TESIS DE LA UNIVERSIDAD DE ZARAGOZA

2019

34

Nikolaos Efkolidis

Development of Sustainable Methodologies in Product Design, Manufacturing and Education

Departamento

Ingeniería de Diseño y Fabricación

Director/es

Kyratsis, Panagiotis
García Hernández, César

EXTRACTO

ISSN 2254-7606

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ISSN 2254-7606

Tesis Doctoral [Extracto]

DEVELOPMENT OF SUSTAINABLE METHODOLOGIES IN PRODUCT DESIGN, MANUFACTURING AND EDUCATION

Autor

Nikolaos Efkolidis

Director/es

Kyratsis, Panagiotis
García Hernández, César

UNIVERSIDAD DE ZARAGOZA
Ingeniería de Diseño y Fabricación

2018

Doctoral Thesis

(Reduced Version)

Development of Sustainable Methodologies in Product Design, Manufacturing and Education

Author

Nikolaos Efkolidis

Directors

Dr. César García Hernández

Dr. Panagiotis Kyratsis

For obtaining the title of Doctor

by University of Zaragoza

Zaragoza, 15 June 2018

UNIVERSITY OF ZARAGOZA

Department of Design and Manufacturing Engineering

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1. PUBLICATIONS INCLUDED IN THE PRESENT DOCTORAL THESIS

1. PUBLICATIONS INCLUDED IN THE PRESENT DOCTORAL THESIS

The present work of Doctoral Thesis is titled "**Development of Sustainable Methodologies in Design, Manufacturing and Educatio**n". It is presented as a thesis by compendium of publications according to Articles 12, 13 and 14 of RD 99/2011 of January 28 (BOE of February 10), which regulates the official teachings of doctorate and Title IV, Chapter III of the Agreement of 20/12/2013, of the Governing Council of the University of Zaragoza, by which the Regulation of Doctoral Thesis is approved (BOUZ 10/01/2014).

This Doctoral Thesis is composed by the following publications:

- Efkolidis N., Garcia-Hernandez C., Kyratsis P., Huertas-Talon J.L., (2015), Design for Green Usability: A New User Centered Methodology for Product Development. Applied Mechanics and Materials, Vol. 809-810 (Part 2), pp. 1372-1377.

- Efkolidis N., Garcia-Hernandez C., Kyratsis P., Huertas-Talon J.L. "**Promoting sustainable principles through user education**", 6th Manufacturing Engineering Society International Conference (MESIC 2015), Barcelona, Spain, 2015.

- Efkolidis N., Garcia-Hernandez C., Huertas-Talon J.L., Kyratsis P., (2018), '**Modelling and prediction of thrust force and torque in drilling operations of Al7075 using ANN and RSM Methodologies**', Strojinski vestnik-Journal of Mechanical Engineering, 64(6), 351-361. DOI:10.5545/sv-jme.2017.5188

- Garcia-Hernandez C., Gella-Marin R.M., Huertas-Talon J.L., Efkolidis N., Kyratsis P., (2015) '**WEDM manufacturing method for noncircular gears using CAD/CAM software**', Journal of Mechanical Engineering-Strojniski vestnik, Vol. 62(2), pp. 137-144.

- Efkolidis N., Garcia-Hernandez C., Huertas-Talon J.L., Kyratsis P., (2017), '**Sustainability and distance learning: technical Universities sharing high cost resources**', International Journal of Engineering Education, Vol. 33(5), pp. 1-8.

2. AUTHORIZATION OF DIRECTORS

Departamento de
Ingeniería de
Diseño y Fabricación
Universidad Zaragoza

D. César García Hernández, Doctor por la Universidad Politécnica de Cataluña y Profesor del Departamento de Ingeniería de Diseño y Fabricación de la Universidad de Zaragoza,

INFORMA:

Que la tesis titulada " **Development of Sustainable Methodologies in Product Design, Manufacturing and Education** ", elaborada por **D. Nikolaos Efkolidis**, ha sido realizada bajo mi dirección, se ajusta al proyecto de tesis inicialmente presentado y cumple los requisitos exigidos por la legislación vigente para optar al grado de Doctor por la Universidad de Zaragoza. Una vez finalizada, autorizo su presentación en la modalidad de compendio de publicaciones para ser evaluada por el tribunal correspondiente.

Zaragoza, a 15 de junio de 2018

Fdo.: César García Hernández

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Diseño y Fabricación
Universidad Zaragoza

D. Panagiotis Kyratsis, Doctor por la Technical University of Crete y Profesor del Department of Mechanical Engineering and Industrial Design de la Western Macedonia University of Applied Sciences,

INFORMA:

Que la tesis titulada " **Development of Sustainable Methodologies in Product Design, Manufacturing and Education** ", elaborada por **D. Nikolaos Efkolidis**, ha sido realizada bajo mi dirección, se ajusta al proyecto de tesis inicialmente presentado y cumple los requisitos exigidos por la legislación vigente para optar al grado de Doctor por la Universidad de Zaragoza. Una vez finalizada, autorizo su presentación en la modalidad de compendio de publicaciones para ser evaluada por el tribunal correspondiente.

Zaragoza, a 15 de junio de 2018

Fdo.: Panagiotis Kyratsis

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3. ACKNOWLEDGMENTS

This Doctoral thesis is the account of 4 years of work in the field of sustainability at the University of Zaragoza, which would have not been possible without the help of many. First of all, I would like to thank my directors, Dr. César García and Dr. Panagiotis Kyratsis about their great support during the preparation of my Doctoral Thesis. I would like to thank both of them for encouraging my research and for allowing me to grow as a research scientist. Thanks to them I have trained not only educationally but also in my personal life. Furthermore, I wish to thank Dr. José Luis Huertas for his valuable help. His constructive criticisms on my work as well as some noteworthy and fascinating ideas for further research subjects were invaluable. I would like to give special thanks also to the Direction Team of the Centre of Professional Training ''Corona de Aragon" and to C3 (CAD/CAM/CAE) Lab in the University of Applied Sciences of Western Macedonia, for their valuable help, making available human and technical resources.

Finally I would be grateful forever to the University of Zaragoza, it was an honour for me to be there preparing my Doctoral thesis.

Thank you very much to all.

To my father and to Mr. Vasilis

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6. INTRODUCTION

6. INTRODUCTION

6.1. Framework of Thesis

The influence of sustainability in product design and manufacturing processes can be considered from two different points of view: the design of sustainable products and the sustainable manufacturing of those products. Of course, a basic assumption for the aforementioned elements to be realized is the appropriate training and education for sustainability of the young designers and engineers.

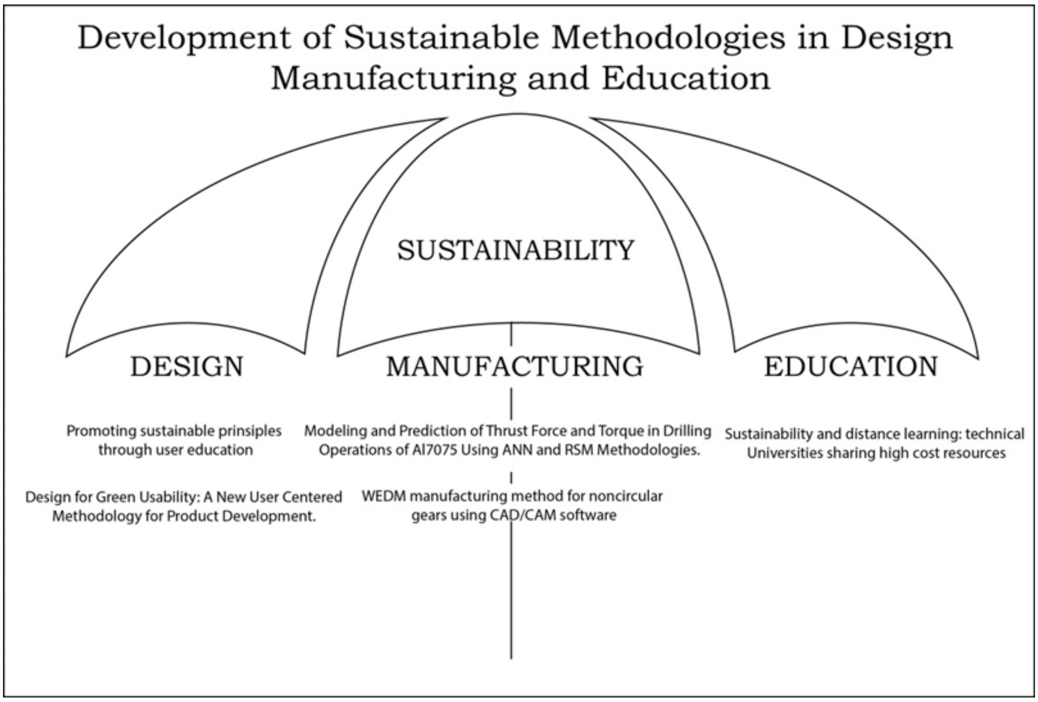


Figure 1. The research umbrella of sustainability

In this research, sustainability has been applied to many fields, including design, manufacturing and education acting as an umbrella (Fig. 1) which covers all the three elements and has as the main target to promote sustainability. In today's world, in which a considerable number of contrasting signs reveal that our society is currently contributing to the planet's collapse, a new kind of engineer is needed, an engineer who is fully aware of what is going on in society and who has the skills to deal with aspects of sustainability.

6.1.1 Promoting Sustainability via product Design or Sustainable Design

Sustainable design research has been until recently mainly focused on the environmental impact of the product itself. End-of-life issues have always played a dominant role, resulting in methods which promote the use of recycling materials for the development of the product and ways that facilitate the environmentally friendly actions as recycling, reuse, remanufacture, etc. Even when the use-phase was concerned, many of the proposed methodologies have been focused on applying more energy-efficient technologies. Recently it has been realized however that user behaviour itself may considerably affect the lifecycle environmental impact of products. For some product categories, around thirty percent of the energy consumption of a product may be due to user-related losses. One way to influence user behaviour is to develop solutions that trigger certain behaviours. This can be managed either by creating products with entirely new functions while giving motivation for new routines and behaviours, or redesign products that simplify everyday actions and change routines and behaviours established long time ago. Many strategies can be used to create user motivation in different ways and promote a behavioural change to decrease resource consumption such as energy consumption of littering and public use of technology.

With all the environmental issues that people are facing in today's world, it is important to grasp the need for a change in our consuming culture and start thinking about promoting more effectively a series of environment friendly ways of life. Designer decisions can impact the social, economic and the environmental aspects of products. Nowadays, sustainability is the new trend in product design and treats the environmental issues in a more spherical manner. This is achieved by considering the whole lifecycle of the product in advance. When design is implemented, this approach becomes the conceptual base for developing a great deal of products and services. There is a need for cultural transformation, which can be directed towards and focused on younger generations of consumers, in order to promote the much needed behavioural change early enough. The key issue is the change on customer perception about the product, with an emphasis on sustainability principles. The new designs have to motivate the end-users to change their lifestyle towards a more environmental friendly attitude. Designer and products could play an increased educational role towards the people of this planet.

Many ‘design for X’ methodologies have been developed, refined, and now they are commonly used. Design for X is not something new as it was introduced over 30 year ago. Design for X (DFX) is a formal methodology that works towards optimizing processes in a specific area of focus (X). Depending on the needs, the methodology works towards designing methods that may help to generate and apply theoretical and technical knowledge in order to control, improve, or even to invent particular characteristics of a product. It is a set of technical guidelines that aim to optimize design. So DfX it is very useful in product design process. The right use of those techniques makes the design and manufacturing teams to produce more easily specific solutions during the design and development process.

At first, DfX philosophy was developed to optimize specific product requirements, with the main goal to satisfy customer needs and react to the high market pressure of product competitiveness. Over the years, many ‘Design for X’ concepts led to enormous benefits including high flexibility in making product changes, effectiveness in estimating impact in terms of cost, manufacturability and generally improvement of quality and reduction of the time to market. In the current research, a number of Design for X techniques are classified under the umbrella of each pillar (economic, environmental, social) of sustainability focused on the different stages of the whole lifecycle of a product (Fig. 2).

The classification of design for X techniques shows clearly the priorities in product development in previous years. The result of this classification shows that:

- The majority of tools and methodologies are directly linked more with the economic and less with the environmental pillar of sustainability. Social sustainability has often been unnoticed as the emphasis on social issues doesn’t exist in many cases.

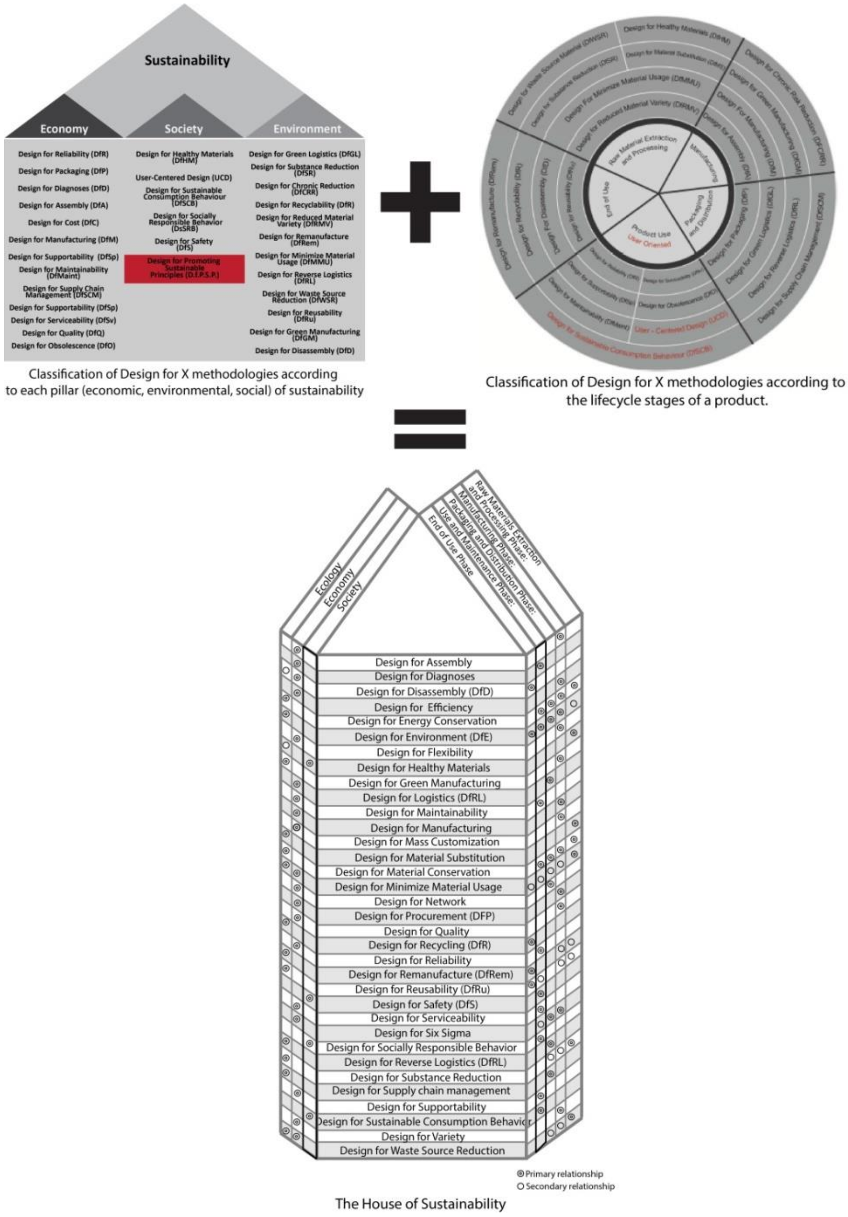


Figure 2. Classification of Design for X methodologies according to each pillar (economic, environmental, social) of sustainability focused on the lifecycle stages of a product.

- Simultaneously the vast majority of design for X' methodologies have a strong focus on manufacturing issues. Even when they focus on the product-use phase, they are dominated by the manufacturer's decisions.

Nowadays, designers should be able to apply design thinking, based on the social issues and create innovative solutions. It should be stressed that the actual demand for energy during the product use phase depends, to a great extent, on the way that people use the product in their everyday practice. The choice of recyclable materials and the design for recyclability has a true meaning only if recycling is performed by consumers. Thus, the use of environmentally sensitive design techniques and technologies for consumer products cannot by itself be the solution for better resources management.

According to the technology-push and the market-pull product design approaches, the model of sustainability push & pull was generated by the need for sustainability consciousness from the majority of people and its rising importance. The term market pull, refers to the need for a new products or a solution to a problem, which comes from the customers or market research. Society has an ever increasing demand for greener products and cultivation of sustainability behaviour. Therefore, according to sustainability pull approach eco products which promote the meaning of sustainability to users, should be developed. The term technology push usually does not involve market research. A new invention is pushed through Research and Development, production and sales and enters onto the market without proper consideration of whether or not it satisfies a user need. Respectively, sustainability push implies that there is a need for a change in our behaviour to a more sustainable way of life. Therefore, eco products with environmental friendly operation which create mindful interaction between the users and their green character should be developed. Sustainability push & pull can be considered as an alternative model for product design. The products developed under this umbrella aim to spread the meaning of sustainable development to citizens promoting a socially and a more sustainable behaviour at the same time.

For a better understanding of the model, two new methodologies have been developed and used as representative examples. For the case of sustainability push approach the Design for Green Usability (D.f.G.U) methodology was developed, while for the sustainability pull the Design for Promoting Sustainable Principles (D.f.P.S.P.) through user education methodology is proposed. The D.f.G.U methodology focuses on the creation of mindful interaction between the users and the green use of the products. Products are developed in order to be and operate really environmental friendly, simultaneously motivating the user to try them. Designers should discover the types of motivation, because it shows the direct way on how to make the product more desirable and user friendly. A characteristic case of a product development under D.f.G.U methodology is the development of the "Eco-Bench" (Fig.3).

For the case of sustainability pull model, a new methodology named Design for Promoting Sustainable Principles (D.f.P.S.P) through user education was developed and used. The D.f.P.S.P through user education has as target the spreading of the meaning of sustainability to users, encouraging and educating them simultaneously, about the greener choices they can have in their everyday activities. The whole concept is mainly built for young age users and their parents. The basic reason for selecting the young users is that managing the improvement of sustainable behaviour towards the young customers of today, it means automatically more sustainable conscious citizens and parents of tomorrow. Figure 3 illustrates a set of developed products based on this methodology.

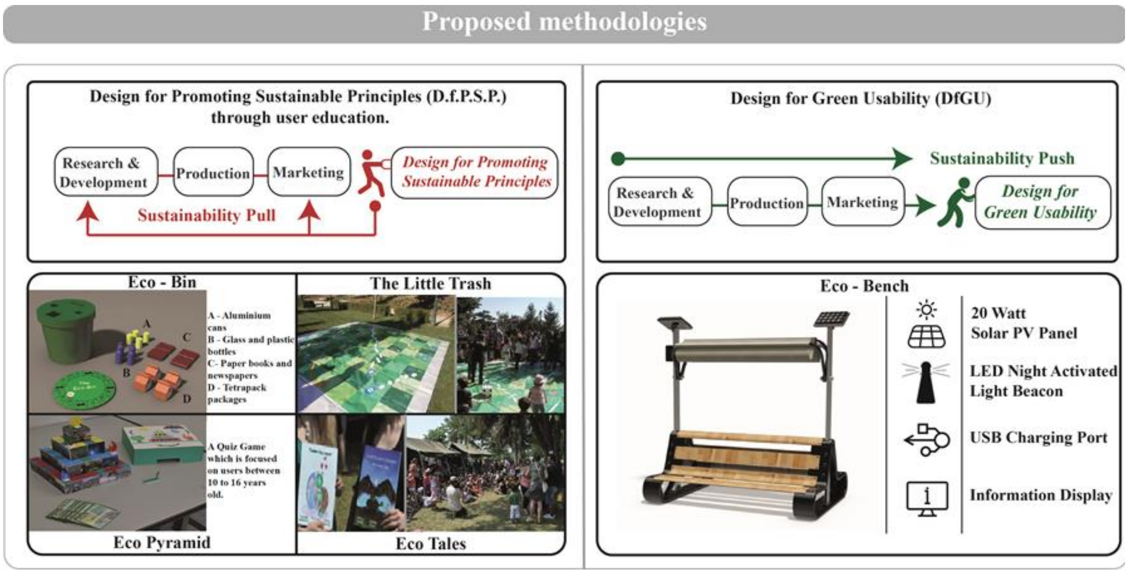


Figure 3. Developed products under proposed methodologies

6.1.2 Promoting Sustainability via Manufacturing or Sustainable Manufacturing

Human factors are fundamental for manufacturing sustainability, which is determined by social, economic and environmental performance. However, there is a lack of engineering methods and tools that are able to integrate their analysis with product and process optimisation according to sustainability principles. For this reason, a lot of research has been started to develop sustainable methodologies in manufacturing, helping sustainable development. The early research to the process of product development helps the integration of sustainability into manufacturing. The early evaluation is very critical, in order to ensure appropriate attention to sustainability at the right time, which is during the design process. Sustainable Manufacturing targets to create manufactured products according to greener processes with as lower as possible negative environmental impacts, conserve energy and natural resources, be safe for employees, communities and consumers and be economic.

According to the Commission of the European Communities (2008) :

"European Industry is globally competitive, contributing substantially to growth and jobs. Sustainable development aims at the continuous improvement of the quality of life and well-being for present and future generations. It is a key objective of the European Union."

This part of the research highlights the importance of the sustainable machining technologies in achieving sustainable development objectives. There are many developed approaches for the improvement of sustainability during machining operations. One of them is the optimized utilization of cutting tools. Increasing the efficient use of cutting tool equals better product quality and longer tool life. Drilling is a basic part of manufacturing processes used in subtractive manufacturing for achieving the desired products. Its massive usage recommends that any parameter optimization in the process promotes the efficiency and the greener machining. Therefore, the best choice of cutting tools and parameters for the quality of the products and the tool life criterion are both important for the sustainability metrics of a drilling process. The right usage of cutting tool can affect the reduction of needed resources and energy for the production of a new one. The aim of this study was the generation of mathematical models for the prediction of the thrust force (Fz) and cutting torque (Mz) related to the cutting tools and other crucial manufacturing parameters i.e. feed rate, cutting speed during the drilling process. Two modeling techniques the Response Surface Methodology (RSM) and the artificial neural network (ANN) were used in order to predict the thrust force and cutting torque in a series of drilling operations of Al7075. The developed models were considered as very accurate for the prediction of the Fz and Mz within the range of the manufacturing parameters used.

The other crucial factor is the appropriate use of CAD-CAM systems, which are tools that use a computing system in the modification, analysis and optimization of design and manufacturing processes. In this part of the research, a method to manufacturing elliptical and oval gears using wire electro-discharge machining (WEDM) is presented. Mathematical models for manufacturing elliptical and oval gears are presented, simulations are carried out, and this method is implemented in a WEDM machine, obtaining two pairs of elliptical and oval gears. This method could be useful in the manufacturing of injection moulds or custom-made metallic gears. Finally, a discussion using bibliographic references is presented about the surface finish and the consequences of using WEDM in comparison to other shaving methods, which do not involve a material phase change. Improving the gear manufacturing process without specific machinery, makes the processes of research, design, and manufacture more sustainable and accessible to a larger number of people. Moreover, in this way, a good method is presented so the developer can control the gear design and also the manufacturing methods which ensure a better gear finishing. This is a good predictor of the performance of a mechanical component used to determine and evaluate the quality of a product. Due to the importance of gears in machinery operation, when establishing its mechanical performance and thus the energy consumption and sustainability, the work implements the principles of computerized tool usage for design and manufacturing accuracy. More than one objectives are met in this case, because the use of these CAD based tools, improve the accuracy of the gear design to a great extent, while at the same time promotes the accurate manufacturing, that can provide a solid basis for achieving better performance and sustainability. At optimization conditions, sustainability is achieved in machining performance and productivity.

6.1.3 Promoting Sustainability via Education or Sustainable Education

Nowadays sustainability concepts meet with general acceptance worldwide and are developed and implemented for a wide range of industries, research and development and manufacturing products. In a globalized, rapidly developing world, training and education sustainability is considered an important issue. In the future, only those regions and companies that develop modern training concepts with an emphasis on sustainability will continue to be competitive. Sustainability has received increasing attention in education over the last decade. The terms Education for Sustainability and Education for Sustainable Development increased their use internationally. It is in this context, that new educational programs, research institutions and scientific publications, all with an emphasis on sustainability in higher education, have emerged. There are different pedagogic methods that have been used in order to educate engineering students about sustainability. These methods were supported with data, indicating whether they achieved their learning targets. Lectures, in-class-active learning, readings and appropriately targeted homework assignments can achieve basic sustainability knowledge and comprehension. This becomes reality by requiring students to define, identify and explain aspects of sustainability. Another way for educating sustainability can be considered the development of case studies and the application of software tools with an aim to achieve application and analysis competencies. Project based learning (PBL) and project-based service learning (PBSL) design projects can reach the synthesis level and may also develop affective outcomes related to sustainability.

Attempts are being made to distinguish different types of sustainability in Higher Education projects. The can be categorized into:

- greening the campus initiatives/campaigns, with a focus on operational improvements (eco-efficiency),
- revision of learning outcomes and curriculum reformulation and
- Institutional research and development projects.

However, despite the progress achieved, sustainability has not become yet an integral part of the university system and further research is needed to tackle the complex challenges and demands within a transition to sustainable universities.

Current research based on positive results and obtained experience of a previous publication has developed a training course of metrology based on sustainable characteristics such as remote control freeware applications, share of valuable resources, distance learning methodology and active participation of the students. This is based on a remote control operation using special software, with a real CMM. Although the CMM was placed at the University of Zaragoza (Spain), ten students from Greece, with the valuable help of a remote control freeware application, participated in real time measuring process from their own computers under the supervision of two instructors. The results of the remote operation of the CMM were very successful.

6.2. Motivation

The motivation of this thesis arises from the desire to develop Sustainable methodologies related to Product Design, Manufacturing and Education. When the thesis was initiated, the first step was to become aware of previous work in order to obtain a starting point of the techniques and methods generated. The tools and methods used in the design, manufacturing and education sectors were previously studied in order to have a global vision of the situation. With this knowledge, it was possible to work on each of the three sectors with a main aim to promote sustainability.

Sustainable product design and manufacturing play a vital role for industrial growth and quality product to the customers. Nowadays, sustainability becomes a major issue for product design and manufacturing. It is also considered as key part to the modern economic model. Sustainable product design and manufacturing has started to become an obligation to environment and society itself, enforced primarily by government regulations and customer perspective on environmental issues. Some of the critical issues that manufacturers should consider in order to remain competitive in the market are a) maintaining high quality products, b) lowering cost and prices, c) decreasing product cycle time and d) protecting environment.

1) The first phase is associated with the sustainability design, in which the model of sustainability push & pull was generated by the need for sustainability consciousness from the majority of people and its rising importance. For a better understanding of the model, two new methodologies have been developed and used as representative examples. For the case of sustainability push approach, the Design for Green Usability (D.f.G.U) methodology was developed, while for the sustainability pull, the Design for Promoting Sustainable Principles (D.f.P.S.P.) through user education methodology was developed. The whole process was implemented based on the proposed User Assessment Tool (UAT) which helps the designer to communicate with the consumers and to design for their values and needs, while incorporating them in the whole process of product development. It is a creative and educating process because the individual user's opinion is the center of interest and plays an important role in the product design.

2) The second phase is directly linked with the sustainable manufacturing. Manufacturing operations is an important part of the energy consumption during the whole life cycle of a product. Sustainable manufacturing is dealing with the efficiency of production processes. The first of the selected processes was the drilling process, which is one of the most popular manufacturing processes in the metal-cutting industry. The effects of cutting parameters (cutting velocity, feed rate) and tool diameter on thrust force (Fz) and cutting torque (Mz) are investigated in the drilling of an Al7075 workpiece using solid carbide tools. Artificial neural networks

(ANN) and response surface methodology (RSM) approaches are used to acquire mathematical models for both the thrust force (Fz) and torque (Mz) related to the drilling process. RSM and ANN based models are compared, and it was clearly determined that the proposed models are capable of predicting the thrust force (Fz) and cutting torque (Mz).

The second of the selected processes was a method to design and manufacture elliptical and oval gears using Wire Electro Discharge Machining. The improvement of the gear design and manufacturing process without expensive machinery, make the processes of research, design, and manufacture more sustainable and accessible to a larger number of people. The appropriate use of CAD-CAM systems is a key for successful implementation of technology integration.

3) Once the design and manufacturing parts have been analyzed, the next phase was linked with the sustainable education or education for sustainability. If designers and engineers are capable to contribute truly to sustainable development, then sustainability must become part of their everyday thinking. This, can only be reached if sustainability becomes an important part of engineering education programs, not only as specific modules, but as complete philosophy of the curriculum. This specific research was built based on sustainable characteristics such as a) remote control freeware applications, b) share of valuable resources and c) distance learning methodology. A unique sustainable experience was investigated as a team of students from the Western Macedonia University of Applied Sciences (Greece), with the valuable help of a remote control freeware application, participated in real time measuring process from their own computers under the supervision of two instructors in a metrology module on a CMM which was placed at the University of Zaragoza (Spain).

6.3. Presentation and justification of publication thematic parts.

The publications presented in this Doctoral Thesis work are part of the processes of sustainable design, manufacture and education and as indicated above, are the following:

Sustainable Design

- **Promoting sustainable principles through user education**
- **Design for Green Usability: A New User Centered Methodology for Product Development.**

Sustainable Manufacturing

- **Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies**
- **WEDM manufacturing method for noncircular gears using CAD/CAM software**

Sustainable Education

- **Sustainability and distance learning: technical Universities sharing high cost resources**

With all the environmental issues that people are facing in today's world, it is important to grasp the need for a change in our consuming culture and start thinking about promoting more effectively a series of environment friendly ways of life. Designer decisions can impact the social, economic and the environmental aspects of products. The publication entitled "**Promoting sustainable principles through user education"** shows that the majority of tools and methodologies are directly linked with the environmental pillar of sustainability, while simultaneously most of them are indirectly linked with the economic one. As a result, a need for methodologies appears, in order to emphasis the social aspect. There is a need for a cultural transformation, which can be focused on consumers and promote the needed behavioural change. The key issue is the change on customer perception about the product, with an emphasis on the sustainability principles. A new methodology is proposed under the name of Design for Promoting Sustainable Principles through user education.

Nowadays, sustainability is the new trend in product design and treats the environmental issues in a more spherical manner. This is achieved by considering the whole lifecycle of the product in advance. When design is implemented, this approach becomes the conceptual base for developing a great deal of products and services. Many design for X methodologies have been developed, refined, and now they are commonly used. The publication entitled "**Design for Green Usability: A New User Centered Methodology for Product Development"** reviews a series of available design methodologies. It classifies them based on the life cycle stage that they are implemented. The vast majority of them have a strong focus on manufacturing issues. Even when they focus on the product-use phase, they are dominated by the manufacturer's decisions. The users' interaction with a product may strongly influence its environmental impact, and for this reason designers should put extra effort in order to influence this behaviour. Based on this demand, there is a necessity for the development of novel methodologies and tools, which would be directly related to the use phase of the products. In recent years, a design methodology called User-Centered Design (UCD) is under consideration with an aim to understand the users' needs, goals, limitations, possibilities, previous experiences and how they are affecting the user interaction with objects. The present paper proposes a new methodology named Design for Green Usability (DfGU), which is directly linked to the user requirements during the use phase of the product.

Many developed approaches for the improvement of sustainability during machining operations; one of which is the optimized utilization of cutting tools. Increasing the efficient use of cutting tool results in better product quality and longer tool life. Drilling is one of the most widely used machining operations in industry. It is usually carried out at the final steps of the production process. The publication entitled "**Modelling and Prediction of Thrust Force and Torque in Drilling**

Operations of Al7075 Using ANN and RSM Methodologies" investigated the effects of cutting parameters (cutting velocity, feed rate) and tool diameter on thrust force (Fz) and torque (Mz) in the drilling of an Al7075 workpiece using solid carbide tools. The full factorial experimental design is implemented in order to increase the confidence limit and reliability of the experimental data. Artificial neural networks (ANN) and response surface methodology (RSM) approaches are used to acquire mathematical models for both the thrust force (Fz) and torque (Mz) related to the drilling process. RSM and ANN based models are compared, and it is clearly determined that the proposed models are capable of predicting the thrust force (Fz) and torque (Mz). Nevertheless, the ANN models estimate in a more accurate way the outputs used in comparison to the RSM models.

Noncircular gears are used in several technological applications in order to enhance the performance of different mechanical instruments (flow meters, bikes, internal combustion engines, etc.), in order to unify speed in assembly lines and research. In this research, a method to manufacture elliptical and oval gears using wire electro-discharge machining (WEDM) is presented. The right use of CAD-CAM systems simplifying the gear manufacturing process without specific machinery, makes the processes of research, design, and manufacture more sustainable and accessible to a larger number of people. Moreover, in this way, a good method is presented so the developer can control the gear design and also the manufacturing methods which ensure a better gear finishing. This is a good predictor of the performance of a mechanical component used to determine and evaluate the quality of a product. At optimization conditions, sustainability is achieved in machining performance and productivity. In the publication entitled "**EDM manufacturing method for noncircular gears using CAD/CAM software**" are developed mathematical models for manufacturing elliptical and oval gears. Simulations were carried out. This method is implemented in a WEDM machine, obtaining two pairs of elliptical and oval gears, and could be useful in the manufacturing of injection moulds or custom-made metallic gears.

In a sustainable society, where people take more responsibility for the consequences of their actions and play a more active role as users and employees, they must have access to sustainable oriented education throughout their lives. The present research entitled “**Sustainability and distance learning: technical Universities sharing high cost resources**” is based on a remote control operation using special software, with a real CMM. Although the CMM was placed at the University of Zaragoza (Spain), ten students from Greece, with the valuable help of a remote control freeware application, participated in real time measuring process from their own computers under the supervision of two instructors. The results showed that the feeling of responsibility for using a remote piece of equipment and the extra care that the students should prove created a more stimulating learning environment. The process as a whole was provided a unique sustainable oriented experience.

6.3.1. Presentation of the publication "Promoting sustainable principles through user education"

Traditionally, the environmentally friendly product design focuses on Eco-design or Design for Environment, which both aim to reduce the environmental impact of each stage of the product lifecycle; emphasizes how can impacts be lowered through design-for-disassembly, recyclability, use of environmentally conscious materials and dematerialization. This has led to the development of a variety of tools, such as cradle-to-grave, cradle-to-cradle and lifecycle analysis in an attempt to better quantify the environmental impact of products. It could therefore be said, that part of the designer’s role, when designing sustainable products, is to design products that maximize their economic and social impact, while at the same time their harmful effects on the environment are minimised. Until recently, most efforts have been made to lower the energy consumption of products, with the focus being on environmentally conscious energy sources and increasing energy efficiency through technological solutions. Nowadays, designers should be able to apply design thinking, based on the social issues and create innovative solutions. It should be stressed that the actual demand for energy during the product use phase depends, to a great extent, on the way that people use the product in their everyday practice. The choice of recyclable materials and the design for recyclability has a true meaning only if recycling is performed by consumers. Thus, the use of environmentally sensitive design techniques and technologies for consumer products cannot by itself be the solution for better resources management.

Environmental standards and regulations, together with the growing expectations of customers, have made the sustainability concept crucial. Historically, sustainability has been initially linked only to the environmental dimension. Nowadays it is directly associated with the social and economic concerns. So, designers should not only consider environmental problems, when developing a new product or upgrading an already existing one, but according to the Design for Sustainability (DfS) perspective, environmental aspects have to be balanced with the economic and societal ones, in order to achieve the goal of sustainability. In order to manage sustainability a number of design for X techniques and methodologies have been developed, based on the three basic pillars of sustainability (economic, environmental and social).

The current research review is based on formative, influential and well-cited works that contribute most to the development of a series of DfX methodologies in order to provide the most informative overview possible. Figure 4, depicts the “House of Sustainability”. On this figure, sustainability is appeared as the roof of a “design” house, which is based on the three sustainability pillars: economy, ecology and society. Each pillar is composed from the related design for X methodologies which are developed for supporting it. Sustainability can be built only if the design process uses the right elements (techniques) from each pillar to “build” the product/process. It is obvious that the societal pillar is not strong enough since there is a substantial gap towards the social aspect of the product development. The present research has as its main goal to fill this gap by proposing a new “design for” technique oriented to the social aspect of sustainability.

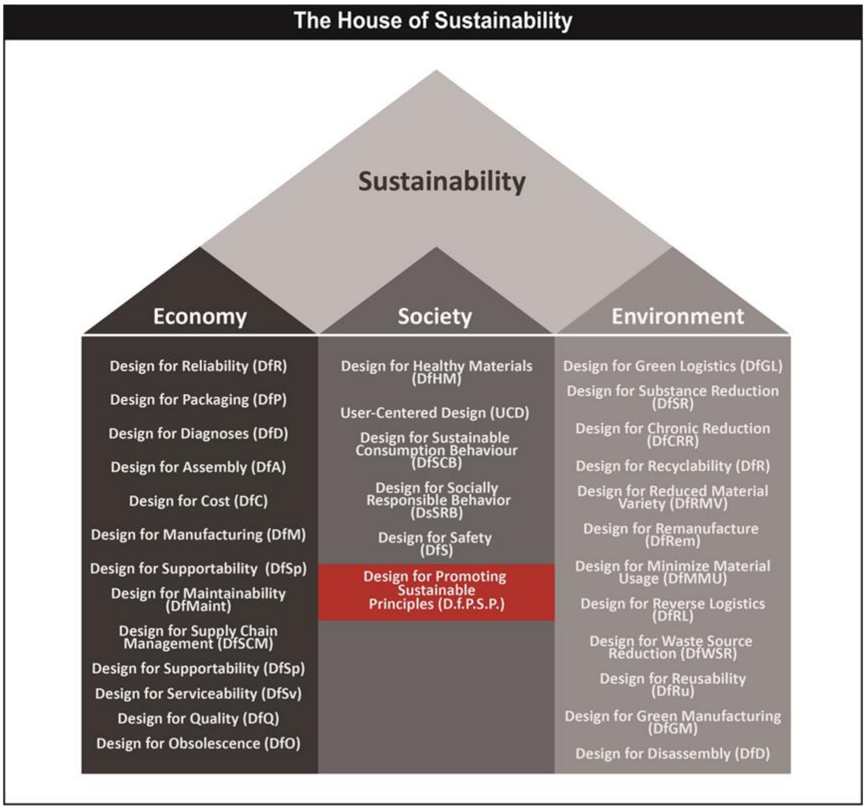


Figure 4. Categorization of Design for X methodologies based on the three pillars of sustainability. The "House of Sustainability"

Sustainable design research has been until recently mainly focused on the environmental impact of the product itself. End-of-life issues have always played a dominant role, resulting in methods which promote the use of recycling materials for the development of the product and ways that facilitate the environmentally friendly actions as recycling, reuse, remanufacture, etc. Even when the use-phase was concerned, many of the proposed methodologies have been focused on applying more energy-efficient technologies. Recently it has been realized however that user behaviour itself may considerably affect the lifecycle environmental impact of products. For some product categories, around thirty percent of the energy consumption of a product may be due to user-related losses. One way to influence user behaviour is to develop solutions that trigger certain behaviours. This can be managed either by creating products with entirely new functions while giving motivation for new routines and behaviours, or redesign products that simplify everyday actions and change routines and behaviours established long time ago. Many strategies can be used to create user motivation in different ways and promote a behavioural change to decrease resource consumption such as energy consumption of littering and public use of technology.

Design for Promoting Sustainable Principles (D.f.P.S.P) through user education focuses on the importance of understanding the consumer behaviour finding factors influencing green consumption at the early stage of product development. By analyzing which factors develop and maintain user habits in specific consumption situations, knowledge can be gained on how to effectively focus on the development of new products towards functions and solutions that promote sustainable consumption actions. The concept of D.f.P.S.P is generated by the need for green consciousness to the majority of people and the spreading of sustainability importance. There are two main groups where D.f.P.S.P should be focused on. The first one is this which contains users of young ages, while the second one focuses on older people. Managing the development of green behaviour towards the young people of today, it means automatically more environmentally conscious customers and parents for tomorrow. Managing change behaviour of today citizens to a greener way of life means automatically a greener way of growing up for the future generations.

Based on these principles, a push strategy from the marketing point of view is necessary. Product design implies the conception and realization of human needs and desires. The D.f.P.S.P through user education can be used as a new model for the development of products which have as target the spreading of the meaning of sustainability to consumers in all over the world, encouraging and educating them simultaneously about the greener use of the product and mostly the green end of life activities. A number of different products can be developed in order to prove the efficiency of the proposed D.f.P.S.P. through user education methodology. In the present paper, the product that was selected in order to be designed, keeping in mind all the principles previously mentioned, is a toy which is called 'Eco-Bin' (Figure 5). It consists of a basic bin, together with a number of additional parts such as bottles, cans, books and tetra Pack-like packages. The target of the product is to transform the action of recycling to a game. Every player can choose a different material and try to recycle first all the chosen packages. Each player, with the help of a dice, is moving to a circular trail and trying to put his pawn to the right boxes. Every successful movement equals the placing of a package to the bin. The first one who manages to include into the bin all his/her packages is this one who wins the game.

All these parts can be made of moulded pulp recycled paper. It is only recently, that moulded pulp has emerged as the interior packaging of choice for many electronic and consumer products. Moulded pulp paper is 100% recyclable, 100% biodegradable, light in weight, safe, sanitary, non-toxic, acid-proof, alkali proof, water proof and finally is easily shaped and practical. Additionally, it is a sustainable product which is compliant with the ISO 14040:2006 and the European Green Dot standards. The choice of the material has been done based on the reduction of the environmental impact of each stage of the product lifecycle. The product under research has obviously as a target group the young users in the age range of 3-5 years old. This target group was not chosen randomly, while by educating the children, the future can be shaped easier towards the sustainable development. There is a demand for behaviour transformation and those needs can be addressed to the young people in order to promote the appropriate culture early enough in their life.

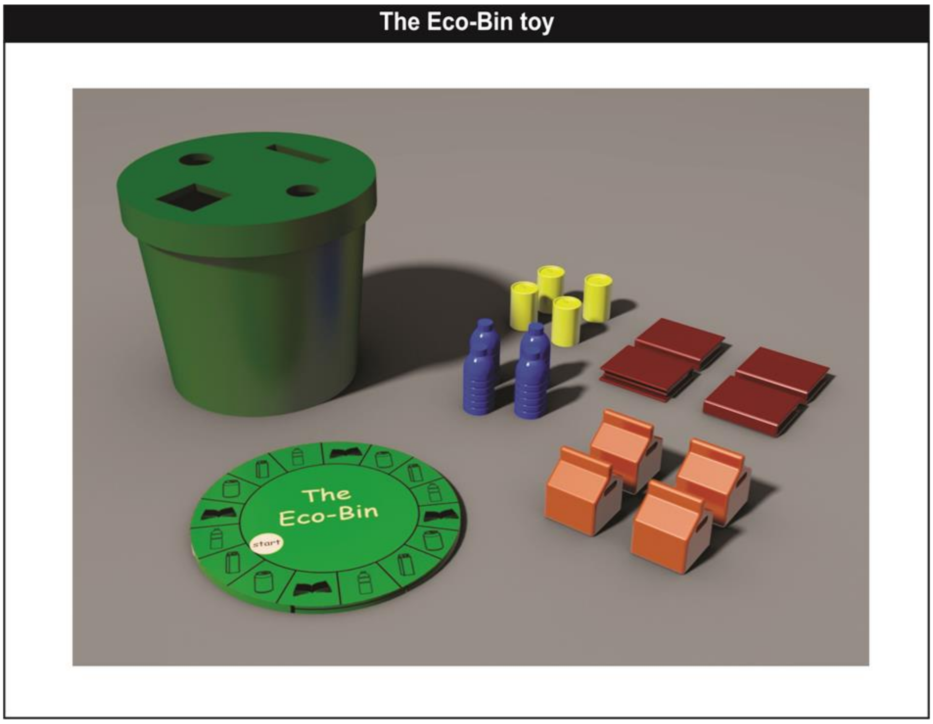


Figure 5. The Eco-Bin toy

6.3.2. Presentation of the publication " Design for Green Usability: A New User Centered Methodology For Product Development "

Over the years, many design for X (DfX) concepts led to enormous benefits including simplification of products, reduction of assembly and manufacturing costs, improvement of quality and reduction of the time to market. The effort to reduce total lifecycle costs for a product through its design process was an essential part of the manufacturing industry. This activity started a trend which focuses on the environmental issues of the product design. The ultimate purpose of green design is to design a product, which will have minimum negative environmental impact during its complete lifecycle. Lifecycle thinking plays a key role on the concept of pollution prevention, including the whole product lifecycle and sustainability. Sustainability is a growing area of concern for many businesses, as in the last few years, a lot of research developed addressed the concept of design for sustainability.

Raw Materials Extraction and Processing Phase. There are many sustainable methods developed for the first phase of lifecycle. The Design for Minimize Material Usage (DfMMU) is one of them. Its main target is the reduction of the amount of material used over the complete product lifecycle. It is an effective method for reducing the product’s environmental impact. Design for Material Substitution (DfMS) is an additional method developed, where the substitution of high environmental impact materials with superior materials in terms of sustainability is desired. The reduction of the undesirable substances, which are used during the products lifecycle, should be minimized through Design for Substance Reduction (DfSR), while Design for Waste Source Reduction (DfWSR) has as its goal the reduction of materials that the product and its package needs.

Manufacturing Phase. Design for Green Manufacturing (DfGM) plays a strategic role in an organization that tries to build a competitive advantage and improved performance. With rapid changes in technology and customer needs manufacturing itself is constantly transforming and evolving. Design for Manufacturing (DfM) has been used with focus on reducing both the production lead time and its cost. Design for Chronic Risk Reduction (DfCRR) minimizes long term ecological harm to the plants, community and workforce. This is a method that focuses on the reduction of hazardous materials used.

Packaging and Distribution Phase. Design for Green Logistics (DfGL) is associated mainly with climate change, air pollution, noise, vibration and accidents. A key part of green logistics is now considered the Design for Reverse Logistics (DfRL), which incorporates the return of waste product and packaging for reuse, recycling and disposal. In addition, a new approach has been developed named Design for Supply Chain Management (DfSCM). It can be defined as the integration of the environmental management within the supply chain management. Finally, Design for Network (DfN) is proposed as an extension for the DfM. It attempts to create a more successful network for both the service providers and the vendors.

Use and Maintenance Phase. During this stage, the manufacturability of the product is the main issue. This is easy detectable from the design methods that have been developed. One crucial factor for this phase is the maintainability of the product, which is the degree that can be maintained or repaired easily, economically and efficiently. Design for Maintainability (DfMaint) encompasses the measures taken in order to reduce the time and other resources spent in keeping a product performing well. Another method developed towards this direction is the Design for Serviceability (DfS), which describes the ability to diagnose, remove, replace, replenish and repair a component or a subassembly to original specifications. Reliability is another issue which is essential in designing a reliable product capable of meeting the customers' expectations. Design for Reliability (DfR) ensures that designs meets customers' needs, only if there is an understanding of the full design requirements i.e. environment hazards to full product operating life, potential product use, misuse, total product cost goals, reliability service life needs.

End of Use Phase. At the end of the product's life a number of different strategies are available i.e. remanufacture, reuse, recycling, landfill after an appropriate process of disassembly. Remanufacturing is the process of returning a used product to like-new condition. The Design for Remanufacture (DfRem) methodology includes sorting, inspection, disassembling, cleaning, reprocessing and reassembling. Different components, which cannot be brought back to original quality, are replaced. The design process is able to increase the profitability of remanufacture and make it a more viable and lucrative product end-of-life strategy [10]. Design for Reusability (DfRu) is the process of harvesting working parts and components for reuse, often in the form of repairs and replacements. The target is the standardization of the components across the age of product models, the enhancement of durability of reused targeted components and the improvement of recovery of products and parts. The Design for Recyclability (DfR) takes a more proactive approach with an aim to increase the recyclability of a product. Instead of simply recycling components after disassembly, DfR looks at the materials selected during the design phase and evaluates whether they can be recycled or not and, if not, seeks a recyclable material which can be used instead. Of course, all the above processes can be properly managed through the process of disassembly. The Design for Disassembly (DfD) is one of the Eco-Design methodologies. It intends to optimize the disassembly operations to which the product will be exposed during its lifetime, in order to reduce maintenance costs or to allow cost-effective reuse, remanufacturing and recycling. In the present research, a review is established in order to focus on the design for sustainability. The principles used are based on a number of DfX methodologies. It is obvious that the design for sustainability can usefully exploit the DfX methodologies and conceive a sustainable product. In addition, it is clear that there is a gap when considering the environmental influence on the user’s behaviour and for this reason the Design for Green Usability was created.

Another interesting approach of design for sustainability is the field of design for sustainable behaviour, which explores how design can be used to influence consumer behaviour in order to improve sustainability. This approach focuses on consumers through the lens of social psychology and associated methodologies, rather than focusing purely on the design aspects that play a key role in the sustainability of a product. Energy consumption during the use phase of products’ lifecycle has a considerable environmental impact mainly influenced by the consumer’s behaviour. There are a numerous campaigns which have been implemented towards this direction and proved ineffective in creating the long term behavioural shift needed to reduce the impact of product use. UCD is a methodology with an aim to describe design processes that promote a real approach of design teams to end-users. The users influence how a design is implemented because their own needs, goals, limitations, possibilities, previous experiences and how those are affecting their interaction with objects are taken into account. Designers should enhance their work with a number of methods that promotes a closer approach to the people who should use products.

As mentioned, traditional eco-design has a strong focus on the supply side. Even when attention is paid to the use phase, it is often true that the impacts are influenced by the manufacturer. It is very common in these cases that the manufacturers do not consider or pay little attention to the user demands. Yet, it is the way that users interact with a product that can often strongly influence the environmental impact of that product. Of course, encouraging people to change their behaviour towards more sustainable product usage is not easy. Designers should try to influence this behaviour through the products they design and for this reason a series of tools have been reviewed (Fig. 6).

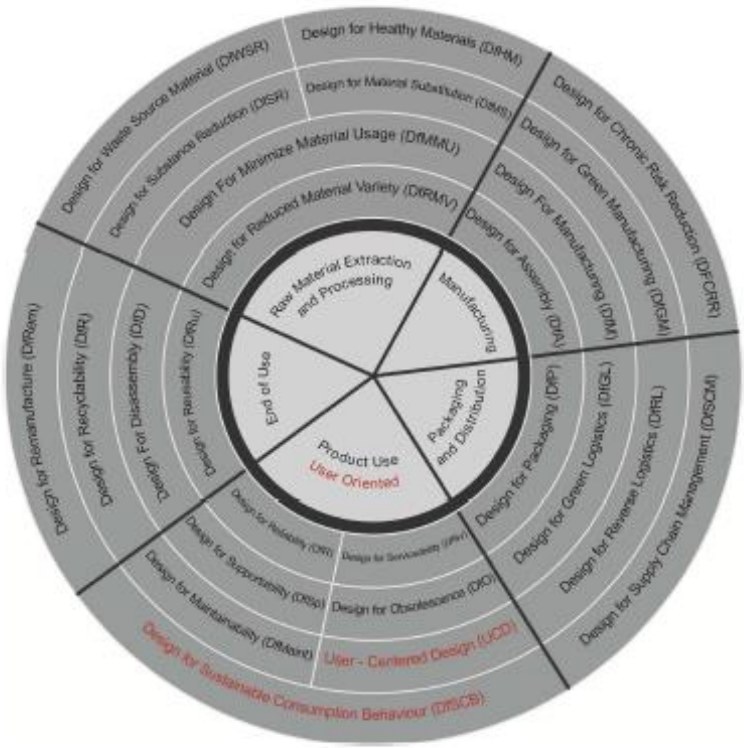


Figure 6.The cycle of the methodologies reviewed

The DfGU methodology considers the design process as a mean for creating mindful interaction through the use of objects in ecological context. The assumption is that products can stimulate the user's behaviour by means of their function, thus causing mindful reflection and interaction. All the designed products considered are a lot more than physical objects. They are experiences or activities or services, all of which are integrated into a new understanding of what a product is or could be. The conventional goal of design for green usability is to design products that are environmental friendly and developed based on green design principles i.e. require the least energy in order to be produced, consume less energy when they are used and they could be recycled at the end of their lifecycle. Currently, this concept is growing and is focused on a really effective change, where the design must be capable of changing the end user behaviour. The design strategy under this concept should be 'offensive' to the user. Its main target is the promotion of the green character of the product/system. This product green character should be the central element which would force anyone to make use of its function. When interacting with a product, the user has a specific goal related to the product function. This strategy is about including a design element that requires the user to perform a specific behaviour in order to reach his goal. In our case, the use of the product designed under the proposed methodology makes the user automatically a conscious 'green' user. Developed products should influence the average user towards environmental friendly characteristics for managing a positive (greener) changing behaviour.

Design for Green Usability is a design approach that incorporates the user during the entire design process. Instead of concentrating on technological issues and environmental measurements in terms of components, it takes the user considerations as a starting point, taking into account needs, wishes, characteristics and abilities of the targeted user group and measures them after the completion of the product development. The aim of adopting a Design for Green Usability approach is to improve the quality of the interaction between the user and the product. During the feasibility and specification stage of a product, the user target group should be asked about its mindful interaction through the ecological character of the product. Designer should discover from his communication with the user which elements could stimulate the user's behaviour by means of the product's green functions (Fig. 7)

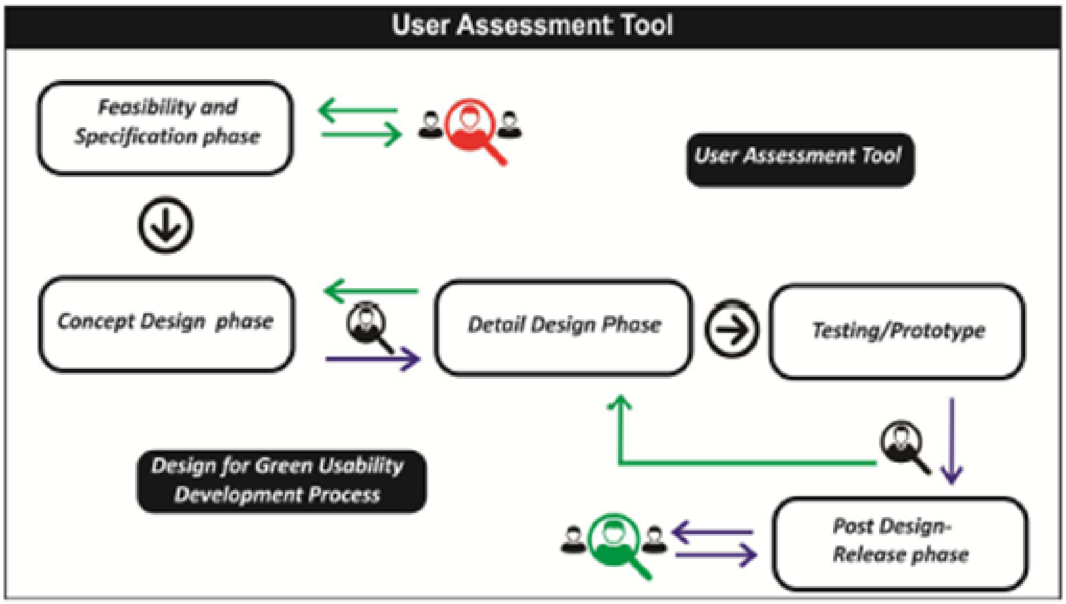


Figure 7. Assessment tool framework

Further to the feasibility study, designers proceed to the conceptual design of the product. They should incorporate eco-design principles and by the end of that phase, customers come into the picture and assess the concepts. The assessment is based on a questionnaire which has two aims. First, the customers define their idea about the product functionality, worthiness, aesthetics, ergonomics etc. Second, if the promotion of the product's green character is positively accepted, it means that the user desires to make use of the product and its function. A relative questionnaire and several interview sessions are taking place, in order to capture the customer perception on the ecological message that the product offers. In the next step, the product development process is undergoing in the further activities such as detail design, testing and prototype building. It is then that a new customer assessment is executed, in order to provide evidence that the expected product is according to the customer demands and at the same time it promotes the sustainability principles. Both the assessment activities result in redesigning the product in order to take into account the customer feedback. After the release phase of the product the user is expected to be a step forward towards a conscious green user. A representative example of a product designed based on the DfGU methodology is the Self-Luminous Bench (S-L) depicted in Figure. 8. This S-L bench collects solar energy during the day and mainly uses it to be self-illuminated over the night. Additionally, it contains a socket for the outdoor electric supply needs of people. The target is the design of a fashionable bench, which decorates the place where is positioned.

Figure 8. The Self-Luminous Bench

Simultaneously it offers a shade on the sunny days and light during the night. This bench makes more romantic and safer the walk around the city, something which provides a more social character to it. Its use could create a new trend in products designed for the municipality services. The dimensions of the bench are based on the ergonomics of an average human body, while it is easily accessible to vulnerable groups of people. The basic material for its construction is wood, which is a local and renewable raw material. Moreover the symmetry makes easier and more environmental friendly its production and assembly. The number of the components used is kept to a minimum, while at the same time it is easily disassembled, maintained and recycled if needed.

6.3.3. Presentation of the publication " Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies "

Drilling is an essential part of processes used in subtractive manufacturing for achieving the desired products. Its massive usage requires that any parameter optimization in the process promotes the efficiency and the greener machining. Cutting tool technology is considered one of the most significant impact factors on the sustainability of machining processes and systems. Therefore, the best choice of cutting tools and parameters for the quality of the products and the tool life criterion are both critical for the sustainability metrics of a drilling process. The correct usage of the cutting tool can affect the reduction of needed resources and energy for the production of a new one. Aluminium alloy 7075 (Al7075) is suitable for a variety of specific applications in the aerospace and chemical industries because of its excellent mechanical properties. Its strength, which is comparable to many steels and its excellent corrosion resistance are the main reasons that researchers focus on it. The chemical composition of Al7075 is given in Table 1.

Table 1. Chemical composition of Al7075

Elements	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti	Al
Percentage	6	3	2	0.3	0.6	0.5	0.4	0.3	Balance

The development of an appropriate cutting factor analytical model is challenging. Nevertheless, there is much research developed about the suitability of different empirical models to predict different factors during several cutting processes. A number of methods, such as artificial neural networks (ANN) and response surface methodology (RSM), have been developed for modelling many manufacturing parameters. The successful application of ANN for prediction and modelling purposes in several science and engineering domains is substantial. ANN is utilized for modelling and prediction purposes due to its advantages in non-linear response and when time variability occurs. It covers the difficulty in inferring input/output mapping and the search algorithms for optimization, based on genetic and evolution principles. RSM is a reliable statistical tool for the mathematical modelling of engineering systems and for the optimization of different manufacturing processes. It has been considered to be useful with minimum knowledge about the process under consideration, while simultaneously reducing the resources needed for experiments. It is an appropriate methodology when many factors and interactions affect the desired responses for a given process and an effective technique for evaluating the process parameters with the least number of experiments.

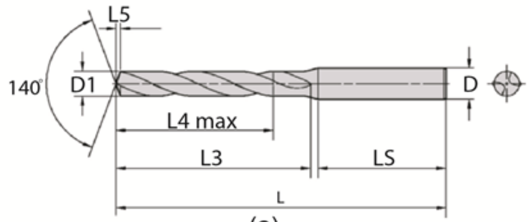
The present paper deals with the study of the drilling process of Al7075 when using solid carbide tools. A series of different diameters were used, together with a number of different cutting speeds and feed rates. A complete set of experimental work was implemented, and different mathematical models of the thrust force and torque developed were calculated. Both RSM and ANN methodologies were applied, and although their results were highly accurate, the ANN model was more effective.

In this study, an Al7075 plate was used as the workpiece material (150 mm × 150 mm × 15 mm). The drilling tests were performed using a HAAS VF1 CNC machining centre with continuous speed and feed control within their boundaries. The cutting forces were measured by utilizing a Kistler four components dynamometer (type 9123) with all the appropriate accessories. The dynamometer signals were processed via charge amplifiers and an A/D converter to a personal computer. The measured thrust force and torque were displayed and analysed to implement an early error detection strategy.

Table 2. Cutting variables used in the experiments

Parameters	Values
Cutting velocity [m/min] *V*	10, 40 ,70
Feed rate [mm/rev] *f*	0.2, 0.4, 0.6
Tool diameter [mm] *D*	8, 10, 12, 14
Axial depth of cut [mm] *ap*	15
Workpiece dimension [mm]	150 × 150 × 15

During the drilling tests, thrust force (Fz) and torque (Mz) values were measured in 36 experiments which were performed by using solid carbide drill tools (Kennametal - multilayer TiAlN-PVD-coated universal fine-grain grade). Fig. 9 shows details of the cutting tool geometry.



(a)

Catalogue number	(L4) max drill depth [mm]	(L3) flute length [mm]	(LS) flute length [mm]	(D) shank diameter [mm]
B041A08000CPG	29	41	36	8
B041A10000CPG	35	47	40	10
B041A10000CPG	40	55	45	12
B041A10000CPG	43	60	45	14

(b)

Figure 9. Cutting tool; a) Geometry details and b) Dimensions

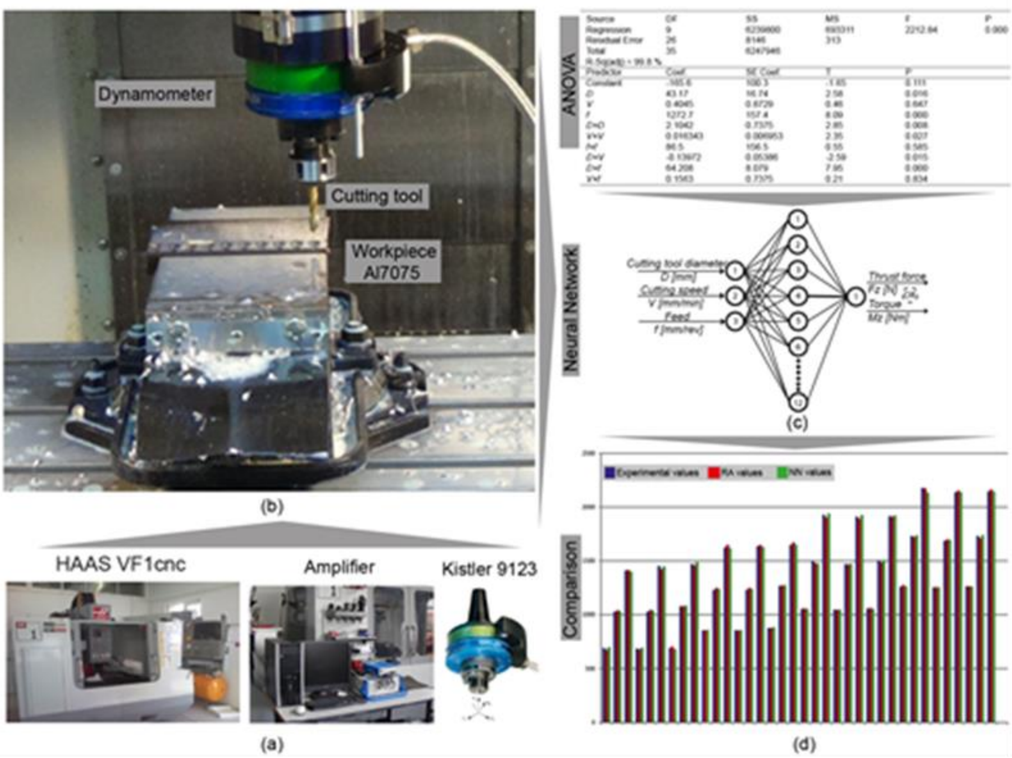


Figure 10. Experimental workflow; a) The required hardware equipment, b) Drilling process, c) Development of mathematical models, d) Comparison between experimental and predicted values for thrust force and cutting torque.

The cutting tools are not through coolant category tools; therefore, coolant fluid (90% water, 10% KOOLRite 2270 coolant) was provided by the delivery system near the cutting tool. The feed rates of 0.2 mm/rev, 0.4 mm/rev, and 0.6 mm/rev were used together with cutting velocity values of 10 m/min, 40 m/min, and 70 m/min. The constant depth of the holes drilled was 15 mm. The full factorial set of tests was performed for all the combinations of cutting speeds, feed rates, and tool diameters. The workflow of the research is depicted in Fig. 10 and the cutting parameters, units, and notations are listed in Table 2.

Figure 11 expresses the evolution of thrust force and the cutting torque related to different feed rates and cutting speeds. According to the graph, it can be seen that when the tool diameter increases, both the thrust force and the cutting torque values are increased as expected. The same happens in the case of the feed rate. As feed rate values are increased, the thrust force and the cutting torque are then increased respectively. In contrast, the different values of cutting speed do not noticeably affect the experimental values. The importance of cutting tool diameter and feed rate is much greater than that of cutting speed related to thrust force and cutting torque.

The RSM is an accurate tool used to check the influence of a series of input variables on the response when studying a complex phenomenon. The models produced use the least square fitting in order to provide a reliable mathematical model. In this case, a full factorial strategy was followed, 36 drilling experiments were performed, and both the thrust force and torque were modelled using polynomial mathematical models. The following form was selected for this case:

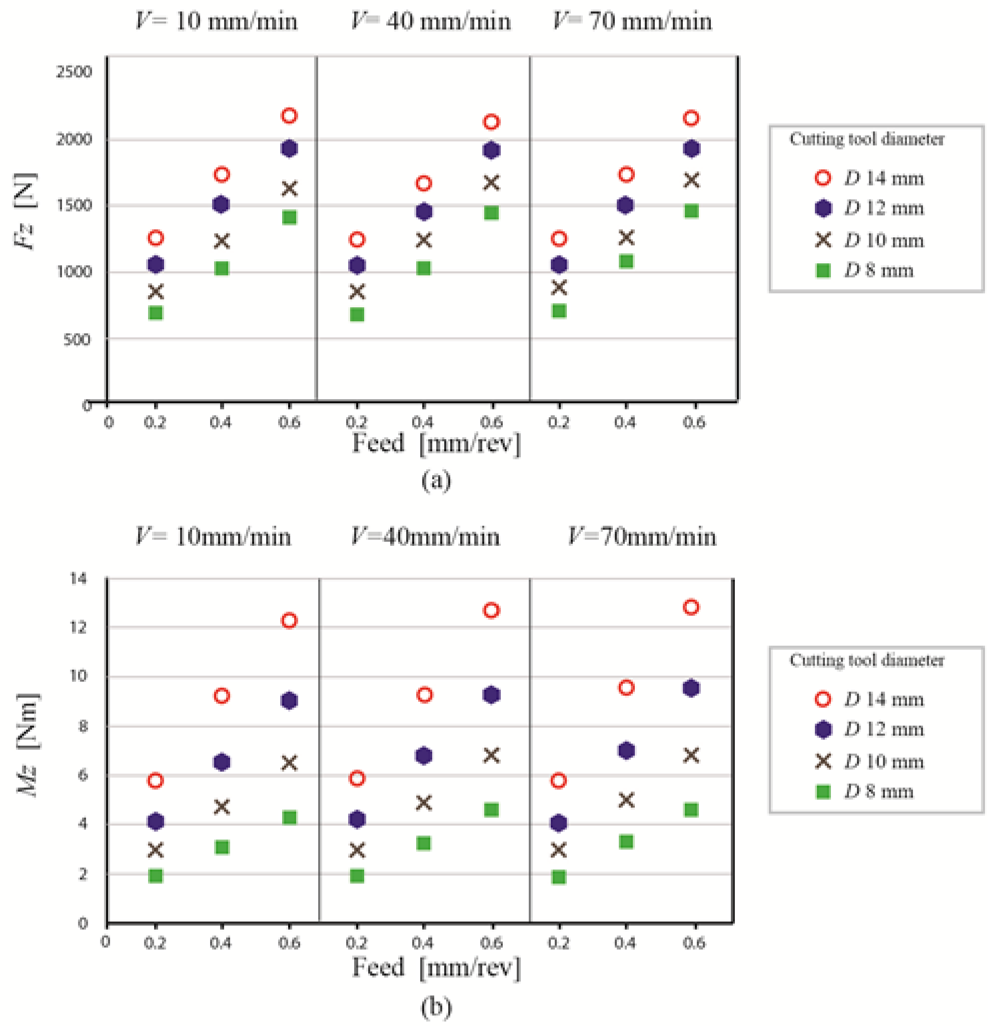


Figure 11. Experimental values derived from Kistler 9123, a) Fz and b) Mz

Y=b0+b1X1+b2X2+b3X3+b4X4+b11X12+b22X22+b33X32+b44X42+b12X1X2+b13X1X3+ b14X1X4+b23X2X3+b24X2X4+b34X3X4 , (1)

where Y is the response, Xi stands for the coded values and b0,…,b34 stand for the models' regression coefficients.

Based on this mathematical model, the data acquired formed the following equations for the thrust forces in [N] and the torque in [Nm] respectively:

Fz = - 166 + 43.2 D + 0.405 V + 1273 f + 2.10 D×D + 0.0163 V2+ 86 f2 - 0.140 D×V + 64.2 D×f + 0.156 V×f (2) and Mz = 4.52 – 0.913 D – 0.00502 V – 7.31 f + 0.0548 D×D – 0.000046 V2- 1.39 f2 + 0.000405 D×V + 1.73 D×f + 0.0197 V×f (3)

where D is the tool diameter [mm], f is the feed rate [mm/rev], and V is the cutting speed used [m/min] and solid carbide tools and Al7075 workpiece.

Table 3. ANOVA table for the Fz (thrust force)

Source	*DF*	*SS*	*MS*	*F*	*P*
Regression	9	6239800	693311	2212.84	0.000
Residual Error	26	8146	313		
Total	35	6247946			
R-Sq(adj) = 99.8 %					

Predictor	*Coef.*	*SE Coef.*	*T*	*P*
Constant	-165.6	100.3	-1.65	0.111
D	43.17	16.74	2.58	0.016
V	0.4045	0.8729	0.46	0.647
f	1272.7	157.4	8.09	0.000
D×D	2.1042	0.7375	2.85	0.008
V×V	0.016343	0.006953	2.35	0.027
f×f	86.5	156.5	0.55	0.585
D×V	-0.13972	0.05386	-2.59	0.015
D×f	64.208	8.079	7.95	0.000
V×f	0.1563	0.7375	0.21	0.834

Table 4. ANOVA table for the Mz (torque)

Source	*DF*	*SS*	*MS*	*F*	*P*
Regression	9	322.187	35.799	2908.77	0.000
Residual Error	26	0.320	0.012		
Total	35	322.507			
R-Sq(adj) = 99.9 %					

Predictor	*Coef.*	*SE Coef.*	*T*	*P*
Constant	4.5188	0.6287	7.19	0.000
D	-0.9134	0.1049	-8.71	0.000
V	-0.005017	0.005471	-0.92	0.368
F	-7.3081	0.9862	-7.41	0.000
D×D	0.054812	0.004622	11.86	0.000
V×V	-0.00004644	0.00004358	-1.07	0.296

f×f	-1.3917	0.9806	-1.42	0.168
D×V	0.0004053	0.0003376	1.20	0.241
D×f	1.73142	0.05064	34.19	0.000
V×f	0.019729	0.004622	4.27	0.000

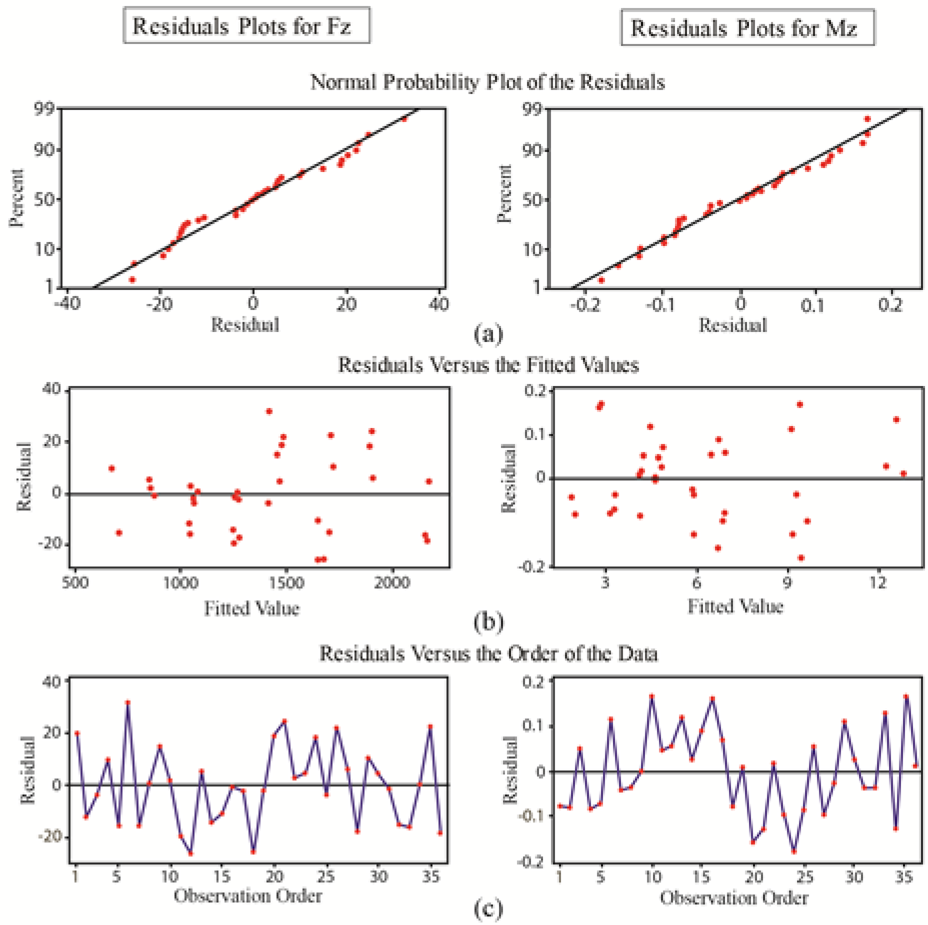


Figure 12. Residuals analyses for the Fz and Mz a) Normal Probability Plot of the Residuals, b) Residuals Versus the Fitted Values, c) Residuals Versus the Order of the Data

The adequacy of the models is provided at a 5% level of significance. ANOVA was used for establishing the validity of the developed models. The calculated values of the F-ratio of the developed models (Tables 3 and 4), are significantly increased compared to the tabulated value of the F-table at a 95% confidence level (2212.84 for the Fz and 2908.77 for the Mz), while the P-values are 0.000, which proves the highest correlation between data and model in each case. The validity of the models is also proved because the R-sq(adj) is very high in both cases (99.8% for the Fz and 99.9% for the Mz). In addition, the significant terms of the models, when a level of significance of 5% is used, are those with a P-value less than 0.05. For the Fz these factors are: D (P = 0.016), f (P = 0.000), D×D (P = 0.008), V×V (P = 0.015) and D×f (P = 0.000), while for the Mz the significant terms are: D (P = 0.000), f (P = 0.000), D2 (P = 0.000), D×f (P = 0.000), V×f (P = 0.000).

Residual analysis was performed to test the models' accuracy; in both cases, the residuals follow the normal distribution. They follow straight lines (almost linear patterns) proving that the errors follow the normal distribution. All the scatter diagrams of the Fz and Mz residuals versus the fitted values depict that the residuals are evenly distributed on both sides of the centreline.

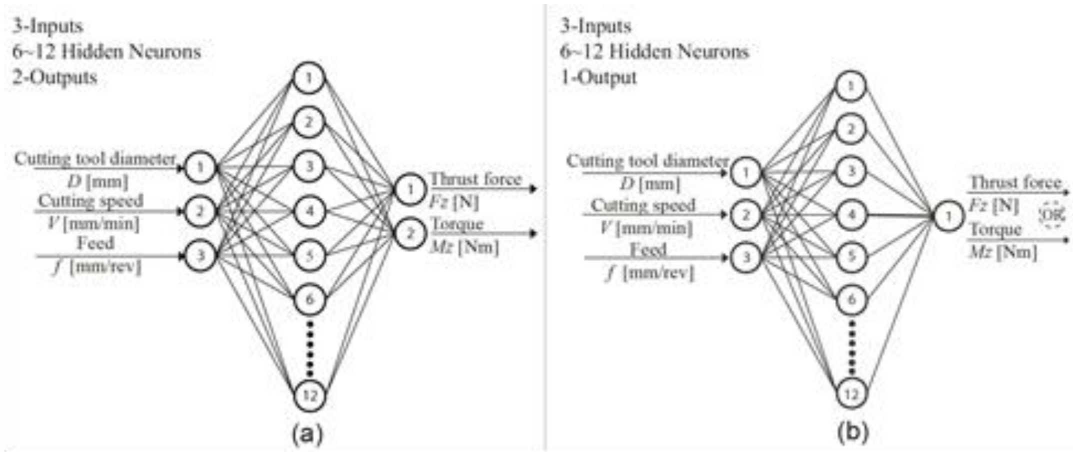


Figure 13. Architecture of ANN with a) 3 inputs-6 to 12 hidden neurons -2 outputs, and b) 3 inputs-6 to 12 hidden neurons-1 output topology

The same is true for the residuals versus the order of the data (see Fig. 12). The accuracy achieved is very high when comparing the measured values and those calculated from the mathematical models (3% and 5.6%, respectively). The derived mathematical models can be considered to be very accurate and can be used directly for predicting both the thrust force and the cutting torque within the limits of the tool diameter, feed rate, and cutting speed used.

Artificial Neural Network ability to learn complex non-linear and multivariable relationships between process parameters makes them very useful in many applications. An ANN consists of a number of neurons, which are divided into the three basic layers: input, hidden, and output. The neurons between the layers are linked, having synaptic weights. One of the basic advantages of ANN is its ability to learn from the process. When the architecture of the network is defined, then, through a learning process, weights are calculated to present the desired output.

The present research used a series of neural network pieces of software available for the development of a multilayer feed forward neural network. An elementary neuron with R inputs is shown in Figure 14a. Each input is weighted with an appropriate value (w). The sum of the weighted inputs and the bias forms the input to the transfer function (f). Neurons can use any differentiable transfer function (f) to generate their output.

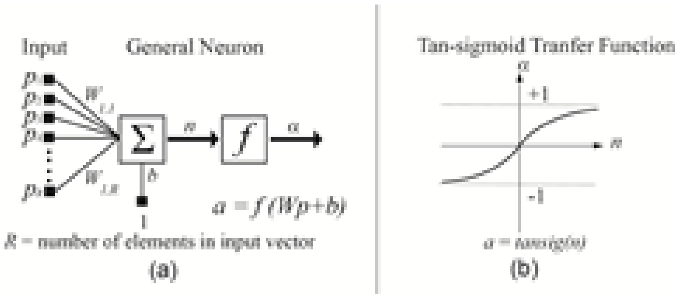


Figure 14. Multilayer neuron network architecture, a) elementary neuron with R inputs, b) linear transfer function

The standard network that is used for function fitting is a two-layer feed forward network, with a tan-sigmoid transfer function in the hidden layer and a linear transfer function in the output layer (see Fig. 14b). Assuming that the activation function used in the hidden and the outer layer is sigmoidal, the outputs of the hidden and outer layer were calculated using the following equation:

$$f(net) = \frac{1}{1 + e^{-net}} \qquad (4)$$

All of the original (36) experimental data were randomly divided into three data sets including training, validation and testing. The back-propagation training algorithms, the scaled conjugate gradient (SCG) and Levenberg–Marquardt (LM), were used for ANNs training. The training set used 70 % of the data to build the network, 15 % to measure network generalization and 15 % as a testing set of the neural network.

Three-layer network architectures were used to predict the thrust force and torque as shown in Fig. 13.

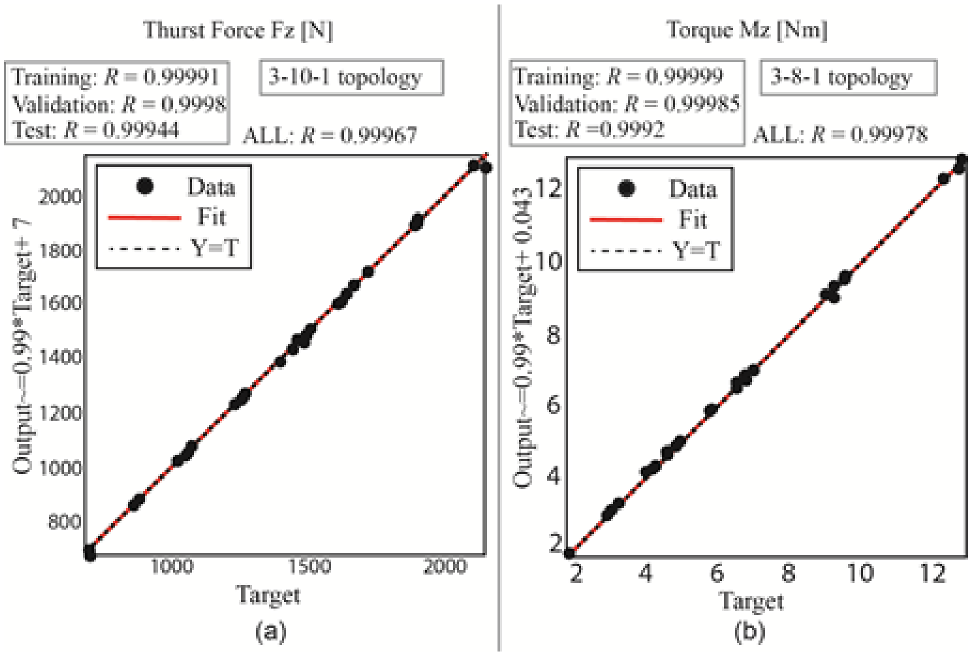


Figure 15. Neural network plot linear regressions for a) Fz and b) Mz

In the first case, a 3-(6~12)-2 ANN topology was used, which consists of three input nodes (tool diameter, cutting speed, feed rate), one hidden layer (6 to 12 neurons) and two outputs (thrust force and torque). In the second case, two different 3-(6~12)-1 ANN topologies were used as the output layer consists of one neuron corresponding to one output variable Fz and Mz, respectively.

In consequence of trials, the best network architecture for the prediction of thrust force was the 3-10-1 topology. The comparison of predicted results from ANN model with experimental measurements shows that there is a very good correlation between them. It is obvious that a neural network is an excellent tool for predicted values of Fz according to experimentally measured ones. The correlation coefficient (R value) between the outputs and targets is a measure of model accuracy. The R value for the entire dataset (training, validation and testing) is 0.99967, and it represents high correlation. In addition, all the categorized R-values (training, validation and test) are very close to 1 (see Fig. 15). When comparing both the measured and the predicted Fz values the highest discrepancy observed is 2.18%. In the case of Mz, the best network architecture for the prediction of the experimental values was the 3-8-1 topology. The R value for all the dataset (training, validation and testing) is 0.99978 and in each one of them separately is close to 1. As a result, the network achieves high accuracy (see Fig. 15). When comparing the measured with the predicted Mz values the highest difference observed is 3.15%. From the output of both cases, it is concluded that the training of the ANN with one output for each case offers greater accuracy than in the case of the network with two outputs.

A full factorial experimentation design is implemented to search for the effects of the cutting parameters (i.e. cutting speed, feed rate, and tool diameter) on the thrust force and torque in the case of drilling.

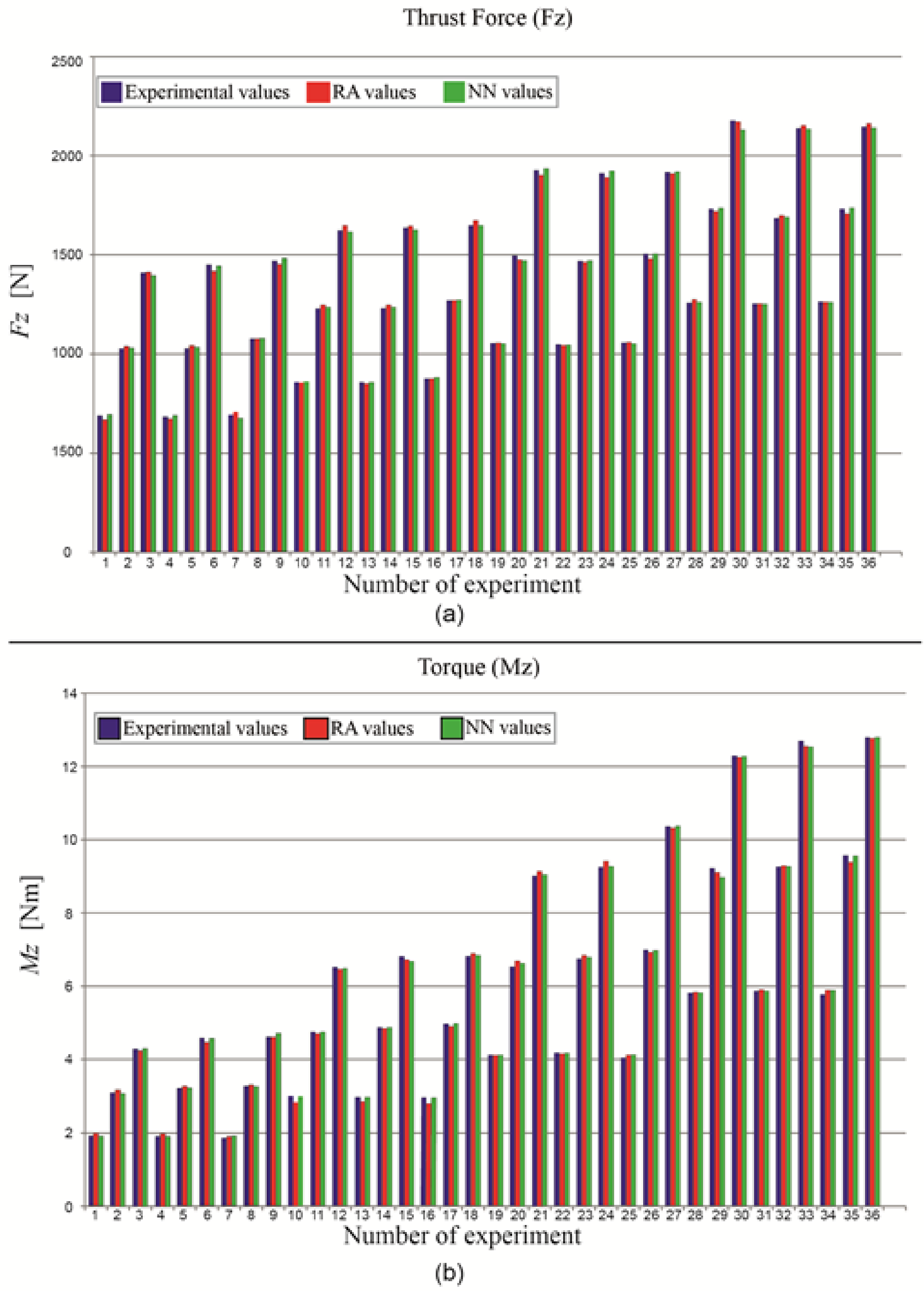
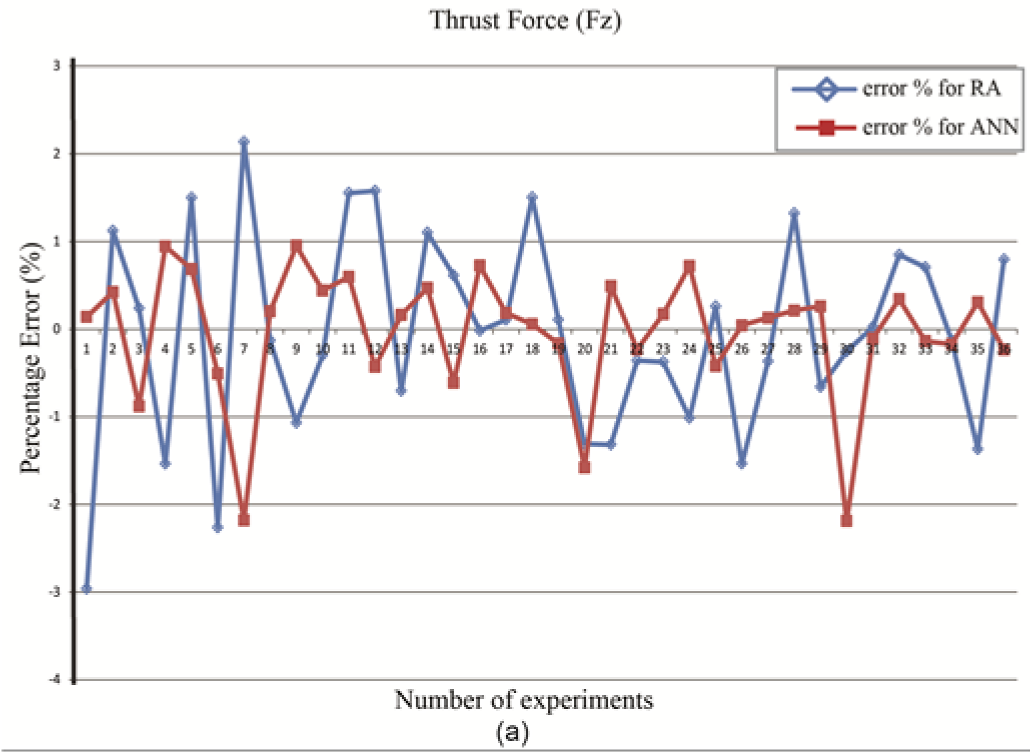


Figure 16. Comparison of the experimental values with the predicted values for a) Fz and b) Mz



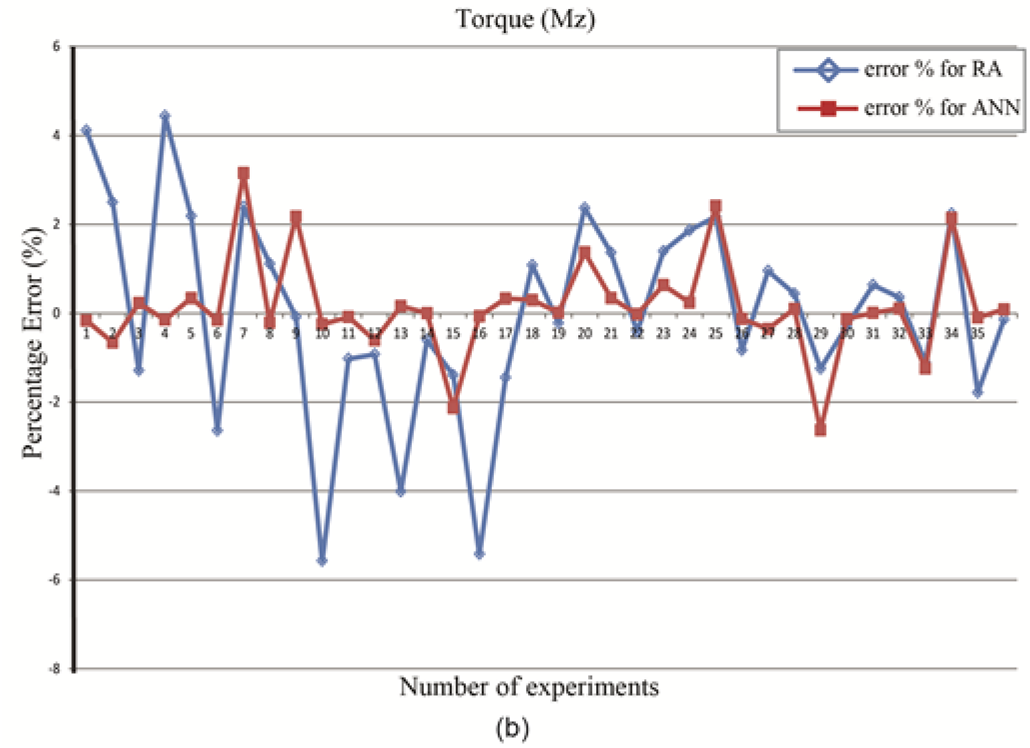


Figure 17. Error between experimental and predicted values for a) Fz and b) Mz

After each hole was made, the measurements of thrust force and torque were documented. Artificial neural network and response surface methodology models were developed to predict the thrust force and torque using the experimental data.

A comparison was established between the experimental values of Fz and Mz (see Fig. 16) and their values of ANN and RSM model, respectively. It is obvious that the predicted values from both models approximate the experimental values. Nevertheless, the predicted values from the ANN more accurately predict the experimental values than the regression analysis model. This can also be proved from the calculated percentage of error between experimental and predicted values of the models which are depicted in Figure 17 for both the Fz and the Mz. In the case of the ANN models, the accuracy achieved was 2.18% and 3.15% for both the thrust force and torque, while in the case of the response surface methodology model the accuracy achieved was 3% and 5.6%, respectively.

6.3.4. Presentation of the publication ""'WEDM manufacturing method for noncircular gears using CAD/CAM software"

The method presented in this research addresses the development procedures in order to design and manufacture elliptical gears and oval gears. Even though two different methods are addressed to develop elliptical and oval gears, a common flowchart has been developed to organize the process. It is described in the following Figure 18.

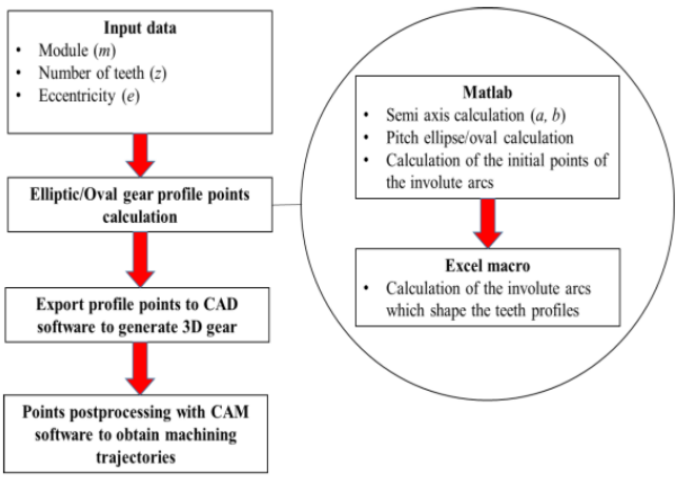


Figure 18. Flow chart for design and manufacturing

According to this flowchart, the designing process is arranged using Matlab™ and an Excel™ macro. Starting from an initial input data, Matlab™ is used to calculate the semiaxis, the pitch ellipse/oval and the initial points distributed on it from where the involute arcs define the teeth start. Then, an Excel™ macro is used to calculate the involute arcs which define the teeth profiles. These points define the gear and they are exported to a general purpose CAD software in order to obtain the 3D gear model and, after that, they are post processed in a CAM software in order to obtain the milling trajectories required to manufacture the gear. Elliptical and oval gears may be similar, but their behaviour is not the same, not only from a geometrical point of view, but also from a kinematic point of view as described below.

In this article, a Cartesian coordinate system is used in the elliptical gear case and a polar coordinate system to develop the oval one. Being a and b the semi major and the semi minor axes respectively, elliptical gears rotate with respect to their focuses and oval gears rotate around their centres. These differences, along with the equations describing the pitch ellipse and the pitch oval are represented in Figs. 19 and 20, as shown below.

Elliptical gears rotating with respect to their focuses (Fig. 19):

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \qquad (5)$$

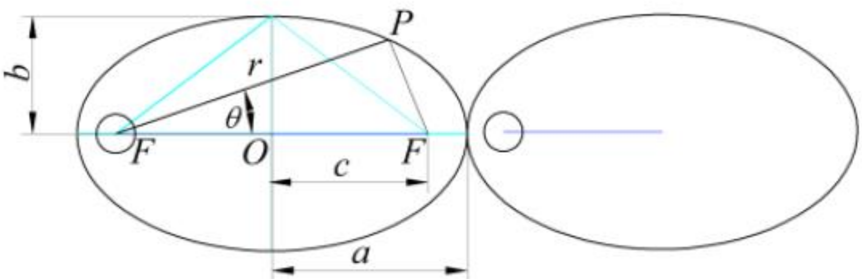


Figure 19. Elliptical gears.

Oval gears rotating with respect to their focuses (Fig. 20):

$$r = \frac{2ab}{(a+b)-(a-b)\cos 2\theta} \quad (6)$$

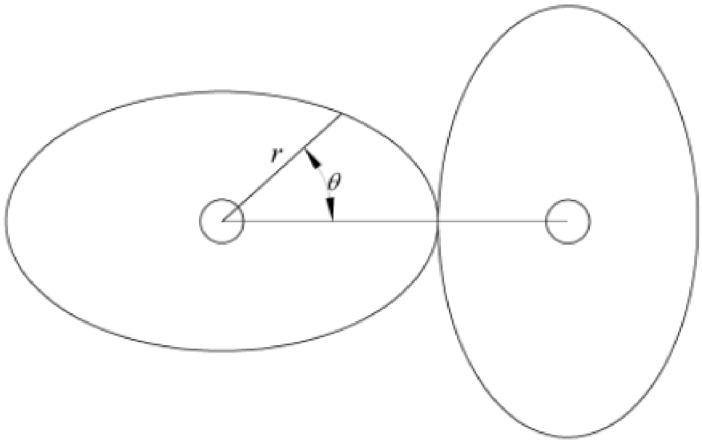


Figure 20. Oval gears.

The procedure presented in this paper approaches the design by approximating and calculating the teeth as in the spur gears, but taking into account the local curvature of theellipse and the oval. In order obtain the teeth of the gears, the radius of curvature of the expressions (7) and (8) can be applied. It is expressed in Cartesian and polar coordinates respectively by:

$$\rho = \frac{\left[1+\left(\frac{\mathrm{d}y}{\mathrm{d}x}\right)^2\right]^{3/2}}{\frac{\mathrm{d}^2 y}{\mathrm{d}x^2}} \quad (7)$$

$$\rho = \frac{\left[r^2+\left(\frac{\mathrm{d}r}{\mathrm{d}\theta}\right)^2\right]^{\frac{3}{2}}}{r^2+2\left(\frac{\mathrm{d}r}{\mathrm{d}\theta}\right)^2 - r\frac{\mathrm{d}^2 r}{\mathrm{d}\theta^2}} \quad (8)$$

For the ellipse equation (5), applying (7), the radius of curvature in cartesian coordinates is:

$$\rho = -\frac{\left[a^4y^2 + b^4x^2\right]^{3/2}}{a^4b^4} \qquad (9)$$

As an example, the extreme values of the radius of curvature, for a=100 and b=60, are represented in Figure 21.

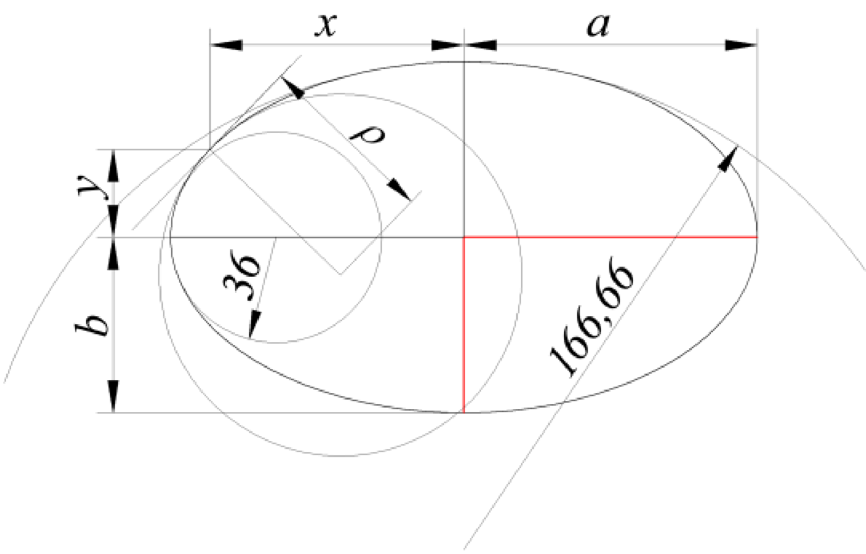


Figure 21. Extreme radii of curvature of an ellipse using equation (1).

The radius of curvature obtained for the oval equation (6), as a result of applying (8), is a complex expression. It is important to note that the oval equation (6) presents points with zero slope. When $a \leq 2b$ its aspect is similar to an ellipse. For greater values of the parameter a, six points with zero slope are obtained, Fig. 22a. In Fig. 22b, the maximum and the minimum radii of curvature are represented for a=100 and b=60.

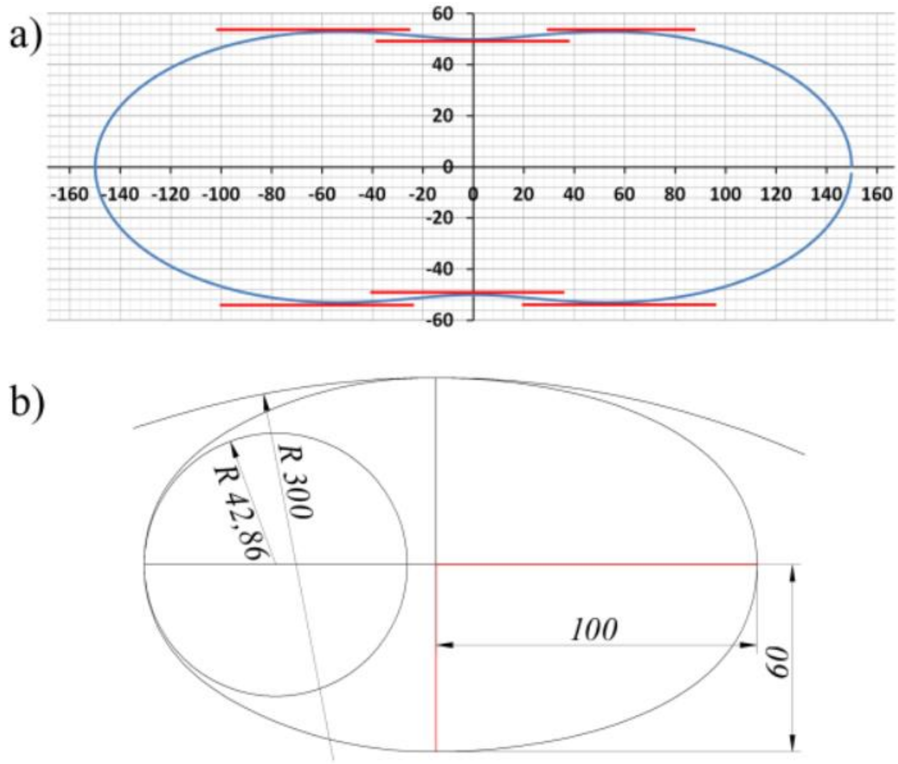


Figure 22. Different ovals; a) With a>2b; b) With a=100 and b=60.

It is considered that in the intersection point of the symmetry axis of the tooth with the ellipse/oval, the constructive radius of this tooth is the radius of curvature of the pitch ellipse/oval, in order to generate the tooth, Fig. 23.

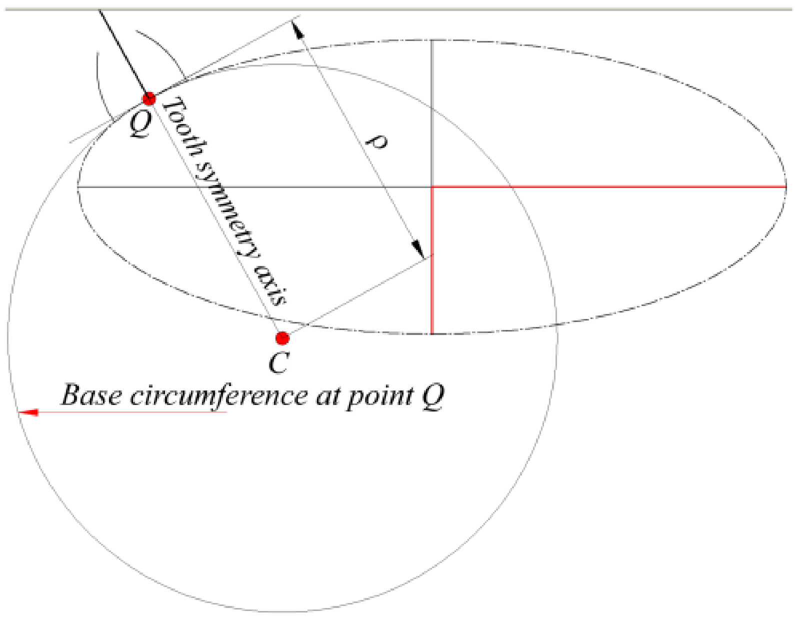


Figure 23. The tooth of the ellipse/oval corresponds to the tooth of a circle with the same curvature.

The following considerations must be taken into account as well:

The tooth thickness measured in the pitch ellipse/oval must be the same for all the teeth, otherwise the teeth would not mesh with the hole between flanks of consecutive teeth. As the final thickness is always lower than the nominal one, there is a bigger space between consecutive teeth.

In a pair of gears, each one has z teeth, and a tooth pitch measured on the ellipse/oval of $p=\pi\cdot m$ (Where m is the module), which is the double of the tooth thickness.

If the tooth pitch in the pitch ellipse/oval is ◎·m, then the perimeter is $\pi\cdot m\cdot z$, being this last value the pitch ellipse/oval length.

In this case, the calculation starts using the pitch ellipse/oval length, obtaining the values of a and b through another condition, such as the eccentricity. In this way, if a gear with module m=2.5, teeth number z=53 and eccentricity e=0.85 is manufactured, being the ellipse/oval length $l=\pi\cdot m\cdot z=\pi\cdot 2.5\cdot 53=416.2610$. In order to obtain simpler values of a and b, other non-conventional module can be applied.

Here, two different methods are discussed to obtain the semiaxes a and b. They are not the same because different approaches are used with an ellipse and an oval, as follows.

The ellipse length is obtained applying this integral:

$$l = 4\int_0^a \sqrt{\mathrm{d}\,x^2 + \mathrm{d}\,y^2} \qquad (10)$$

Solving this equation leads to an elliptic integral of the second order. Evaluating it with Matlab™ and equalizing it to the value of the ellipse perimeter, it is possible to solve it and to obtain the value of the semiaxes a and b.

The oval length is obtained applying the integral:

$$l = 4\int_{0}^{\frac{\pi}{2}} \sqrt{\left(\frac{\mathrm{d}r}{\mathrm{d}\theta}\right)^{2} + r^{2}}\,\mathrm{d}\theta \qquad (11)$$

It is not possible to solve this equation directly with Matlab™, so, numerical methods can be applied in order to evaluate the integral and equalize it to the value of the oval perimeter with an error smaller than the value set by the gear designer.

The numerical method to obtain the value of the semiaxes *a* and *b* is presented in Fig. 24.

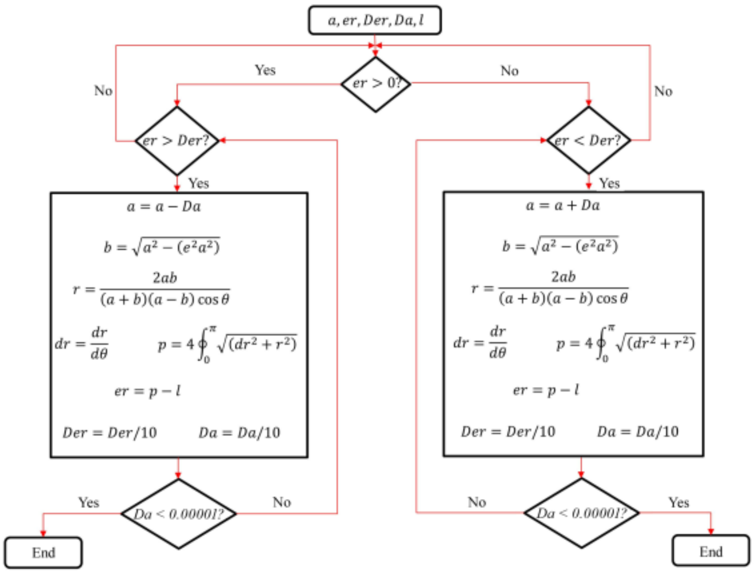


Figure 24. Numerical method to obtain semiaxes a and b, solving equation (11).

The uncertainties in the algorithm are summarized in the Table 1. In this algorithm, the initial values for the major and the minor semiaxes a and b are considered. Using input data, the perimeter value is calculated. Then, using the algorithm, the initial value of the major semiaxis a is increased or decreased until the difference between the perimeter calculated using these values and the perimeter obtained from the input data is smaller than a given error.

Table 5. Uncertainties in the algorithm

l	Oval perimeter calculated with the input data
a	Major semi-axis
b	Minor Semi-axis
e	Eccentricity
er	Error between the calculated perimeter by the numerical method and by the input data
r	Oval polar equation
p	Oval perimeter calculated by integration
Der	Error increment between iterations
Da	Value to decrement or increment the semimajor axis initial value between iterations

A starting point for the pitch ellipse/oval is chosen, in this case (a, 0), and the points of the pitch ellipse or the pitch oval are calculated. The calculation of the teeth distribution starts with a Matlab™ program and ends with an Excel™ macro.

The Matlab™ program determines the pitch ellipse points with a chordal error lower than a given value.

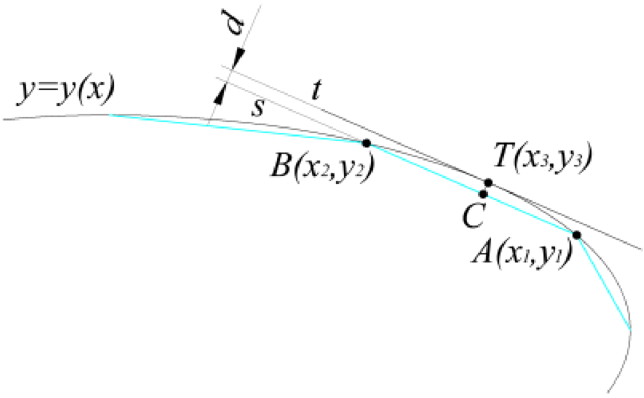


Figure 25. Obtaining the ellipse points.

In the environment of a point *A(x1, y1)*, another point *B(x2, y2)* is obtained satisfying the condition that the secant *AB* maintains a maximum distance d to the curve. This distance is obtained by substituting the coordinates *T(x3, y3)* in the normal equation of the line.

$$d = \frac{a \cdot x_3 + b \cdot y_3 + c}{\sqrt{a^2 + b^2}} \qquad (12)$$

It must also be kept in mind the sign of the distance *d*, which indicates the semiplane where the point taken as a reference for that distance is placed. In this case, the square of the distance has been evaluated in order not to take into consideration the distance sign.

$$d^2 = \frac{(a \cdot x_3 + b \cdot y_3 + c)^2}{(a^2 + b^2)} \qquad (13)$$

The point *T* is the point of tangency of the parallel line to the secant segment *AB* with the function graph. Therefore, the first derivate in *T* is equal to the tangent of the a angle.

$$y'_{x=x_3} = \frac{y_2 - y_1}{x_2 - x_1} \qquad (14)$$

In this way, the two conditions which will allow solving the two uncertainties (*x*2, *y*2) are found. It is not necessary to analyse the sign of the tangent, because the trajectory is known. In order to solve this system of two equations with numerical methods MATLAB™ makes possible to apply the following command:

maple(fsolve({equ1,equ2},{var1,var2},{var1=v1initial.. v1final,var2=v2initial..v2final}))

Knowing the tooth thickness, the ellipse arc segments of the calculated length are distributed on the ellipse and the radius of curvature of these points are determined (Fig. 26).

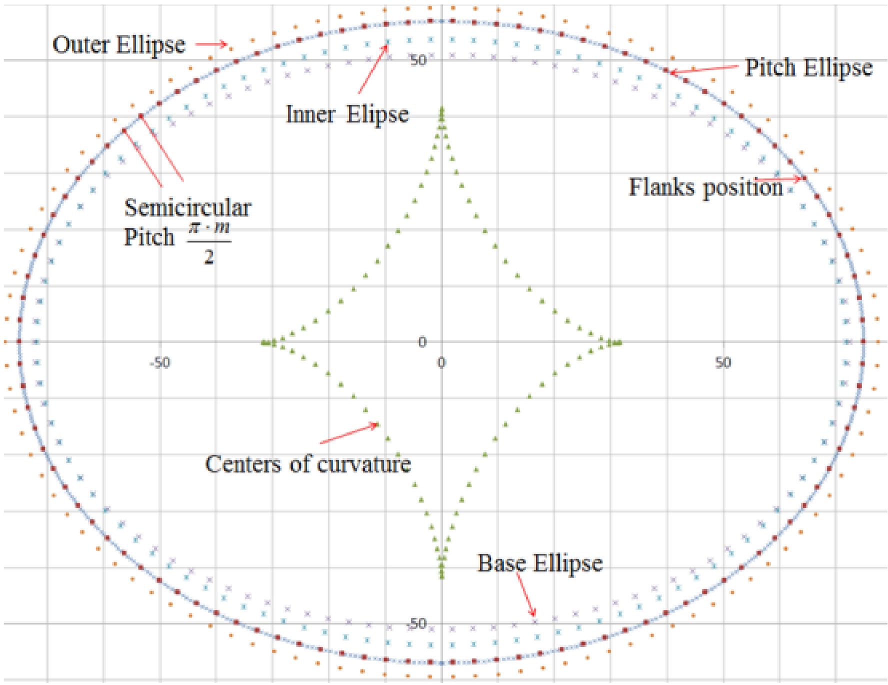


Figure 26. Points to position the flanks and other characteristic points.

In order to obtain the initial points of the involute arcs, it must be taken into account that the ellipse/oval length obtained by the equations (10) and (11) lead to elliptical integrals. For this reason, these calculations have been carried out in MATLAB™, but once the points of the pitch ellipse have been obtained, the separation value of the half tooth pitch is calculated with Excel™, finding the points which have a separation of this value between them. The following equation is used:

$$l = \sum \sqrt{\left(x_{i+1} - x_i\right)^2 + \left(y_{i+1} - y_i\right)^2} \qquad (15)$$

When the length is greater than the tooth thickness on the pitch ellipse/oval, an additional point is interpolated, and this additional point becomes a part of the series of points of the lineal approximation (Fig. 27).

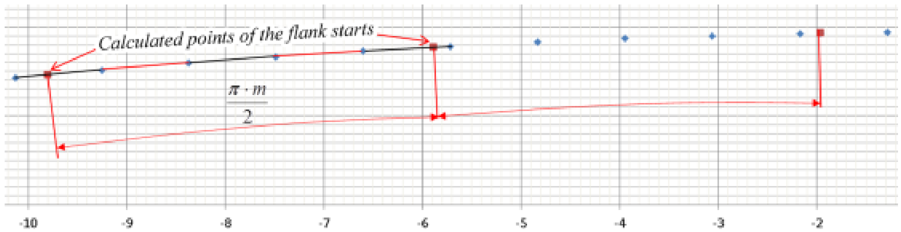


Figure 27. Starting flank points calculated on the pitch ellipse/oval.

The absolute error, which is obtained on a perimeter of 416.2589, is smaller than 0.0021 for a chordal error below 0.001.

On these points, the involute arcs corresponding to the radius of the local curvature have been placed (Fig. 28). These arcs start from the base ellipse/oval (equivalent to the base circumference for the local radius of curvature), have been extended beyond the exterior ellipse/oval. The real tooth will be located between the interior and the exterior ellipse/oval. However, it must be taken into account that not all the teeth can reach the bottom of the calculated involute profile, because when there are a low number of local teeth, where the curvature is smaller, the inner locally equivalent diameter is bigger than the base one.

This involute profile, Fig. 28b, has been calculated as in reference, but using an Excel™ macro, being possible to export the Excel™ data to a general purpose CAD software. In this case, the command "curve by table" of Solid Edge has been used. This process can be automated with a Visual Basic macro. This command makes also possible to export the points of the addendum, dedendum and pitch ellipses/ovals.

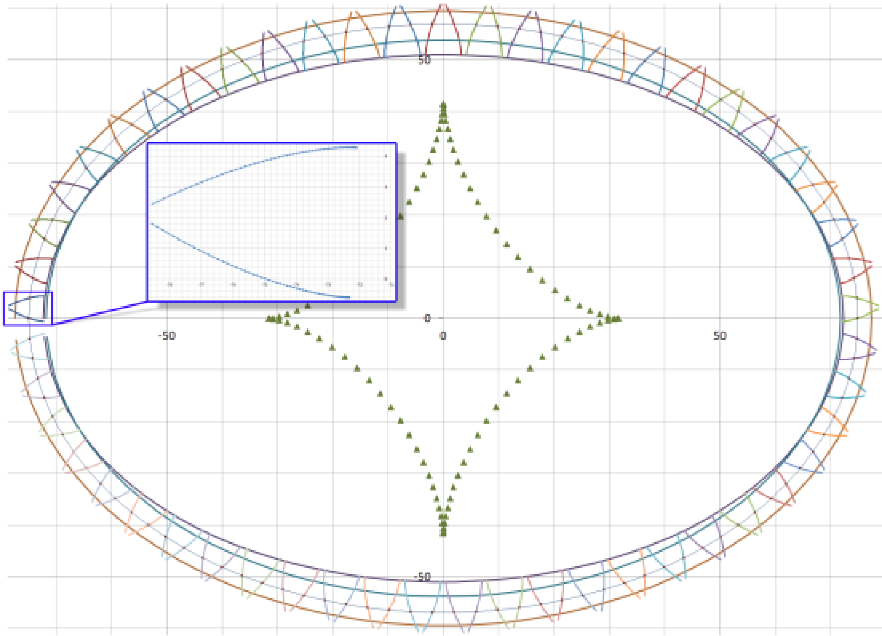


Figure 28. Points of the different involutes according to the radius of curvature

Once all these curves have been exported to Solid Edge, the correspondent extrusions and the rounding of the teeth fillet are carried out (Figs. 29 and 30).

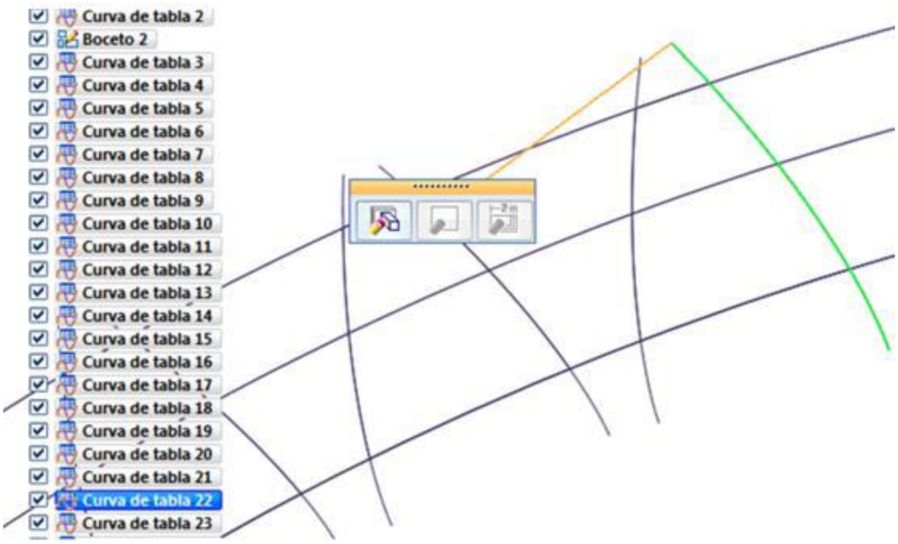


Figure 29. Calculated points imported in Solid Edge™

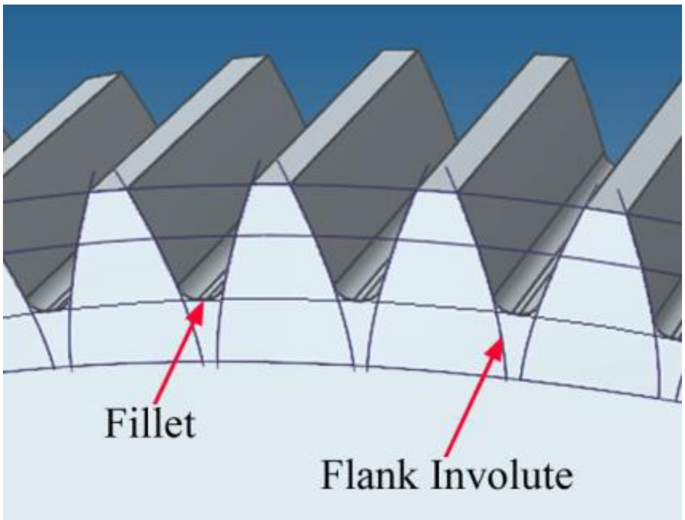


Figure 30. Extrusions and fillets.

All these operations could have been carried out directly with Excel™ or Matlab™, calculating the position of the rounding points for each tooth, as described in. The continuity in the points of the dedendum, addendum and the flank points, which correspond to a specific tooth profile, provide the path of the WEDM. A wire radius correction plus a gap is applied to these points. However, in this case, a general purpose CAD software was used in the process and, later, CAM software was applied. As an example, EdgeCAM™ has been used to make a pair of gears with an eccentricity of 0.75 and 80 teeth are shown.

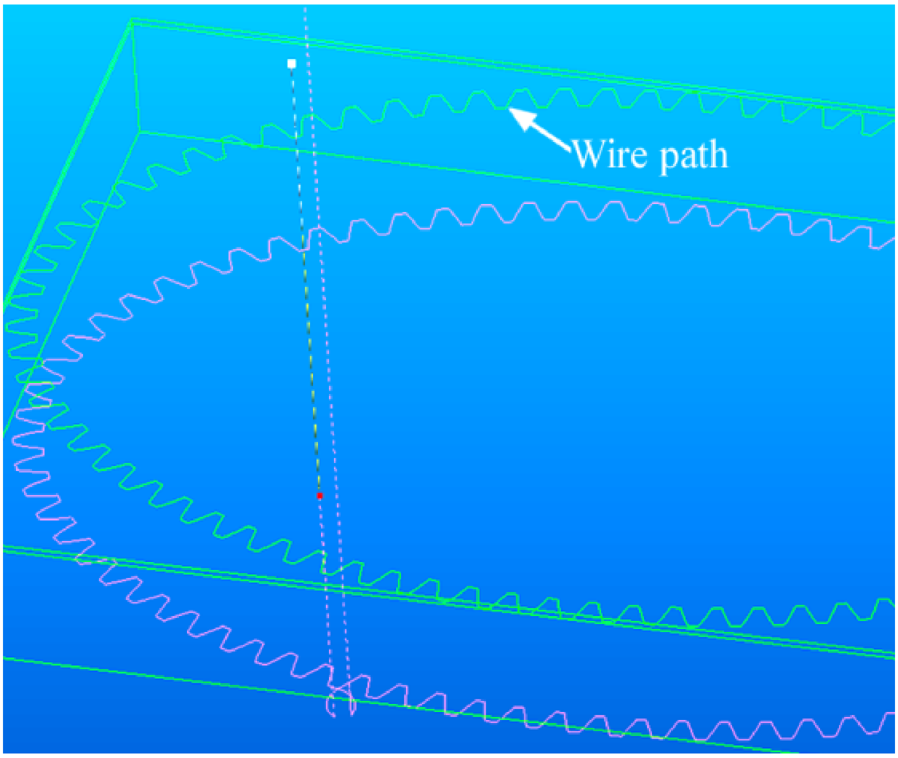


Figure 31. Points postprocessed in a CAM software.

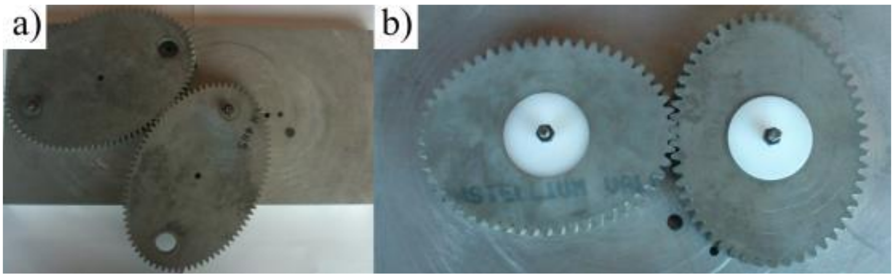


Figure 32. Two manufactured gears; a) elliptical; b) oval.

Figure 33. Validation of the algorithm with a coordinate measuring machine.

6.3.5. Presentation of the publication "Sustainability and Distance Learning: Technical Universities Sharing High Cost Resources"

Nowadays sustainability concepts meet with general acceptance worldwide and are developed and implemented for a wide range of industries, research and development and manufacturing products. In a globalized, rapidly developing world, training and education sustainability is considered an important issue. In the future, only those regions and companies that develop modern training concepts with an emphasis on sustainability will continue to be competitive. Sustainability has received increasing attention in education over the last decade. The terms Education for Sustainability and Education for Sustainable Development increased their use internationally. It is in this context, that new educational programs, research institutions and scientific publications, all with an emphasis on sustainability in higher education, have emerged.

In all aspects of engineering, metrology plays a significant role in acquiring precise and reliable measurements and thus results. For this reason, CMMs are used more and more often due to their universality and flexibility. It plays a vital role in the mechanization of the inspection process. Some of them can even be used as layout machines before machining and for checking feature locations after machining. Measurement and analysis involve gathering quantitative data about products, processes and projects. A number of actions and plans are influencing on the results from analyzing these data. Operators of CMM machine should be highly trained in order to minimize technicians' influence, they need to be provided with the necessary knowledge to carry out such tasks. In this study, a group of 10 students, with ages of 20 to 24 years old, during the spring semester of course 2014–2015, participated in this pilot study. They were Greek students of the Dept. of Mechanical Engineering and Industrial Design, Western Macedonia University of Applied Sciences, Kozani, Greece. Each student had a laptop, which was a property of the CAD/CAM/CAE laboratory, Dept. of Mechanical Engineering and Industrial Design. The operating system was Windows™ XP. A basic step before the starting of the process was the installation of the AnyDesk™ software. Each laptop used the available campus Wi-Fi for their connection to the web, in order to link the local computers with the computer that controlled the CMM. Two projectors (SONY VPL-VW1100ES) were connected to a set of two cameras used at the laboratory in Spain.

The connected computer to the CMM was placed at the Centre of Professional Training ''Corona de Aragon'' at Zaragoza, Spain. It was a PC with Intel Core 2 6400, 2.13 GHz and 1 GB RAM and 128 GB hard drive. The operating system was Windows™ XP. The AnyDesk™ software was installed on this computer too and the Ethernet protocol was used for the web connection. The main software for controlling the CMM was MCOSMOS™ 1 v3.0. Two conventional video cameras were used. The first one was providing real-time images from the CMM probe when performing the measurement process on the workpiece used (Fig. 31). The second was used to show a panoramic view of the CMM lab environment and the Spanish Tutor at the same time. The CMM model was a Mitutoyo EUROC544 and the sample workpiece measured was recommended by the equipment manufacturer for training purposes. The lecturers on both laboratories used whiteboards that were useful for the required explanations of the measuring process, supporting conventional explanations and presenting interesting graphical materials.

A day prior to the implementation of the web based training, an additional course was organized for the students participating. The aim was to offer a presentation of the next day's session and explain the aims and the steps to be followed. In addition, a specially prepared material about the operation of the CMM and the measurement process was delivered in order to provide a better understanding of the next day's experiment. At the beginning of the class, the Tutor from Spain explained how to use the CMM in order to measure dimensions using a series of generic workpieces. He connected his laptop to the CMM computer using AnyDesk™ and performed a workpiece partial measurement. At the same time with the tutor, the students had their laptops connected to the Tutor's laptop via AnyDesk™ and watch the CMM control software. Simultaneously with the use of two projectors, they were following up both the:

- measurement process via the camera placed next to the CMM probe, and
- presentation of the tutor from the CMM room camera.

After the initial measurements performed by the tutor, each student was connecting with its laptop to the computer controlling the CMM and was taking a series of measurements of the workpiece geometry. They were performing the measurements in real time, while everybody else was watching all the measurement activities. It was then that each student participated as a user of the CMM, although he/she was in a different country.

Figure 34. CMM (from the room camera) used in the Spanish laboratory to measure a gear.

In order to evaluate the success of the presented new teaching method, it was crucial that the students had no previous knowledge related to CMM. Students were, prior to the measurement training class, evaluated with an initial test, named pre-training test. Questions used in this test were directly linked to required mathematical concepts and aspects related to numeric control, computer aided manufacturing and

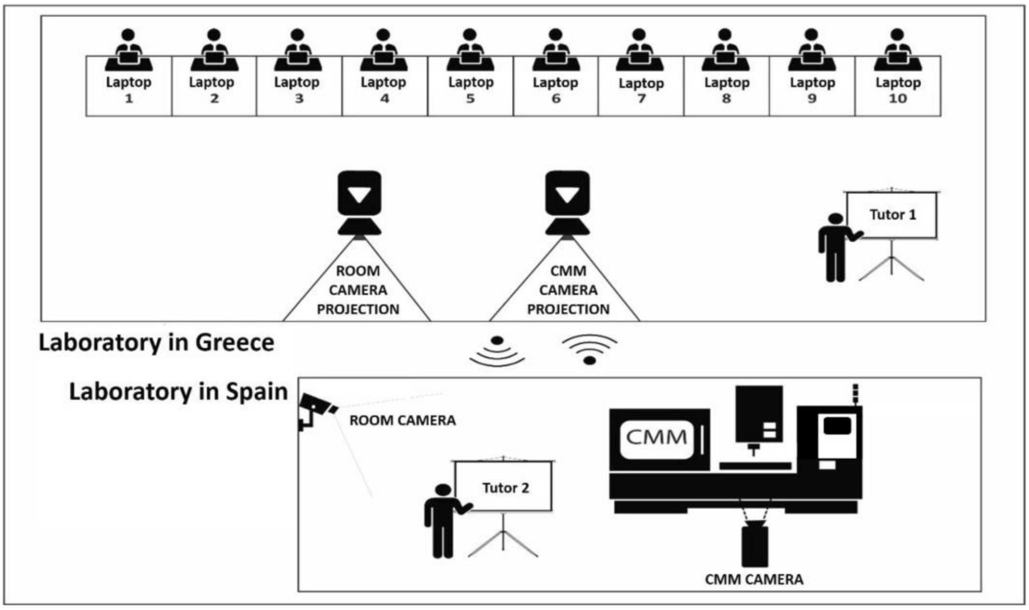


Figure 35. Measuring process developed using the CMM placed in Spain, being controlled from students in Greece.

machining technology. After the training class, students were reevaluated, using the same questionnaire (post-training test) in order to evaluate the acquired knowledge. Figure 33 depicts the number of the total right answers from both the tests (pre and post training) for each of the participating students. The difference between the number of correct answers delivered by the students is clear. Only two students answered correctly in the same way on both tests. The rest of the students greatly increased the number of correct answers given in the post-training test. A second questionnaire used a five-level Likert scale, in order to access the feeling of the participating students about the proposed methodology (Table 6). A series of outcomes were concluded after the students experience in using the distance learning methodology:

- The workpiece model used for the study gave the students the opportunity to experience the remote control of the CMM from their own laptops via a web connection. Both the students and the web based tutor collaborated very effectively.

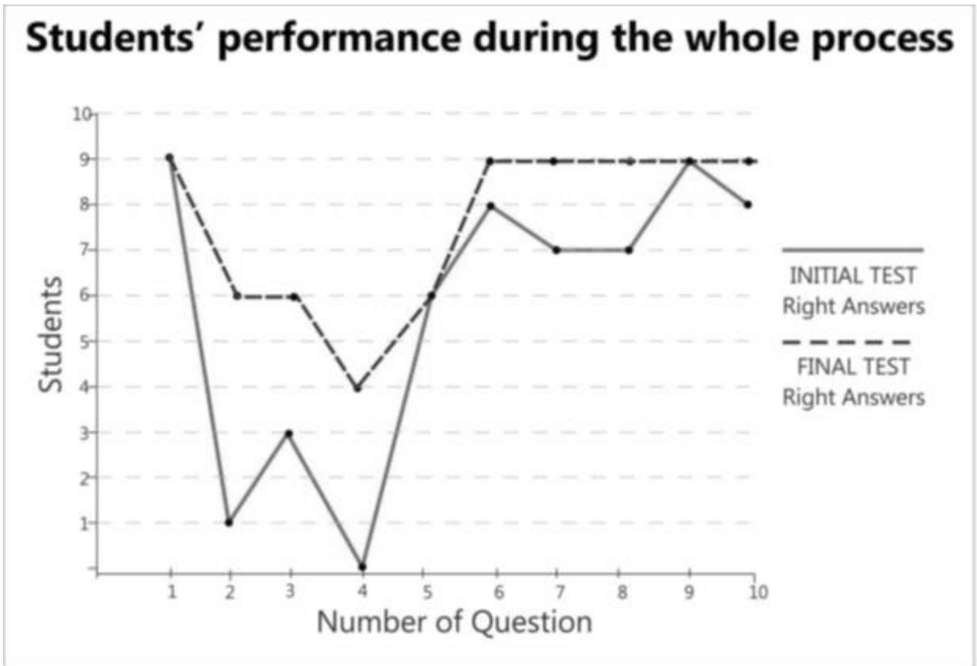


Figure 36. Right answers for each participating student for pre and post training tests.

Table 6. Results of the students' satisfaction assessment

Item (Five-level Likert: 0 = "Totally disagree" ; 5 = "Totally agree") Total number of students: 10		Average value	Standard deviation
1	Learning to use the CMM with is method is better than just watching the teacher using the machine.	4.8	0.42
2	I feel I can measure the manufacturing quality of a gear after this class.	3	0.47
3	With this method, I can take a more active part in class.	4.1	0.56
4	I think I will apply these tools (teleconferencing and remote desktop) in future works, either as a student or as a professional.	3.8	0.78
5	I think that this is a friendly learning method.	4.6	0.51
6	I have been paying attention and I have understood what has been taught in class.	4.1	0.56
7	I think that with this method I can learn more details about how to use a CMM than just by watching somebody else measuring a gear.	4.1	0.73
8	I think this is a good method to learn how to use this type of machinery.	4.1	0.56
9	This method has improved my learning process.	3.7	0.82
10	The class has been pleasant.	4.5	0.70

- To a great extent, students strongly believe that learning to use the CMM with the proposed methodology is better than watching the teacher using the equipment.
- A high proportion (60%) of the students mentioned that, after their experience, they feel comfortable that they can measure real workpieces in an industrial manufacturing environment.
- The majority of them reported that with this methodology they felt the satisfaction of actively participating in the class.
- Because of their exposure to the new use of the aforementioned communication tools, they consider both teleconferencing and remote desktop utilities extremely useful for the future. They would even prefer to use them either as students or as professionals.
- They found the methodology proposed extremely friendly and very interesting for themselves. The responsibility of using a costly piece of equipment led the students to be focused on the tutor's guidelines.
- To a great extent they felt that the proposed methodology is successful for learning how to use this type of machinery and their experience was very positive and improved their learning process.

The development of the user-friendly piece of software helped the whole process to be implemented with a minimum amount of resources and thus promote the low cost and sustainable use of the available CMM. The use of both measuring and data analysis offered a complete learning experience to the students. They have the opportunity to get involved in the measurements and then obtain valuable results from the analysis of the data acquired. After the practical session, all students were able to access their own educational material (i.e. tutor's notes, measurement files) for further study. They were able to share results among themselves and generate valuable feedback for their final report. The role of the tutors was also extremely important. All tutors on both sides of the web had to assess continuously the process on both laboratories, making corrections or improvements in the design and implementation of the class.

Current research is developed based on characteristics of the three pillars of sustainability (social- economic- environmental). From the economic point of view, the expensive CMM equipment (hardware and software license) could be virtually shared to other laboratories all over the world. The only resources needed are the remote control software and the commonly available personal computers. The rest of the financial costs are low while apart from the CMM, the used equipment (or similar) is commonly available in the universities or training centers worldwide. Moreover, many travel costs are avoided, thus making this method more attractive and appropriate for the Universities and companies cooperation. At this point should be mentioned that the total cost of a CMM machine is superior to 50.000 euro, while in the case of in person educating method, the travel, accommodation and the rest of operational costs for the ten students who participated to this process are estimated to approximately 10.000 euros, plus the additional required time. In this way, there are many possibilities for creating revenue, especially for the Universities. From the environmental point of view, the distance learning courses prevent people from traveling, which have a great effect on the environmental protection. Furthermore, the need of fewer pieces of equipment makes possible to decrease the energy and material consumption. Last but not least, from the social point of view, this study promotes the cooperation between universities and training centers in all over the world. This kind of co-operation is considered as promising for the future. The participants have to collaborate with people from different countries, with different culture and beliefs. It is an experience for the students to be taught from foreigner tutors and operate equipment in a different country just by sitting in their laboratory.

7. PUBLISHED WORK

The published content is referred below and it has been eliminated in this reduced version of the Doctoral Thesis in order to protect the copyright.

List of removed publications:

- Efkolidis N., Garcia-Hernandez C., Kyratsis P., Huertas-Talon J.L., (2015), **Design for Green Usability: A New User Centered Methodology for Product Development**. Applied Mechanics and Materials, Vol. 809-810 (Part 2), pp. 1372-1377.

- Efkolidis N., Garcia-Hernandez C., Kyratsis P., Huertas-Talon J.L. **Promoting sustainable principles through user education**, 6th Manufacturing Engineering Society International Conference (MESIC 2015), Barcelona, Spain, 2015.

- Efkolidis N., Garcia-Hernandez C., Huertas-Talon J.L., Kyratsis P., (2018), **Modelling and prediction of thrust force and torque in drilling operations of Al7075 using ANN and RSM Methodologies**, Strojinski vestnik-Journal of Mechanical Engineering, 64(6), 351-361. DOI:10.5545/sv-jme.2017.5188.

- Garcia-Hernandez C., Gella-Marin R.M., Huertas-Talon J.L., Efkolidis N., Kyratsis P., (2015) **WEDM manufacturing method for noncircular gears using CAD/CAM software**, Journal of Mechanical Engineering-Strojniski vestnik, Vol. 62(2), pp. 137-144.

- Efkolidis N., Garcia-Hernandez C., Huertas-Talon J.L., Kyratsis P., (2017), **Sustainability and distance learning: technical Universities sharing high cost resources**, International Journal of Engineering Education, Vol. 33(5), pp. 1-8.

8. FINAL REPORT

8.1. Goals

This Doctoral Thesis is part of the Development of Sustainable methodologies in Product Design, Manufacturing and Education. The aim of the Thesis is the creation and evaluation of tools and methodologies oriented to the cultivation of sustainability to the product designers, engineers, students, simple users and generally citizens.

For achieving these objectives, the whole work was divided into the following tasks that have been carried out:

State of the art

- A literature review on the state-of-the-art has been carried out in each submitted work, in order to obtain an overview of the state of the technology in the field that it was desired to study. In this way, it has been determined what methodologies could be developed in the research work.
- Development of tools and methodologies that are related to product design, manufacturing and education.

Design

- The first part is related to product design. Decisions early in the design process have a significant impact on the life cycle performance of a product. Many characteristics of a product can be improved if different design options can rapidly be implemented to assist the user and design team in making informed decisions in the design process. For this reason, the design part of the research work was based on a framework, which was built according to the direct communication between users and designers. In this way, users and potential customers played an active role to the product development. Of course, the basic aim of the research was not the commercial success of the developed products, but the change of the customer perception about the product, with an emphasis on the sustainability principles. Based on this demand, there is a necessity for the development of novel methodologies and tools, which would be directly related to the use phase of the products and emphasise the social aspect. There is a need for a cultural transformation, which can be focused on consumers and promote the needed behavioural change. Moreover there is a need for a cultural transformation on the role of designers and engineers to the product design process, with an aim to address sustainability as well as emerging priorities from societal to environmental challenges.

Manufacturing

- The second basic aspect of the research is related with the product manufacturing process. Generally, sustainable manufacturing faces new challenges for developing predictive models and optimization techniques in order to produce more products**.** The first part of current research, associated to manufacturing, is related to the drilling process and cutting tool technology. From the most well-known processes such as milling, turning, tapping etc., drilling constitute the most commonly used. The massive usage of a drilling requires that any parameter optimization in the process promotes the efficiency and the greener machining. Cutting tool technology is considered one of the most significant impact factors on the sustainability of machining processes and systems. Therefore, the best choice of cutting tools and parameters for the quality of the products and the tool life criterion are both critical for the sustainability metrics of a drilling process. The correct usage of the cutting tool can affect the reduction of needed resources and energy for the production of a new one. Many efforts have been done in order manufacturing sustainability to be improved. Among these, is the creation of mathematical models focused on maximization of productivity and cost reduction by identifying crucial parameters and processes influencing manufacturing effectiveness. Any optimization in the process directly equals to a greener machining. This research deals with the application of Artificial Neural Networks (ANN) and Response Surface Methodology (RSM) approaches that are used to acquire mathematical models for both the thrust force (Fz) and torque (Mz) related to the drilling process.

- The second part of current research is associated to manufacturing and it is related to CAD/CAM systems. The CAD-CAM systems are tools that use computing methodologies in the modification, analysis and optimization of design and manufacturing. The created models used by CAD/ CAM, allow a rapid improvement and an efficient design. The basic advantage of such systems is the fact that these components can be tested before the development of a prototype via simulations in terms of mechanical stress, manufacturing G codes files, and thus eliminating significant amount of cost, which means less waste or adjustments. A basic aspect of sustainability is that consumption should be streamlined and waste production must be minimized. In order to increase reliability, efficiency, flexibility, manufacturability, terms that are associated to sustainability, there is a need of use Computer-Aided Design systems, Computer Aided Engineering, Computer-Aided Manufacturing (CAD, CAE and CAM) and design standardization. These tools allow a more efficient communication between different systems. In this part of the research, the mathematical models for design and manufacturing elliptical and oval gears are presented. CAD/CAM simulations are carried out and after that WEDM and CMM machines are used for the production and application of measurements test in prototypes. The improvement of the gear design and manufacturing process without expensive machinery makes the processes more sustainable as design, and manufacture became more sustainable and accessible to a larger number of people. The use of CAD/CAM systems allow manufacturing with a number of several methods such as WEDM, water jet cut, laser cut, milling, etc. In this way, WEDM proved to be an effective method. It is presented so the developer can control the gear design and also the manufacturing methods which ensure a better gear finishing.

  Education

- The third aspect of the research is associated with the education related to sustainability. Most students, after taking a course on sustainability, focus on the technological role of sustainability in terms of technology as the solution to environmental problems. The engineering students should develop sustainability competences such as critical thinking, systemic thinking, an ability to work in frameworks, and to have values consistent with the sustainability paradigm. There is a direct relationship between transdisciplinary and systemic thinking learning. Students achieve better cognitive learning as more community-oriented and constructive-learning pedagogies are applied. Multi-methodological experiential active learning education increases cognitive learning of sustainability. In addition, the role of the educator is very important for SD learning in terms of implicit learning of sustainability values, principles and critical thinking. Focus on that organized and executed a training course of metrology, based on sustainable characteristics such as a) remote control freeware applications, b) share of valuable resources, c) distance learning methodology and d) active participation of the students. In a sustainable society, where people take more responsibility for the consequences of their actions and play a more active role as citizens and workers, they have to access high quality education courses throughout their lives.

8.2. Contributions from the doctoral student

The present Doctoral Thesis work coincides with the proposed objectives. It has been the result of various tasks that have been carried out. This section presents a summary of the contributions that have been used in order to develop the publications that are part of the compendium presented in this Doctoral Thesis. In the field of research, new applicable methodologies and tools have been developed in the design, manufacturing and education sectors for the promotion of sustainability.

These tools and methodologies have been:

- A suggested model named **Sustainability Push & Pull**, which is focused on the cultivation of sustainable behaviour to the citizens. Focused on this target, two new "design for X" methodologies a) **Design for Promoting Sustainable Principles through user education** and b) **Design for Green Usability** developed following the guidelines of the proposed **User Assessment Tool.**
- The creation of mathematical models based on Artificial Neural Networks (ANN) and Response Surface Methodology (RSM) approaches for the prediction of both the thrust force (Fz) and torque (Mz) related to the drilling process. Moreover, an example of the optimal use of CAD/CAM systems for the design and manufacturing of elliptical and oval gears without expensive machinery makes the processes more sustainable and accessible to a larger number of people. At the same time, it promotes sustainability due to its higher efficiency in designing and manufacturing high quality gears.
- The development of a method when developing a metrology training course based on sustainable characteristics i.e. a) remote control freeware applications, b) share of valuable resources, c) distance learning methodology and d) active participation of the students from a different country.

8.3. Methodology

In order to prepare the publications which are presented in this thesis work, it was necessary to follow a methodology throughout all the works. In this section, this methodology is described.

8.3.1. Making a bibliographic review

For each publication, a bibliographic review was previously carried out reflecting the current state of the art separately in each case. In this way, it was possible to evaluate if the research work contributed a differentiating innovation to the field of research.

It was also helped to study the techniques that other researchers have been applying to develop their work.

8.3.2. Realization of tools, methodologies and mathematical models.

After carried out of the bibliographic review and thus having a scientific base for the start point, the necessary mathematical models, tools and methodologies were generated. In each work, the strategy was defined and it was implemented on the design, manufacturing and educational processes. Finally, the results were discussed.

In the case of the following publications:

- "Promoting sustainable principles through user education",
- "Design for Green Usability: A New User Centered Methodology for Product Development"
- "Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies"
- "WEDM manufacturing method for noncircular gears using CAD/CAM software"
- "Sustainability and distance learning: technical Universities sharing high cost resources"

it was necessary to develop separately methodologies, tools and mathematical models for the development of each work.

In "Promoting sustainable principles through user education" and "Design for Green Usability: A New User Centered Methodology for Product Development", new tools and methodologies were generated, in order to promote sustainability to the users/citizens bringing them inside to the product design process, giving them the opportunity to be a vital part of it.

In "Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies" and "WEDM manufacturing method for noncircular gears using CAD/CAM software" mathematical models and CAD/CAM tools were developed used for the optimization of the manufacturing processes and the promotion of sustainability values to designers and engineers.

In the case of "Sustainability and distance learning: technical Universities sharing high cost resources" a new method for promoting sustainability value via education to engineer students was accomplished.

8.3.3. Implementation and Testing methodologies

The tools and methodologies that were selected and developed in this doctoral thesis were evaluated in each work.

In “Promoting sustainable principles through user education” and “Design for Green Usability: A New User Centered Methodology for Product Development”, the research garnered responses from 72 participants (41 female and 31 male), who answered detailed questions during their participation in the process.

In “Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies” and “WEDM manufacturing method for noncircular gears using CAD/CAM software”, mathematical models were developed and evaluated using ANN and RSM methodologies for the prediction of the thrust force (Fz) and torque (Mz) related to the cutting tools and other crucial cutting parameters. Moreover, pairs of elliptical gears were designed and manufactured using the mathematical models and the developed simulations using CAD/CAM systems and it was verified that they worked properly and effectively.

In “Sustainability and distance learning: technical Universities sharing high cost resources” the results of the remote operation of the CMM were very successful. The feeling of responsibility for using a remote piece of equipment and the extra care that the students should prove created a more stimulating learning environment. Moreover, according to the students’ opinion, the process as a whole was impressive and provided a unique experience.

8.4. Conclusions

In "**Promoting Sustainable Principles (PSP) Through User Education**" paper it was clearly defined that with all the environmental issues people facing in today’s world, it is important to grasp the need for a change in our consuming behaviour. We have to start thinking the promotion of the environmentally friendly way of life.

Designing products with techniques and technologies environmentally friendly cannot be by itself the solution towards better resources management. Given that most of the research in this area concerns either the design process or the product itself, the proposed methodology focuses on the consumer behaviour as a way forward to increase the uptake of green behaviour. The phase of the product use and its end of life stage creates potentials for decreasing the environmental impact. Designers have the privilege to plan and shape the way in which consumption habits occurs and bridge the behaviour gap between environmental values and consumers' everyday actions. Consequently, design engineers have to be more innovative, creative and engaged in seeking to ensure that their products will enhance the present and future sustainable social lifestyles. The key issue is the change on customer perception about the product, with an emphasis on the sustainability principles. A new methodology is proposed under the name of Design for Promoting Sustainable Principles through user education. There is a need for a cultural transformation, which can be focused on consumers and promote the needed behavioural change.

In **"Design for Green Usability: A New User Centered Methodology for Product Development"** paper shows that many published lists of Design for Environment principles focus on a single lifecycle stage, often following different Design for X strategies. These types of principles and guidelines have been developed and published separately, so the risk is that the designer may focus on the optimization based on a single strategy and lose the holistic, lifecycle perspective provided by a more comprehensive set of principles. In addition, Design for Sustainability must be capable of changing the user behaviour. The proposed DfGU methodology is oriented with an aim to turn the users towards a more environmentally friendly way of life, when using specifically designed products that influence their behaviour and covers the existing research methodological gap.

The paper entitled " **Modelling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies** " shows that the optimization of a drilling process focused on cutting tools and parameters is a basic part of the entirely machining process, which influences sustainability. The aim of this study was the generation of mathematical models for the prediction of the thrust force (Fz) and torque (Mz) related to the cutting tools and other crucial cutting parameters as feed rate and cutting velocity during the drilling process. Two modelling techniques the RSM and ANN were used to predict the thrust force and torque in a series of drilling operations of Al7075. The developed models were considered to be very accurate for the prediction of the Fz and Mz within the range of the manufacturing parameters used. A number of different ANN architectures (3-(6~12)-2) and (3-(6~12)-1) have been tested to obtain the best neural network configuration in each case. Finally, the best architecture was the (3-10-1) for the case of the thrust force and the (3-8-1) for the case of torque. The outcomes proved that the accuracy achieved was 2.18 % and 3.15 % when using the ANN models for both the thrust force and torque measured, respectively. In the case of the RSM model, the accuracy achieved was 3% and 5.6%, respectively. As a result, both strategies are suitable for modelling and predicting thrust force and torque when drilling is concerned, but the application of ANN is slightly more accurate than the RSM one.

The paper entitled “**WEDM manufacturing method for noncircular gears using CAD/CAM software**” shows that improving the gear design and manufacturing process without expensive machinery, makes the processes of research, design, and manufacture more sustainable and accessible to a larger number of people. The example described in this study has been generalized to obtain machining paths, using CAM software. The use of CAM allows manufacturing with several methods: WEDM, water jet cut, laser cut, milling, etc. In this way, an effective method is applied via WEDM so the developer can control the gear design and also the manufacturing methods, which ensure a better gear finishing. Although MATLAB™ has been used to solve the equations; it is also possible to apply Excel™, implementing numerical methods with a macro. Finally, with the analysed references about the obtained superficial features in the process, it can be concluded that, with the available machinery and an optimum selection of the conditions which define the process, e.g. intensity, pulse time, etc. (paying attention to the manufacturer advice), the obtained metrological, physical and chemical properties are similar to any other manufacturing process. Due to the importance of gears in machinery operation, when establishing its mechanical performance and thus the energy consumption and sustainability, the work implements the principles of computerized tool usage for design and manufacturing accuracy. The use of these CAD based tools, improves the accuracy of the gear design to a great extent, while at the same time promotes the accurate manufacturing that can provide a solid basis for achieving better performance and sustainability.

The paper entitled "**Sustainability and Distance Learning: Technical Universities Sharing High Cost Resources**" shows that further development of this kind of resource-sharing projects would help to the creation of an educational network is absolutely necessary to increase the number of benefited students or professionals that will be able to practice with real life equipment. The majority of similar approaches are based on remote laboratories and simulations. The current project is based on the use of professional tools, which are useful for the students, who are learning now the real machines and their control software. The visualization of the path of the measuring probe on a CMM, which is projected in real time, made possible to understand all the software commands and their effects. It is very important that the time required to adapt classes to use this method and prepare tutors to put it into practice was not excessive, especially if it is compared with the helpful results. The results can be considered only as positive. According to student opinion about the whole process, this study should be continued, while managed to improve factors such participation, interest, friendliness and even professional applicability of the introduced tools. Current research is developed based on characteristics of the three pillars of sustainability. From the economic point of view, the expensive CMM equipment (hardware and software license) could be virtually shared to other laboratories all over the world. The only resources needed are the remote control software and the commonly available personal computers. The rest of the financial costs are low while apart from the CMM, the used equipment (or similar) is commonly available in the universities or training centers worldwide. Moreover, many travel costs are avoided, thus making this method more attractive and appropriate for the Universities and companies cooperation. In this way, there are many possibilities for creating revenue, especially for the Universities. From the environmental point of view, the distance learning courses prevent people from traveling, which have a great effect on the environmental protection. Furthermore, the need of fewer pieces of equipment makes possible to decrease the energy and material consumption. Last but not least, from the social point of view, this study promotes the cooperation between universities and training centers in all over the world. This kind of co-operation is considered as promising for the future. The participants have to collaborate with people from different countries, with different culture and beliefs. It is an experience for the students to be taught from foreigner tutors and operate equipment in a different country just by sitting in their laboratory.

8.5. Future work

Sustainable Design

The gained experiences from the direct communication with the participants/citizens and their positive feedback for the whole process guides the current research to the implementation of the proposed framework to existing or new ‘design for X’ methodologies, but more socially oriented. It involves citizens and communities participation in order to address social problems. As a representative one can be considered the Design for Homeless. Homelessness is the condition of people without a dwelling house. Latest research show that single homeless adults are more likely to be male than female while the number of homeless families with children has increased significantly over the past decade. Homelessness is an undeniable social problem. The Design for Homelessness should be targeted to develop techniques oriented to the successfully confrontation and eradication of the homelessness. Designers should be ready to face this problem giving solutions to the physical facilities aspect of this issue. One of the most challenging aspect is the fully understanding a Homeless person's point of view. This experience can effect a dramatic change in a person's world view, impacting their needs and priorities. Another challenge can be considered the Design for Refugees. According to the UNHCR, the number of people that have been forced to flee their homes has reached a post-war peak of 60 million, one third of whom have had to leave their country. The refugee crisis requires time and a series of far-reaching global efforts to solve. Design for refugees should have as target the Improvement of their life making easier their needs satisfaction, but also their normal adaptation from the communities which are directly involved. Of course, designers and engineers can't save the world themselves, but even the smallest intervention could help improve the conditions to the cities and society.

Sustainable Manufacturing

Cutting tool technology is considered as one of the most significant impact factors on the sustainability of machining processes and systems. People working with CNC machines, very often are faced with dilemmas about which cutting parameters are the most appropriate for the available cutting tools in order to treat materials such as Aluminum alloy 7075 which is suitable for a variety of specific applications in aerospace and chemical industries. The optimum usage of cutting tools is something crucial for the CNC users as it can affect the whole machining process. In a future paper, an experimental study will be conducted to determine the effect of different cutting parameters such as cutting speed and feed rate on thrust force (Fz) and torque (Mz) in the drilling of Al6082 workpiece. Data obtained from experiments will be used for the development of Artificial neural networks (ANNs) and multiple regression analysis to model the thrust force and torque.

Even though the application field of elliptical/oval gears is not very extended, it can be very convenient when a non-constant torque must be transmitted, as well as for research works. Improving the gear manufacturing process without expensive machinery, makes the processes of research, design, and manufacture more sustainable and accessible to a larger number of people. The example described in this study has been generalized to obtain machining paths, using CAM software. The use of CAM allows manufacturing with several methods: WEDM, water jet cut, laser cut, milling, etc. In this way, an effective method on WEDM is presented so the developer can control the gear design and also the manufacturing methods which ensure a better gear finishing.

Sustainable Education

Further development of this kind of resource-sharing projects would help to the creation of an educational network is absolutely necessary to increase the number of benefited students or professionals that will be able to practice with real life equipment. The obtained experience made both the university laboratories to decide to keep on using this teaching methodology, at least in the metrology sector, in which the required equipment has been already installed. The most promising aspect is that those laboratories would also be able to share other machines conversely following the same process. The future plans have as target this methodology to be cultivated to the CNC machines sector. In a sustainable society, where people take more responsibility for the consequences of their actions and play a more active role as citizens and workers, they must have access to quality education throughout their lives. This process can facilitate the development of collaborative projects with participants from different centers, not necessarily in the same country. This kind of actions is conventional with the rules of the globally free market promoting simultaneously the value of the three pillars of sustainability.

9. APPENDIX

9.1. Impact factor of the journals and areas corresponding to the publications included in the Thesis.

In this section we present the impact factors of the journals and areas of the publications included in this Thesis.

"Promoting sustainable prinsiples through user education"		
Journals in the release of JCR	Impact factor	Area
Proceedings of the 6th Manufacturing Engineering Society International Conference – Barcelona	-	Mechanical Engineering

"Design for Green Usability: A New User Centered Methodology for Product Development"		
Journals not in the release of JCR	Impact factor	Area
Journal of Applied Mechanics and Materials	0.2	Mechanical Engineering

Modeling and Prediction of Thrust Force and Torque in Drilling Operations of Al7075 Using ANN and RSM Methodologies.		
Journals in the release of JCR	Impact factor	Area
Journal of Mechanical Engineering-Strojniski vestnik	0.821	Mechanical Engineering

WEDM manufacturing method for noncircular gears using CAD/CAM software		
Journals in the release of JCR	Impact factor	Area
Journal of Mechanical Engineering-Strojniski vestnik	0.677	Mechanical Engineering

Sustainability and Distance Learning: Technical Universities Sharing High Cost Resources		
Journals in the release of JCR	Impact factor	Area
International Journal of Engineering Education	0.609	Mechanical Engineering Education

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