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The Development of a Suite of Design Methods Appropriate for Teaching Product Design*

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The development of new *methods* for design for manufacture and assembly, the need to incorporate quality during the design phase and the recent focus on transparent design work and communication have all created a need for a more structured approach to design. However the number of design methods and tools available to the designer in the process of design is numerous and for many practicing designers it has become unclear when and how to apply these. In addition, the teaching of these methods is even more problematic because of the extent of the proliferation of design methods and because design teaching is overwhelmed by other subjects in traditional mechanical engineering programmes. In industrial design the situation is similar, with a lack of knowledge about the appropriate methods and tools and a culture that believes methods impede creativity. This paper reviews present knowledge and state of the art associated with design methodology and clarifies the relationship of design methods to stages in the design process.

INTRODUCTION

Design methodology includes the study of the principles, practices and procedures of design. Its primary focus is to develop a deep and practical understanding of the design process and how this process can be modified, made more effective and transparent, and be managed to achieve sustainable design outcomes. Design methodology involves a number of considerations; these include:

- Reflection on the nature and extent of design knowledge and how this might be applied to the design process.
- The research and application of new methods, techniques and procedures.
- The study of how designers work and think.
- The establishment of appropriate structures for the design process [1].

Beitz describes design methodology in that:

> *...it is used for knowledge about practical steps and rules for the development and design of technical systems, based on the findings of design science and of practical experience in various applications* [2].

Hein also defines design methodology as being: *not in itself a method but rather a body of knowledge related to methodical and systematic techniques* [3].

The term *systematic design* is alternately used in lieu of *design methodology*, particularly in practical applications within industry [4].

The term *design methods* describes any procedures, techniques, aids or tools that contribute to the design process. They represent a number of distinct kinds of activities that the designer might use and combine towards the solution of design tasks. Examples of design methods applicable to both product and industrial design include, amongst others:

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- Design-by-drawing
- Computer Aided Design (CAD)
- Brainstorming
- Concurrent engineering
- Value analysis
- Quality Function Deployment
- Design for X

The most common method of design is *design-by-drawing* and all levels of product design include this in the conceptual and embodiment phases of the design process.

The field of study that is termed design methodology evolved from the introduction of new *systematic* design methods first introduced in the 1960s. Those methods were applied in certain fields of design practice and these included engineering, industrial, architectural and urban design. During the same period, the techniques of creative engineering and brainstorming became more widespread and these provided some bases for idea generation. Some of the early methods did not work very well in practice. They were cumbersome to apply and required considerable input data and paperwork. For these reasons designers did not embrace those methods and believed that they constrained the design process.

During the 1980s, Computer Aided Design (CAD) was introduced and this in itself became a highly accepted design method. Similarly at that time, there occurred a greater incidence of application of methodological processes such as Value Analysis (VA), Design for Manufacture and Assembly (DFMA) and, in the later period of the 1980s, Quality Function Deployment (QFD).

In the 1990s, interest returned to design methods because of a trend towards integrated product development. The integration of various disciplines into the product development process required that the thinking, upon which the design was based, needed to become more transparent and amenable to internal communication within a company. Shortening the time required for product development became important together with a quality philosophy that sought to *get-it-right-the-first-time*. As a consequence, the design process had to become more sophisticated with greater certainty afforded by high-quality concepts, rather than relying on random inspiration. This required further use of design methods. Wallace and Hales argued that in order to coordinate designer activity in Britain and improve design capabilities to compete in the world market the design process needs to be carefully structured [5].

Other researchers also focused on both the design methodology and methods. In particular, the Workshop Design-Konstruktion (WDK) in Denmark is a design organisation that has sought to establish design research with a major focus on the methods, the theory of technical systems and design education [6].

DESIGN METHODS: THE CURRENT SITUATION

The design methods introduced in the 1960s and 1970s were significant in that they drew attention to the need for design to become more transparent and more substantially based on a structure of analysis. However, these failed to achieve wide acceptance as part of the normal process of designing and were not incorporated into the teaching of design on a significant scale. Hence, the generation of designers that experienced the ill-fated introduction of design methods did not consider their relevance to the process of design.

Huang and Mak discuss the adoption of formal design techniques or methodologies by industry and their research applicable to:

- Quality Function Deployment (QFD)
- Value analysis (VA)
- Failure Mode and Effect Analysis (FMEA)
- Design for Manufacture and Assembly (DFMA)
- Morphological Charts (MC) [7].

Their discussion refers to findings contained in various reports Wright (1996), Norell (1993), McQuater (1996), Dale and Shaw (1990), and Pandey and Clausing (1991) who generally conclude a low incidence of usage in industry.

One reason advanced for the limited use of methodologies was that formal design tools have not been taught widely at colleges and universities in the past (Gill 1990). Thus, design methods are seen as something outside the design process, additional and optional. Designers come to learn of design tools through short-course training. However, the problem arises that designers cannot readily include these tools in the design process because it is difficult to change established and proven techniques of design. Many of these tools and methods require significant input data and paperwork and as a result they are time-consuming. Since most design is done under the pressure of deadlines, it is difficult to introduce new ways under these circumstances.

Others write about the low incidence of the use of design science and methods. Eder explains that certain methods are accepted by industry; examples include TQM, QFD and Taguchi [8]. He also points out that such methodologies are used only in a small fraction of industry. Maffin considers the low use of methods in industry and argues that much design in industry is non-original and design is based on established concepts and does not require elaborate exploration [9]. Frost supports this point of view arguing that much design in industry is incremental and not original, and therefore not requiring methodological approaches [10].

In summary, there is considerable evidence that design methods are not extensively used in industry despite the fact that there is wide appreciation of these methods. It would appear that it is one thing to have an appreciation but another to be able to directly and productively apply these in actual design work.

DESIGN METHODS AND THE PROCESS OF DESIGN

In engineering design, models of the design process have been developed and over the years a consensus model has evolved. This is manifest in the VDI model of the engineering process described by Cross and Roozenburg [11]. The activities associated with this model of the design process are grouped into four phases:

- Clarification of the task
- Conceptual design
- Embodiment design
- Detail design

A number of authors, including Jones, Alexander and Archer, amongst others, have proposed models of the industrial design process. Archer's model included six phases, namely: programming, data collection, analysis, synthesis, development and communication [12].

Bonollo and Lewis considered the various approaches to industrial design and proposed a generic model suitable for application to biographical, professional and educational situations [13]. Their model rationalises the industrial design process to a number of phases and these are: task clarification, concept generation, evaluation and refinement of design concepts, detailed design and communication of results. This generic model has since been adapted and applied successfully to a complex product design and development project in a sanitary-ware manufacturing company [14]. Table 1 shows the phases of the industrial design process in relation to engineering design and product development.

This paper proposes additional and complementary phases, namely *product planning* and *preparation for production* to fully encapsulate the product development process. The phase of product planning is concerned principally with exploration of the market, competitors and the strategic positioning of the product. Preparing for production is an important phase that takes the product design and develops it for production.

Table 1: Phases of the design process.

Engineering Design	Industrial Design	Product Development
		Product planning
Clarification	Clarification	Clarification
Conceptualising	Concept generation	Concept generation
Embodiment	Evaluation and refinement of design concepts	Evaluation/ embodiment
Elaboration and detailing	Detailed design	Detailed design
	Communication of results	Communication of results
		Preparing for production

SPECIFIC METHODS AND THEIR APPLICATION TO THE DESIGN PROCESS

The list of design methods shown in Tables 2-4 is categorised into sections that correspond to the generally accepted phases of the design process. However, there are added phases to represent the entire product development process. The list shown in Tables 2-4 draws upon the research of Maffin [9] and Eder [8]. Additionally, it includes various methods from general reading of industry journals. The list itself serves to illustrate the diverse nature of design methods and as a result the obvious difficulty in including them in a rational way in the curriculum of university design courses.

There are numerous factors that arise from the internal and external arrangements of the company. These factors influence the requirements and characteristics of design projects [9]. This is why the phase of product planning or marketing analysis is included.

Modern approaches to product development such as *concurrent engineering* and *integrated product development* involve the formation of teams and increasingly engineers and designers are included in teams dealing with market and business considerations. Certain methods occur in more than one category; a particular method, for example, *brain-*

Table 2: The product planning phase.

Phase	Method
1. Product planning	Project time plan Literature searches Parametric analysis Matrix analysis Brainstorming Integrated product development Competition analysis - Literature, sales reports, trade fairs and exhibitions - SWOT analysis (strengths, weaknesses, opportunities and threats) - Features analysis - Peeves analysis - Reverse engineering Market research analysis - Trend studies Needs analysis (customer requirements) - Market feedback mechanisms - Customer interviews and customer questionnaires - Competition benchmarking - Quality function deployment (QFD) matrices

storming, may be equally valid in *product planning* or *concept development*. Similarly the use of QFD matrices can occur in all of the phases.

The need to consider *preparation for production* is significantly important to the design process because aspects of the product's design will hinge on the constraints of the existing manufacturing system and the need to include considerations of design for manufacture and assembly. In addition, the design itself may include innovations in manufacturing. As such, consideration of this has to occur in the detailed design phases as well as the preparation for production phase.

DISCUSSION OF THE TEACHING OF DESIGN METHODS

A number of issues apply in the teaching of design methods and the integration of these into the normal design process include:

- It is unlikely that *space* within industrial design and engineering programmes can be made to accommodate a specific course in design methods. The time and credit points allocated to design courses seems to be diminishing in many engineering programmes in Australia and overseas.

Table 3: The clarification, concept, evaluation/embodiment and detail phases.

Phase	Method
2. Clarification	QFD Matrices - Engineering requirements - Competition benchmarking - Engineering targets - Performance specification method - Specification checklists and questionnaires
3. Concept	Concept generation - Objectives tree and functional decomposition - Brainstorming - Principle of division of tasks - Design catalogues - Literature and patent search results - Function-concept mapping (morphological charts)
4. Evaluation/ embodiment	Concept evaluation - Feasibility judgement (gut feel) - Technology readiness assessment - Go/no-go screening (customer requirements) - Value analysis (VA) - Design for manufacture and assembly (DFMA) - Evaluation matrix (relative or weighted objective) - Graphical or physical mock-ups - Design review QFD Matrices
5. Detailed design	Product generation - Component design specifications - Engineering design standards - Producability engineering (materials, form, process) Product evaluation - Evaluation matrix (engineering matrix) - Evaluating performance - Analytical, physical and graphical model development - Evaluating costs - Design review - Rapid prototyping - DFMA - Taguchi/robust design - Failure-mode-effect (FMEA) - Value analysis/engineering (VA/VE) - Functional cost analysis - QFD Matrices - Prototyping and testing

- The list shown in Tables 2-4 includes a wide variety of design methods and many methods that are specifically developed for certain product groups and industries are not included.
- The teaching of these methods should be an integral part of design teaching. In this way

Table 4: The communication of results and preparation for production phases.

Phase	Method
6. Communicate results	Design drawings Renderings Solid modelling Models Rapid prototyping Prototypes
7. Prepare for production	Total quality management - Statistical process control (SPC) - Fault tree analysis - QFD matrices Integrated product development Computer integrated manufacture (CIM) Rapid prototyping Computer Aided Design (CAD) Computer Aided Engineering (CAE) Design for manufacture and assembly Design of experiments (Taguchi) Failure mode, effects analysis

they may become an integral part of the design process.

- These methods should be computer integrated. Many of the methods require considerable paperwork and if this can be shifted to the computer then the method may be perceived more as an expert system, as a sub-routine of the design process.

How can design methods be taught effectively and with wide user acceptance? How can these be integrated into design teaching so that they become a fundamental part of the design process and not an optional extra? They cannot all be taught, just as not all CAD packages can be taught.

An effective approach may involve the rationalisation of the range of methods. For example, included in the evaluation phase are the QFD and VA methods. These have certain similarities and one might be eliminated. This approach applied to the broad range of methods may yield a reduced suite of complementary methods that can be taught as a group. Additionally, the learning of an entire method such as value analysis (VA) can be daunting. Yet within VA there are discrete methods that can have a focused application to specific aspects of the design process. An example of this might apply to function analysis, a part of VA that can be applied as a discrete method to considerations of product design, ergonomics or mechanical design.

Table 5: Proposed suite of design methods.

Phase	Method
1. Product planning	Project time plan Product status checklist Features analysis Peeves analysis SWOT analysis
2. Clarification	The Objectives Tree method Competition benchmarking Cost evaluation Cost visibility analysis Pareto analysis Function and cost-function analysis
3. Concept generation	Brainstorming Catalogue search Design-by-drawing
4. Evaluation/ embodiment	Interaction matrix House of quality (QFD) Design-by-drawing CAD
5. Detailed design	CAD Evaluation matrix Value engineering
6. Communicate results	Renderings Design drawings Prototypes
7. Prepare for production	Change proposal Design for manufacture and assembly

Table 5 lists the seven phases of the product development process and against these proposes a reduced number of methods. These considerably reduce the number of methods listed in Tables 2-4 and as a consequence reduce the complexity associated with teaching and applying methods to the design process. Bonollo and Green describe this suite of methods in more detail and describe how these may be computer integrated and made available to the student for application to a design project [15].

The entire suite of spreadsheets and text files may be contained on a compact disc and the contents can be taught and applied to design projects within the studio course. One major factor in the lack of use of design methods is the requirement to enter considerable quantities of information on forms and tables. This becomes tedious and messy and discourages effective application to design projects.

It is believed that the provision of a suite of computer-based design methods would make more convenient the recording of information and the preparation of reports. This resource may facilitate a more logical progression through the design phases and make more apparent the thinking upon which design decision making is based.

CONCLUSIONS

Design methods, first introduced in the 1960s, have not been particularly successful, especially in the educational context. However since then, their incorporation into the design process has increased although some published evidence suggests that their adoption by industry is limited. A major factor in this lack of broad acceptance is that such methods have not been widely taught as a fundamental part of the process of designing.

Design methods provide a structure for the design process and externalise the thinking of designers. However, a problem exists in the related design teaching because of the wide variety of methods that are available and difficult challenge associated with their understanding and application.

This paper has proposed a means of improving both the student-learning outcomes and the quality of product design solutions typical of the product design studio. The methods specified in this paper and the outcomes associated with their inclusion in a product design programme are currently the subject of a research project undertaken by the senior author in collaboration with the University of Canberra. In-depth research will be conducted over the next year with the objective of providing a computer-integrated suite of generally applicable design methods and a detailed evaluation of their contribution to the student design process.

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BIOGRAPHIES

Lance Green is Director of postgraduate programmes in industrial design at the University of New South Wales, Sydney, Australia. From 1994 until 2000, he has supervised the undergraduate and postgraduate programmes in industrial design. In 2000, he relinquished supervision of the undergraduate programmes to focus on the postgraduate area.

Prior to his present role, he has occupied senior positions in Australian industry such as: General Manager of Poly Industries (product design and plastics manufacture); Technical Director at Plastic Processors (plastics and health-care manufacturing); Research & Development Manager, Baxter Healthcare (Aust) (R&D Healthcare Products); Divisional Engineer at Rheem (Aust) (product and process development for packaging group); and Technical Manager for Advance Industries (product and process development of plastics and packaging products).

Lance is a Chartered Engineer and holds a Bachelor Degree from the New South Wales Institute of Technology, a Masters Degree in Design from the University of Technology, Sydney, and a

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Professor Elivio Bonollo is Pro Vice-Chancellor (promoting international relations) and Professor of Industrial Design at the University of Canberra (UC), and formerly Dean of the Faculty of Environmental Design (1997-1998) at the UC. He is also Director of the National Institute of Design, a collaborative design partnership between the UC and the Canberra Institute of Technology. He was Professor and foundation Director of the Centre for Industrial Design at Monash University (1989-1996), and before this Senior Lecturer in charge of Industrial Design at the then Royal Melbourne Institue of Technology (RMIT) (1979-1989). He is the principal author of the original industrial design degrees at RMIT and Monash University.

He is an active researcher and publisher in the field and currently the UC project leader for an AusIndustry $1M Collaborative R&D Start Grant with Caroma Industries in Sydney, Australia. This project is concerned with the design and development of water saving systems for water closets and related plumbing. His current overseas appointments include External Examiner in product design at Temasek Polytechnic, Singapore, and Visiting Professor in the Faculty of Engineering at Ubon Ratchathani University, Thailand. Livio holds a Bachelor Degree in engineering, a Master of Engineering Science and a PhD from the University of Melbourne, Australia. He is a chartered engineer and a member of The Institution of Engineers, Australia and a Chartered Engineer and member of The Institution of Electrical Engineers, London, England, UK.

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