Eindhoven School for Technological Design*
Design Education and Design Research

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1. INTRODUCTION

Nine years after starting the two-year post-graduate programme on technological design [Ackermans and Trum, 1988], Eindhoven University of Technology (EUT) decided to enhance the development of synthesis-oriented engineering education by establishing a post-graduate school for technological design.

In the last decade the industrial, educational and public interest for technological design has grown remarkably. Nowadays, it is considered essential for the international market position of the Netherlands. The post-graduate design programme has to set international standards, as this is the level on which Dutch industry has to compete. The design school shall contribute to attaining and holding the required level. The new school is an interdisciplinary cooperation of all eight faculties of EUT, in which the ten two-year full-time post-graduate design courses of the former Institute for Continuing Education IVO are accommodated with about 330 post-graduate students. Over 450 students already earned their designers' certificate. One of the new tasks of the school is to establish a design research centre in which fields of knowledge, relevant for technological design, such as design philosophy and methodology, design instrumentation and design learning and teaching, will be elaborated. The main new task of the school is to stimulate young designers—working on a design task in close cooperation with industry—to earn a doctorate (Ph.D.) by devising and defending a doctoral design.

2. DESIGN EDUCATION

Unlike traditional university programmes, the advanced design programme was originally proposed by the Dutch employers' organisation RCO. In 1985 the industrial employers urged the establishment of a two-year post-graduate programme in technological design in high-tech areas [RCO, 1985]. The employers' major goal was to bring design education into regular university engineering programmes [Ackermans, 1993].

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The design programme at Eindhoven University of Technology started in 1986 in the Institute for Continuing Education (IVO-TUE). EUT decided to found a special institute to accommodate the design programme because of the fundamentally different nature of the design courses in comparison to the regular first-degree engineering education the faculties provide: all design courses are basically multidisciplinary and can not be fully provided by any single faculty. For every design course a multi-disciplinary programme committee was set up in which specialists from up to four faculties participate.

Technological design is a distinguishing way of practising the technical sciences with specific characteristics. Design courses are exclusively concerned with the development of knowledge, skills and attitudes of engineers who perform complex design tasks with modern means and methods. The design programme therefore differs essentially from traditional university research training. First degree programmes and research training originate from scientific domains; the design programme is concerned with design fields, designated by industry. Each design course covers the fields of a number of disciplines, including some non-technical ones. After all, the external request was inspired by the care for technical products and not by the responsibility for the development of scientific disciplines. In most modern products many technologies are applied. A design programme as desired by industry therefore provides a broad and basically multi-disciplinary orientation.

The emphasis in the design courses is on acquiring and practising skills for finding technological solutions to problems in complex high-tech areas. Since designers have to be specialists in one of the skills of their own trade and should also be able to get a quick insight into their colleagues' activities, both a high specialization and a broad orientation in technology are needed.

All the design courses add an extra dimension to the basic engineering degree (which is the master's) by introducing:

- A broader scope for the original degree through the addition of elements from related areas,
- an emphasis on engineering design in a multidisciplinary context,
- enhanced industrial/management skills, and
- knowledge and skills from areas of science other than engineering or physics.

Emphasis in the design courses is on acquiring and practising skills for finding technological solutions to problems in the following complex areas:

- Designing products and structures,
- designing processes for making these products,
- designing systems for the transport of persons, information and goods,

- designing control systems both for production and transport.

The design courses incorporate interdisciplinary work in teams, creativity, modern design techniques, cost-accounting, manufacturability, design methodology, design strategy, quality, managerial skills, communication, presentation of ideas, both orally and in writing.

Basically, a course consists of two parts: one year of lectures and practical training, and a second year on a supervised design task in industry. As all courses are principally multi-disciplinary, several EUT faculties participate in each course, some in cooperation with other universities or on an international university-industry level. Students are admitted through a highly selective process. Once in the programme, they are appointed by the university as assistants-in-training and receive a modest salary.

The post-graduate programme on technological design comprises courses in the following design fields:

2.1 **Computational Mechanics**

Skillful use of mechanics is the foundation of good design and is essential in the modern computer-aided design and production process. The programme Computational Mechanics concentrates in particular on the development and application of models. Not only the mechanics of solids, fluids and gases play a role, but also knowledge of numerical mathematics, information technology and materials. Other important aspects are interactions in the direction of systems and control theory, thermal processes and chemical reactions.

The programme is aimed at reducing as much as possible the number of experiments required for the design process.

Participating faculties: Mechanical Engineering, Mathematics and Computing Science, Applied Physics, Chemical Engineering. Cooperation with Groningen University, Twente University and Delft University of Technology in the national training programme Computational Mechanics.

2.2 **Computer-aided Design and Manufacturing of Discrete Products**

The programme Computer-aided Design and Manufacturing of Discrete Products is aimed at the automation of all activities required for the manufacture of a product. This not only includes the design of a product via process choice, production control and quality control, but also reliability control. Moreover, the programme pays attention to the management aspects of a completely computeraided manufacturing process.

Participating faculties: Mechanical Engineering, Industrial Engineering, Mathematics and Computing Science, Electrical Engineering.

2.3 **Architectural Design Management Systems** (in preparation);
The programme Architectural Design Management Systems aims at educating technological designers of design management systems for the building industry. It focuses on the design of control systems for architectural design projects: process design (design strategies) and process control (design instruments, information systems and management systems) that qualitatively and quantitatively support complex architectural design projects. Presently this programme is developed so as to fit it to the needs of building industry. The programme will start in September 1995.
Participating faculties: Architecture, Building and Planning and Industrial Engineering.

2.4 **Information and Communication Technology**
The programme Information and Communication Technology concentrates on the design of information systems, placing the emphasis on signal handling. The programme covers subjects as description and simulation of required partial circuits, design and realization of system parts and components, and highlights the interaction between hardware and software. The training environment strongly conforms with the work situation. This means that the design project, which is compulsory for all participants, covers the complete trajectory from idea to product. This includes systems analysis, specification, choice of architecture, synthesis, simulation, implementation and verification.
Participating faculties: Electrical Engineering and Mechanical Engineering.

2.5 **Logistic Control Systems**
Logistic Control includes planning, organising and controlling the flow of goods in industry as well as in distribution and in transport. The increasing international competition and numerous developments in the transport industry, in distribution, technology, industrial automation and in economic policies—in particular in the European integration—have led to higher demands in this field. During the programme Logistic Control Systems all these subjects are dealt with extensively. Those who have successfully completed the programme are able to design, build, test and implement complex logistic control systems.
Participating faculties: Industrial Engineering, Mathematics and Computing Science, Mechanical Engineering.

2.6 **Mathematics for Industry**

The programme Mathematics for Industry focuses on the mathematical contribution to the design of industrial products and processes. During the programme, ample attention is paid to various mathematical techniques and to the development, use and analysis of mathematical models. Moreover, the training emphasizes the connection with technology and physical and management sciences. The programme is conducted within the context of international cooperation under the auspices of the European Consortium for Mathematics in Industry (ECMI). Part of the second year of the programme is spent abroad, either studying at an ECMI-partner university or carrying out a final project.
Participating faculties: Mathematics and Computing Science, Industrial Engineering, Mechanical Engineering.
Cooperation with the European Consortium for Mathematics in Industry (ECMI).

2.7 **Mechatronic Design**

The programme Mechatronic Design combines knowledge from various disciplines in order to design an advanced product. The programme covers in particular the knowledge of construction possibilities, electronics and computer hardware, control technology and theory and information science. The mechatronics approach, with various closely interacting disciplines, ensures products which could not be realized within the separate disciplines, for example the CD-player and the modern robot. A mechatronic designer does not need to be a specialist in all the relevant fields. However, to function well in a mechatronic design team, sufficient knowledge of each of these fields is indeed essential.
Participating faculties: Electrical Engineering, Mechanical Engineering.
Cooperation with Twente University.

2.8 **Physical Instrumentation**

The programme Physical Instrumentation is aimed at the design of measurement setups and systems using charged or neutral particles (sometimes in the form of beams). An example of this is the application of charged or neutral particles in physical or physicochemical processes, particularly in plasma reactors, ion sources, accelerator systems, cyclotrons and ion-optical systems.
Participating faculties: Applied Physics, Electrical Engineering, Chemical Engineering, Mechanical Engineering.

2.9 Process and Product Development in the Process Industry
The programme Process and Product Development in the Process Industry lays the emphasis on product design. The process industry requires integration of chemical, physical and mechanical insight. The programme not only deals with an advanced form of process technology, but also with process theory in relation to the product characteristics, such as synthetics, food and technical ceramics. Processing technologies and design processes, including materials science constitute a part of this. During the design project, participants can focus on materials science, process technology or design of apparatus.
Participating faculties: Chemical Engineering, Applied Physics, Mechanical Engineering.

2.10 Software Technology
The programme Software Technology focuses on the design of large software systems for technical applications. The programme not only concentrates on theoretical questions, but also on practical applications. The design of an overall sys-tem, consisting of hardware and software building blocks, plays an important ro-le. Subject matter includes general design and specification methods, software engineering and systems technology. Relevant practical applications are realized in the form of chosen technical modules and a large project carried out in teamwork.
Participating faculties: Mathematics and Computing Science, Industrial Engineering, Applied Physics, Mechanical Engineering, Electrical Engineering.

3. DESIGN RESEARCH

A major task of the school is to maintain the required high level of technological design education in the long term and therefore—according to Von Humboldt's principle—to perform design research in order to continuously provide new design knowledge, insights and instruments that contribute to the quality improvement of design education.
Technological design is a rapidly developing field of action and knowledge:

- the complexity of technical products, systems and processes increases with a tremendous rate;
- industry and—as a consequence—the national economy increasingly depends on successful new technical products and therefore on the preservation and further development of the quality of a “self creating” industry;
- time-to-market, from the first rough outline up to a production-ready design and finally to a manufactured product, should be as short as possible for reasons of competitiveness and efficiency;

- design and development costs, and therefore financial risks, going with the introduction of new technical systems, products and processes increase rapidly;
- the quality of a new technical product is mainly determined in the design stage;
- the total cost of a new technical product is determined to a considerable degree in the design stage;
- through these developments the consequences of possible design failures may turn out to be disastrous;
- factors like usability, manufacturability, stability and reliability, social and environmental effects increasingly influence the design process. Accordingly, the number of parties involved in the process increases and consequently the complexity and the multi-disciplinarity of the design tasks;
- the ongoing development of design techniques and sophisticated design tools calls for an ever rising educational and training level of the designers, while the life-cycle of relevant knowledge and skills shrinks rapidly;
- the multi-disciplinarity of design tasks requires designers who are capable to co-operate with specialists from an increasing number of different—also other than engineering—disciplines;
- in order to manage a design project successfully, it is not only necessary to have adequate knowledge of and insight in all those specialities, but also the capacity to overview the whole design field so as to integrate specialised partial designs;
- the predictability of both the progress and the final result of a design process is limited; nevertheless it is vitally important to improve the manageability and control of design projects (quality management, technology management, design management, etc.);
- the increasing influence of more, more powerful and more intelligent technical systems on society and on the natural and cultivated environment necessitates to already reckon with the eventual effects during the design of such systems, in order to attain the intended goals with greater precision and to prevent or to minimize unwanted side-effects (technology assessment).

The new school will provide the opportunity to stimulate, coordinate and perform research activities in fields that are considered relevant for the further development of the technological design programme.

In the school a design research centre is being set up with research programmes on at least three fields:

- design philosophy and methodology, including ethics;
- design instrumentation: domain specific and generic design tools, methods, strategies;
- design learning and teaching: design education, adult education.

For scientists the centre will function just as other Dutch research schools. It will also provide the possibility for young graduates to earn a doctorate in one of the research fields of the centre.

The first design research projects of the school are:

3.1 **Towards a multi-disciplinary framework for design**

This project is aimed at inventarization, description and modeling of issues rela-ted to the provision of a multi-disciplinary framework; identification of generic design methods and rules; of the specifics of the different design disciplines. Some aspects of a multi-disciplinary framework are: multiple design dimensions, based on generic high-level frameworks to partition the design space (as provided by e.g. Domain Theory); project management for complex artifacts; simultaneous modeling of static and dynamic system properties; process-oriented design. The research concentrates on design methods, and involves project management methods, tools and environments.
Theme: Design Methodology
Participating faculties: Mathematics and Computing Science; Architecture, Building and Planning; Philosophy and Social Sciences.

3.2 **Design history information system**

Aim of this project is to develop an integral system for archiving and accessing the information, occurring in a design process. A structured system will allow easy acquisition and retrieval of vital design information. The system, in which the whole design process is being archived, can be used for supporting the individual designer as well as the design team. Re-use of the design information will accelerate the design process and increase the product quality.
Theme: Design Instrumentation
Faculty: Mechanical Engineering.

3.3 **A design method for implementing sequential machines with limited building blocks and limited communication channels**

The project aims at the development of an effective and efficient design method for implementing sequential machines with limited building blocks and limited communication channels between the building blocks, and to design and implement a prototype CAD tool which automatizes this method. This design method will be based on the theory and methodology of general decomposition.

Theme: Design Instrumentation
Faculty: Electrical Engineering.

3.4 **Design learning and teaching, design education**
It is necessary to pay attention to the difference between educating students for research or for design. For the understanding of these differences and their implementation in the school it is essential that some research is done in the field of educational psychology. It is clear already that, considering the age of our post-graduate students, inspiration must come more from the field of adult education and andragogy than from the field of pedagogy.
Theme: Design Learning and Teaching
The project will be carried out by a working group of internationally invited experts.

4. A DOCTORAL DEGREE FOR DESIGNERS

It is the task of the design school to stress the specific features of design as a distinct, full-fledged species of practising technical sciences with specific characteristics [Sparkes, 1993]: aimed at synthesis instead of analysis, directed at knowledge of the specific, unique artefact in its environment instead of discovering general laws of nature; engaged in conceiving the not-yet-existing instead of explaining observed phenomena; involved in the realisation of a desired future instead of the description of today's reality. Neither design tasks, nor their results are limited to the boundaries of scientific disciplines. Though design in many respects differs basically from research, the design programme is essentially a scientific programme.

The doctor's degree is the societal distinguishing mark of scientific maturity. For those who practise technical sciences as a designer a doctor's degree should be attainable. Ever since 1905 Dutch law recognises this way of earning a doctoral degree: by devising a doctoral design. Hardly anyone ever made use of it, probably because it did not fit in the traditional university culture, but it also is assumed to be too difficult to do after a regular university research-oriented education. For the design school doctorates on design are of importance, as they lead to developing and establishing criteria by which a "good" design can be judged. This is essential for the quality maintenance of the design programme. A doctorate by design should have the following characteristics [BCO, 1993]:

The doctoral student shall provide evidence of being able to practise science by creating technical solutions for products, systems and processes, starting from functionally and commercially determined demands. Such shall be attained through a methodic approach with the following characteristics:

- The client's objective should be concretized into measurable and verifiable specifications;
- With adequate scientific, technological and domain-specific knowledge, a concept for the product or system should be devised, principally based on existing knowledge and techniques;
- This concept should be checked against the set of requirements and be concretized within a previously set time limit.

So as to give evidence of his professionality the doctoral student should prove being able to plan the complete design process, to compose the design team and to decompose the design task in such a way that participants can work out partial design tasks simultaneously or sequentially. He or she shall give evidence of being able to function in a multi-disciplinary design team. A doctoral design should be presented in any adequate form that—for that type of design—is common in industry. Preferably the designed artefact should be demonstrated at the doctoral degree ceremony.

A doctoral design comprises the description of the artefact devised; of the design process as it was originally planned and eventually carried out; and (if necessary) of the research carried out to acquire new knowledge which is indispensable for successfully completing the design task. The design should meet general scientific demands: intersubjectivity, reliability, verifiability. A profound study of one aspect (cf. research) is not sufficient.

The required description of a designed artefact comprises:

1 Analysis and specification of the design task;
2 Results of testing the design against the initially specified requirements. The synthesis of all properties the artefact should have, is emphasized.
3 Evidence of the quality of the artefact as a means to attain the objectives [Bax and Trum, 1993], as far as relevant for the case considered:
    - properties concerning performance, functioning, effectiveness, utility, usability (in the physical, physiological and psychological sense, e.g. user-friendly, easy-to-handle); wanted and unwanted side-effects, etc;
    - properties concerning the makeability; material, energy and information needed for manufacture, type and means of production, types of work and workers needed, required educational level of production personnel, etc.;

- properties concerning the lifespan: stability, solidity, robustness (also against unintended use), safety, reliability, repairability, main-tainability, etc., including effects of demolition, storage, residue, waste production, pollution, environmental stress, re-use, recycling, etc.;
- properties of the artefact as a successful commercial product on the market: vendibility, price, customer's requirements, warranty, pa-tents, licenses, investments, development-, production-, exploitation costs, etc.;
- properties concerning society requirements: manageability, control (what social groups or individuals have what type and degree of control over the artefact: property, rent, lease, etc.), type of manage-ment, desirability, acceptability, effects of large-scale use, influence on individual and social behaviour, compliance with laws, rules, regulations, norms, standards, etc.
- formal (morphological) properties: structure, composition, (anatomy, in informatics and electronics: "architecture"), the artefact as a sys-tem, composed of parts, the artefact as a constituent part of its envi-ronment;
- static and dynamic properties (temporal/procedural): changeability during the life-cycle, adaptability, the artefact as a stage in a pro-cess of development or as a final stage; intermediate stages in the design process, etc.;
- properties of the artefact concerning the professional organisability of design, production, use, demolition; manageability related to pro-fessional codes and ethics, social responsibilities of professionals (deontology), etc.;
- properties concerning the scientific relevance of the artefact: application of knowledge, the artefact as a source of new knowledge, as a hypothesis, as a touchstone of knowledge, etc.;
- aesthetic properties: the symbol or sign function of the artefact, as an intermediary between the impression of the beholder and the ex-pression of the maker, the artefact as a "work of art";
- properties concerning the embedment of the artefact in the ecologi-cal system: environmental stress, consumption of materials, energy, emissions, toxicity, residue, (in all stages, including production);
- properties concerning the embedment of the artefact in the cultural and geographical context: adjustment to and compatibility with other cultural expressions of society.

Principally, the school shall stimulate that a doctoral design will start as a regular design project in the second year of the design programme. Teachers select suitable projects for students who want to complete their design education with a doctorate.

Preferably, projects in or assigned by industry will be selected. The princi-pal should agree that the design task is worked out into a doctoral design and en-able the student to do so by allowing him to use the firm's design facilities. In-dustry is the eminent environment experienced in judging design work. Therefore, the opinion of industry in judging a doctoral design is highly appreciated.

Doctorate design projects presently being carried out:

4.1 **Design of a high-precision spindle, based on an active axial bearing**

The aim of this project is to develop a spindle for high-precision diamond tur-ning. The concept is based on an active axial spindle bearing, using a voice coil actuator, a position measuring system and a controller system. With respect to the current spindles, this concept has to lead to a higher axial stiffness and a smaller axial error motion of the spindle. The spindle must also have the capability to fa-bricate non-rotationally symmetric optical surfaces, by controlled axial move-ments of the spindle.

Design field: Mechatronic Design.

This is a combined project between industry: Philips Research, and Eind-hoven University of Technology.

4.2 **Large scale continuous flow membrane-electrophoresis**

The prospects of large scale continuous flow membrane-electrophoresis are stu-died with the aim of separating proteins and enzymes from biological suspen-sions. The study comprises the formulation of a general model which describes fluid dynamics, heat generation and transport of charged components inan electric field. This model will be verified experimentally in different electrophoresis cell config-urations and in case of different experimental conditions. Finally, the model is used for simulations to deduce optimal scale and operation of the membrane-electrophoresis cell.

Design field: Process and Product Development in the Process Industry.

The project is carried out at the Faculty of Chemical Engineering in cooperation with industry.

4.3 **Geometrical optimization of lip seals for reciprocating shafts**

The aim of this work is to be able to create new or improve existing seal designs with a for practical seal design applicable design method based on existing theo-retical knowledge about the sealing and lubrication mechanism. The main result of this work will be a new seal design procedure, in which seals can be judged on leakage and friction in the design stage resulting in an optimal, new or impro-ved

seal geometry for a certain given set of demands and operating conditions.
Design field: Computational Mechanics.
This is a combined project between industry, PL Automotive, and Eindhoven University of Technology.

4.4 **Data synchronised parallelism in High Energy Physics software development**
Design and realisation of a software engineering environment to support the development life cycle of parallel programs aimed at the rapid analysis of huge a-mounts of data taken during High Energy Physics (HEP) experiments. Two tools will be added to the existing environment, providing facilities for testing, debug-ging and performance tuning of parallel programs: a tool which visualizes the be-haviour of the program execution, and a tool which allows interactive analysis of different processor-to-processor allocation strategies.
Moreover, the project will yield a set of general design criteria for parallel HEP event reconstruction programs.
Design field: Software Technology.
The project is carried out at CERN, Geneva.

4.5 **On-line parallel HEP event reconstruction using real-time data-bases on massively parallel platforms**
Design and realization of an on-line parallel HEP event reconstruction software system, which uses a high performance real-time parallel database. The amount of data produced by HEP experiments is in the order of Gigabytes or Terabytes. On-line reconstruction means that the events are reconstructed at the moment they are produced. The project will also result in a set of general design rules for constructing on-line parallel event reconstruction systems, aimed at a more structured and easier to maintain HEP software. One of the major design demands is flexibility: with minor changes, it should be possible to use the system in several diffe-rent HEP experiments.
Design field: Software Technology
The project is carried out at CERN, Geneva.

4.6 **Design of a VLSI circuit for lossless data compression and decompression**
The sliding window algorithm with Huffman coding is chosen for its good compression ratio. A hardware implementation can be more than a 1000 times faster than software. A good trade-off between speed and chip area must be made. The design must be flexible so that it can be used for many variations of the chosen algorithm.
Design field: Information and Communication Technology
The project is carried out at the Faculty of Electrical Engineering.

4.7 3-Dimensional Imaging Radar

Applying ISAR (Inverse Synthetic Aperture Radar) allows accurate target identification provided that a physically large aperture and sufficient bandwidth are available. For unknown motion patterns, motion compensation algorithm must be applied first. A new system based on an interferometer radar and advanced tracking algorithm provides motion compensated data in three dimensions. The latter results in 3-dimensional ISAR capabilities and improved identification performance. Various applications are foreseen, i.e. air traffic control, robotics or medical applications.
Design field: Information and Communication Technology.
The project will be carried out at the Faculty of Electrical Engineering in close cooperation with industry.

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6. NOTES

Detailed information concerning the design courses is available from the Eindhoven School for Technological Design, Eindhoven University of Technology, P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands.
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