reconfiguration to improve ease of learning, efficiency of use, ease of remembering, low error rates facilitating the user interaction with the reconfigured system, and supporting the user decisions for customization purposes.
- The development of the case study was important to show the wireless sensor networks applications that can be performed within a manufacturing cell, through the enhancing of reconfigurable manufacturing system characteristics, such modularity, integrability, convertibility, diagnosability and customization.

8.3 General Conclusion

Inclusive design is a new approach that must be applied in the development of new products and improvement of services, the reason is to obtain a well satisfied user that interacts with an entity that its purpose is to facilitate its usability and acceptability.

8.4 Further Research

- Carry out the inclusive design approach to the subsequent stages of mechatronic product design to improve the product features making it inclusive.
- The author proposes the review of the action research cycles developed in this thesis work to improve the application cycles in other types of projects.
- Evaluate the impact of wireless technology in the reconfiguration of a system and investigate more applications of sensors. The following potential areas of development were identified:
- **Control**: Research over the possibility of reconfigure a cell control system to make it flexible to physical arrangement changes.
- **Sensor applications**: The developing of a sensors map to track workpieces, machines and its components within the cell. And other applications that could match any other requirements of cell configurations.
- **Interfaces**: The research over the system interface, modules interfaces, and sub-module interfaces to determine the standardization of machines and modules to make feasible the interconnection of these subsystems.
- **System Levels**: The present research is developed in cell level, and the same methodology can be applied in other cycle oriented to machine level or major levels.

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GLOSSARY

Acceptability
Concept popularized by usability expert Jacob Nielsen in his book "Usability Engineering" whereby system acceptability is "whether the system is good enough to satisfy all the needs and requirements of the users and other potential stakeholders". Acceptability can be subdivided into social and practical acceptability.

Accessibility
Along with utility (functionality) and usability, is a requirement for the practical acceptability of a product or service. Accessibility is the ability of a user to physically interact with a product or service, for example to reach it, has enough strength to move it, etc.

Ageing
Is characterized by the acquisition of progressive multiple minor impairments predominantly related to sight, hearing, dexterity, mobility and cognition. In combination these can lead to high levels of capability loss and need for support. Older people do not see themselves as disabled and are likely to be offended by the term.

Capability
The ability to perform tasks or activities. The Disability Follow-up Survey defined 13 capabilities necessary for participation in everyday life. Seven of those capabilities are important for product and service design: locomotion, reach and stretch, dexterity, vision, hearing, communication, and intellectual function.

Carer-assisted
Supported by another person to perform tasks and activities. If we are to deliver a truly inclusive mix of products, services and environments, it is important that people who are reliant on carers are also accommodated, and that implies considering both user and carer, and the two in combination. Here it is important to note that older people are often cared for by spouses or relatives (who may also be older adults themselves), in which case their requirements could be significantly different to those of younger disabled people and their personal assistants (who are also likely to be younger). NB the term 'personal assistant' is currently preferred by younger disabled people.

Customizable
Computer aided manufacture has made it possible to customize individual products at the production line and assembly level. Coupled with Internet technology such as personal avatars carrying unique descriptions of individuals, this capability offers the possibility of including a wide range of users within the overall specification of a product and delivering unique items matching individual requirements.

Design Exclusion
Term (or approach) developed as a way to give substance to the idea of inclusive design, by focusing attention on those excluded by particular design of products, services or environments. This has resulted in significant attempts to describe how this can happen, to provide case study examples of design exclusion and inclusive design practice, and to make it possible to quantify design exclusion with reference to population data. The key point made is that some people will always be excluded by any specific design, and that design decisions should only be taken with due consideration of the impact on the users.

Design for All
European equivalent to Universal Design, with an emphasis on information on communication technology (ICT). Current EU goal is to encourage the establishment of national centers of excellence across Europe. These are envisaged as virtual, rather than physical centers.

Design for Disability
A significant tradition mainly focused on aids and adaptations to everyday equipment and buildings. Related to the medical model of disability (and ageing), the underlying intent is essentially prosthetic, with origins in post trauma rehabilitation, particularly of war veterans. More recently the approach has been extended to encompass a much broader range of impairments, while attitudes have shifted away from design for disability towards inclusive design.

Design for our Future Selves
A concept developed at the RCA, through the Design-Age program, as a way of encouraging young designers to engage with the challenge of designing for people other than themselves. It became the theme for many events at the RCA and of an annual competition open to all graduating students, resulting in many concept exemplars of age-friendly design. It has the advantage of making considerations of ageing a future-oriented activity and a driver for innovation.

Disability
In the past, people were seen as disabled by their condition, whereas the current move is towards understanding disability as the result of a mismatch between individuals and their social and physical environment. Some congenital conditions and traumatic events lead to considerable impairment and so to high levels of potential disability. In the US the term accepted is 'people with disabilities', in Europe 'disabled people' tends to be preferred.

Disability Follow-up Survey (DFS)
Commissioned by the UK Department of Social Security, a follow-up to the 1996/7 Family Resources Survey, aimed at providing up-to-date information on the physical and emotional characteristics of disabled people. Data from over 7,000 participants was collected.

Ethnography
Observing users (and users interacting with products, etc.) in real-life situations. The development of small video cameras and desktop-editing software makes this a very fertile and rapidly expanding form of design research in both social sciences and the design community.

Family Resources Survey (FRS)
Originally launched in October 1992 and commissioned by the UK Department of Social Security (DSS) primarily to meet the information needs of the DSS, for example in the forecasting of the needs for state benefits. The 1996-97 survey provided the basis for the subsequent Disability Follow-up Survey.

Functional Impairment
Reduction in the ability to perform an action or activity. Interchangeable with the concept of 'capability loss'.

Impairment
Health conditions, congenital conditions, the ageing process and traumatic events can result in impaired capability. Whether or not this impaired capability gives rise to disability is significantly determined by social and environmental factors, and importantly by the design of environments, products, systems and services.

Independence
For older people the most important factor is independence or the ability/possibility of living in their own home for as long as possible. Independence can be compromised by inappropriate design, and is also conditional on being able to carry out key and instrumental activities of daily living like bathing, dressing, cooking and also communicating with family and friends and participating in other aspects of communal life.

Medical Model: disability and ageing
Implies that people are disabled as a consequence of their own condition, and seeks to either remedy or correct the impairment through medication, rehabilitation and surgery, etc., or to offer adaptive aids and equipment as a physical remedy. *See also: Social Model*

Medical Model: assistive technology
Presumes that assistive technology is designed to meet the specific needs rising from a particular medical condition. In other words assistive technology is rehabilitation equipment only. The extension of this logic is that the 'users' are thought as 'patients' and that the 'customers' are typically the health authorities that purchase and prescribe such equipment. *See also: Social Model*

Modular
Designs that, by virtue of interchangeable units or elements can be configured to suit or fit different users, thus extending the range of users potentially served by a single design or product.

Participation
Along with social integration, the most important quality of life factor for disabled people. Some severely disabled people would prefer the help of a personal assistant or carer where activities are difficult or time-consuming to perform. Self-realization and social involvement are extremely important to younger disabled people. To them, being there and taking part are key.

Rehabilitation Design
Closely related to the above, but with a primary focus on enabling social participation of people with severe impairments. Much work in this area has been concerned with developing one-off solutions and specialist equipment for small numbers of people. New and emerging technologies are making adaptive or customizable interfaces and intelligent assistants a real possibility. No matter how inclusively we design in the future, there will always be a need for highly specialist customized solutions, making this an important field alongside inclusive design.

Social Inclusion
Europe-wide political objective, aimed at combating social discrimination, marginalization and conflict due to age, disability, poverty or ethnicity. Particularly important in respect of the diversity of immigrant populations in the EU and aspirations