

THE ROLE OF A SPECIFICATION IN THE DESIGN PROCESS: A CASE STUDY

M. N. Sudin, S. Ahmed-Kristensen and M. M. Andreasen

Keywords: specification, design process, design tasks

1. Introduction

Design specification is a description of the desired solution to a problem [Darlington and Culley, 2002]. The role of design specification in the design process is recognised as significant. In the specification document, the description of the desired solution is described by a set of requirements. A clear description of the desired solution is important because it will increase the probability to achieve a successful design. In order to have a clear description the number of requirement statements must be sufficient to guide design engineers to proceed from the abstract to the concrete solution so as to fulfill the aim of the product. Once the problem has been identified, the criteria for selection of feasible concept are established in the form of a design specification, consisting of a list of requirements to be met by any solution to the problem. Thus the role of specification is twofold: First, to set up the solution space for design engineers to design a product and; second; to evaluate proposed solution to ensure that they fall within the acceptable boundaries.

Many product development methods e.g. [Ulrich and Eppinger, 2000] describe product development as a well-structured, sequential flow starting with a requirements specification, or design specification, and ending with a product solution. Thus establishing a design specification is essential and should be a central issue in design research [Chakrabarti, et al., 2004]. Several procedures for creating requirements for a specification are suggested in literatures e.g. [Pugh, 1997][Ulrich and Eppinger, 2000] acknowledging the benefit of having a comprehensive specification at the start of the design process. Furthermore these literatures provide some guidelines for preparation of a good specification i.e. requirements should be unambiguous, solution-independent formulation, clearly linked to customer needs, measurable (qualitative or quantitative). To ensure the specification is more practical, several authors have distinguished requirement into demand and wishes e.g. [Ulrich and Eppinger, 2000]. Yet, according to Hubka and Eder [Hubka and Eder, 1988] the contents and form of a specification are different from case to case, and are influenced by a number of factors: complexity of the factions; complete plant vs. machine component, design difficulty; new design and development vs. adaptive design, requirement for additional properties; safety, life, appearance and problem initiator or sponsor. To identify a complete set of requirements for a product at the early phase of the design process becomes essential yet impossible in reality.

Based on an empirical study, [Andersson, 2003] writes, "The completeness is a criterion that is basically unachievable". Often new requirements are included as the design process proceeds into the advance state because we do not know the problem fully until the solution is created. The requirements are changed (i.e. developed, explored and expanded) during the design process into a more complete description (final specification). The study of Hansen and Andreasen [Hansen and Andreasen, 2007] supported this statement. They found design engineers generate specifications during the design process.

Change in requirements during the design is essential for improvement or error rectification but from another point of view it may cause consequences to both time to market delay and cost increase. However both consequences rely upon the gap between the initial specification, which is developed before the design process starts to the full specification, and the specification when the design process is completed. The narrower the gap between these two specifications significantly reduces both consequences. Thus to obtain insight about the role of design specifications during the design process, a case study was carried out in a consultancy company. In this study the nature of specification development during the design process was explored and is discussed in this paper. This study is essential to provide some clue for devising supports that can help design engineers to develop a good specification.

2. Research aims and questions

The research aims to understand the nature of specification development during the design process including understanding: the development, contents of, and the roles of specification. To achieve these aims the research has three main questions as follows:

1. What influences the development of a good specification in a collaboration project (i.e. between a client and consultancy)?
2. How do the design engineers define the content of a specification?
3. How are specifications used during the design process?

3. Methodology

3.1 Research object

The study was carried out in a consultancy company. The consultancy company was selected due to their involvement in the development of different types of products (i.e. mechanical, electronic, electro-mechanical), projects (i.e. product development, design review, etc.), dealing with different type of clients and embarking at different stages of a project. These situations provide a bounty of knowledge to the design engineers in the company and their experiences were useful for this research.

3.2 Data collection method

Interviews were carried out in the consultancy company within three themes that were: 'specification development', 'specification roles' and 'specification changes'. In total six interviews with six design engineers were carried out. Each interview was about 40 to 60 minutes and the interviews were audio recorded and transcribed. The interviews were semi-structured, the participants were asked about the topic based on the list of questions but the participants were allowed to expand the discussion. The interviews accumulate 109 years of working experience. The participants' working experience range from 6 to 30 years and the age of participants range from 32 to 55 years old. Each participant explained about a different project that they had been involved in with the consultancy company.

3.3 Data analysis method

The transcription of the interviews was indexed against a predefined coding scheme. The coding scheme was developed based on theory or emerged later from the interviews. The transcription was segmented according to the predefined codes that meant each segment correspond to one predefined coding. In total the transcription was divided into 640 segments and each segment varied in length from single to 20 words. The results of the analysis are mainly quantitative with some initial qualitative result was carried out, through reading the texts and analyzing the relation between results. Some of the predefined coding adopted in this research, together with definition and references, are shown in Table 1

Table 1. Coding scheme

Categories	Codes (Sub codes)		Explanation	References
Factors that influence the specification development process	Company	The company type	Size, technology, value chain position, etc.	[Darlington and Culley 2004]
		Allocation (budget, time)	Low role or high role	
		Working culture	Top-down, self growing team, control culture	
		Education background	Academic, practical, method oriented	
		Company-client relationship	Client specification, company specification, cooperation.	[Darlington and Culley 2004]
		User of the specification	Synthesis, evaluation, decision, etc.	
	Product	Type of product development	e.g. Technology pull, technology push, platform products, customized product, etc.	[Ulrich and Eppinger 2000] [Darlington and Culley 2004]
		Product's target	lead time, cost, quality.	
		Product's complexity	High, medium, low, system, component.	[Darlington and Culley 2004]
	Project	Project phase	The actual stage of the project in which the specification was analysed.	[Darlington and Culley 2004]
Aspects considered leading to identification of requirements	Function		What the product would be able to do.	[Pugh 1997]
	Performance		The capacity of the product	[Pugh 1997]
	Material		Kind of material would be used for the product/component.	[Pugh 1997] [Chakrabarti et al. 2004]
	Geometry		The size and form of the product/component.	[Pugh 1997] [Chakrabarti et al. 2004]
	Option for solution (Improvement)		The available option to improve the product within the requirement.	[Pugh 1997]
	Standard		Specific standard or rule that need to be fulfilled	[Pugh 1997]
	Safety		Safety to the user, standard, test, etc.	[Pugh 1997] [Chakrabarti et al. 2004]
	Cost		Total product cost, project cost, cost demand.	[Pugh 1997] [Chakrabarti et al. 2004]
	Maintenance		How easy the product could be maintained.	[Pugh 1997] [Chakrabarti et al. 2004]
	Mechanical properties		E.g. strength, deformation, etc.	[Pugh 1997]
	Testing		What kind of testing the product/component needs to undergo.	[Pugh 1997]
	Component interface		Interface specs, standard, type.	[Pugh 1997]
	Production		Production requirement, cost, technology, supplier, assembly lead time, automation.	[Pugh 1997] [Chakrabarti et al. 2004]
	Assembly		Manual, automation, volume, etc.	[Pugh 1997] [Chakrabarti et al. 2004]
	User interface (Ergonomic)		safety, easy to learn, easy to use, etc.	[Pugh 1997] [Chakrabarti et al. 2004]
Usage (user, application)		Operator, maintenance personnel, operation hour, etc.	[Pugh 1997] [Chakrabarti et al. 2004]	

4. Results and discussion

4.1 Initial states of specification and the development of full specification

This study aims to understand the early stage of development of specification for a collaboration (i.e. between client and consultancy) project. The full specification development mostly reflects the state of the client's specification. Thus to achieve this aim the study investigates the states of specification received by the consultancy company from their clients at the beginning of the collaboration project. The study found that the consultancy company received the specification from their clients in three different states that were:

- Verbal specification received.
- Semi-developed; i.e. only partially written down and finished.
- Full specification document.

The consultancy company received a semi-developed specification from their client at the beginning of the collaboration project, for the majority of cases as shown in Table 2

Table 2. Types of client's specification

Type of Specification	Verbal	Semi-developed	Full specification
Instance	2	11	2

The full specification needs to be developed in the cases where the clients approach the consultancy company with none (verbal) or semi developed specification. The study also investigated who develops the full specification for a collaboration project. It was found that the full specification developers for a collaboration project were:

- Client of the consultancy company
- The consultancy company
- Both client and consultancy together

The result of the study reveals that the consultancy company was mainly responsible for developing the full specification for a project and the majority of the full specifications were developed by the design engineer in the consultancy company as shown in Table 3. The study also found that the client did provide full specification to the consultancy company for cases where the consultancy company has to solve the problem of an existing product without changing the specification i.e. meeting the specific requirement in the specification. In this case the consultancy company received the full specification of the product together with the encountered problem. There were also cases where the full specification was developed by the collaboration of both the consultancy company and client. The result highlighted that design engineers need to spend a large amount of their time to develop the specification during early product development process. The design engineers in the consultancy company should bear in their mind that developing the full specification is one of their tasks.

Table 3. Full specification developer

Specification developer	Client	Consultancy		Both
		Design Engineer	Design team	
Instance	2	11	4	5

The study also investigates when the specification developer starts to develop the full specification for a project. The result of the study reveals that the majority of the full specification was developed before the design process starts as shown in Table 4, and is the ideal situation as described in literature [Ulrich and Eppinger 2000].

Table 4. Execution of the specification design

Specification design	After the design process	Before the design process
Instance	1	16

The importance to develop specification in early design process was stated in several literatures e.g. [Pugh, 1997]. This result confirmed that industrial practice was in line to design methodology literature. The result of the study has shown that the major role of specification was to control the design engineers to find feasible solutions for a problem. This result was strengthened by several design methodology literatures e.g.[Ulrich and Eppinger, 2000]. The underlying assumption of all literatures, is that it was meaningful to interpret an understanding of the potential customers’ need (customer focus) and perception of value into a set of specification statements in the form of a specification before actually search for design solution. Therefore further research to support design engineers to identify all the necessary requirements at the beginning of the design process become essential i.e. the requirements that helps them to execute the design tasks.

4.2 Factors influencing the development of a specification for a project

The study also investigates the factors that influence the development of specification for a project. The study found three main factors that were:

- Company: The company type, budget allocation, working culture, education background, the user of the specification and company-client relationship.
- Product: Complexity of the product, product’s target and types of product development.
- Project: Project phase.

The company including: budget allocation provided by the company for a project, working culture in the company, education background of the design engineers, user of the specification and company-client relationship (i.e. business to business) was very much influencing the development of the specification as shown in Table 5. Similar results of factors influencing design requirement were also found in another study i.e. company type, stakeholders relationship, product type, product complexity, [Darlington and Culley, 2004]. They also discovered some other factors i.e. maturity of initial design requirement, design activity type, design requirement capture methodology, contract formality, level of design expertise and level of design requirement development expertise. The need for information to develop a specification and the influence of education background of design engineers to the company also was also identified as factor in a separate study [Macdonald and William, 1993].

Table 5. Factors that influence to the full specification development process

No.	Factor	Sub factor	Instance
1.	Company	Budget allocation	14
		Working culture	
		Education background	
		User of the specification	
		Company-client relationship	
2.	Product	Complexity of the product	6
		Product's target	
		Types of product development	
3.	Project	Project phase	1

Figure 1 illustrates how the company plays a central role in the specification development process. The company may embark at different stage of the product development project. The products were differentiated based on the type and complexity. These two factors: project and product are a direct influence of the company and affect the specification development process. Beside that the company also have employees with their own education background and they influencing the working culture in

the company. Despite that the allocated budget for a project and the product target i.e. when it should be release to the market influencing specification developer in the specification development process i.e. how much time they have before the deadline. Meanwhile the user of the specification and company-client relationship influencing specification development, which was considered by specification developer when they begin to develop a specification.

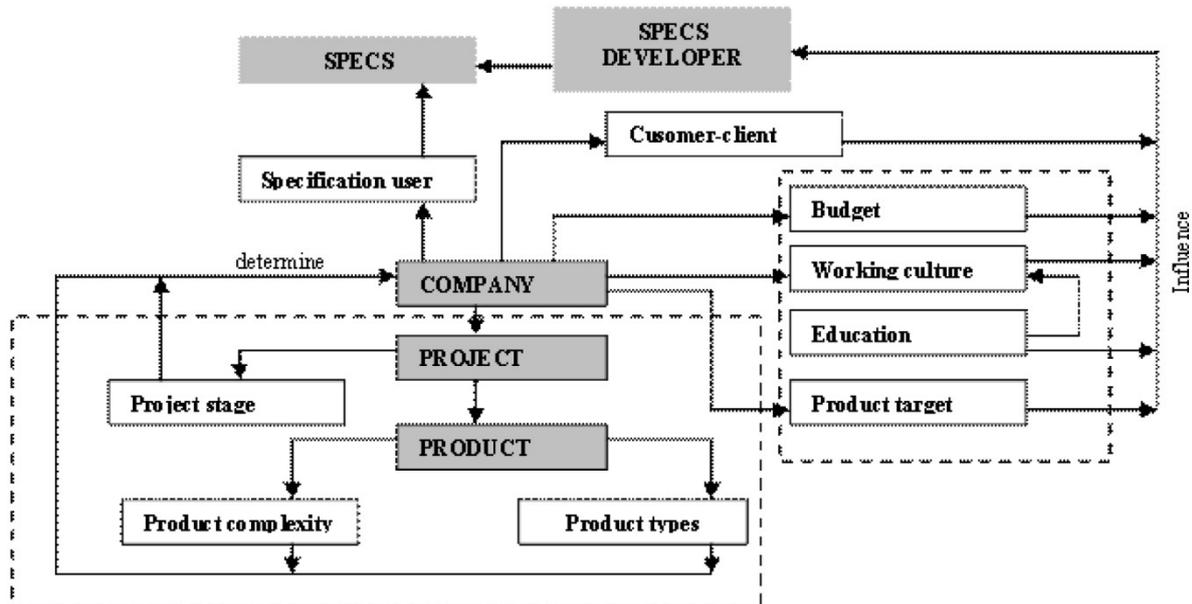


Figure 1. Relationship between factors, sub factors influencing in specification design

4.3 Identification of sources and aspects of requirements

The study also investigates how a specification is developed, through understanding the aspects considered which lead to the identification of requirements which form part of the specific action. The study found the requirements in the specification evolves during the design process. Designer engineers were found to consider seventeen aspects of the product lifecycle leading to identification of requirements as shown in Figure 2.

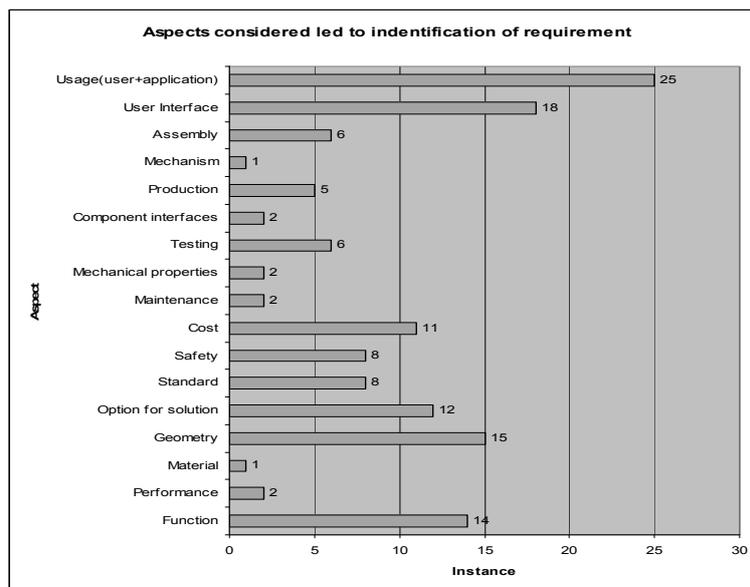


Figure 2. Aspect considered leading to identification of requirement

The majority of the requirements were identified when the design engineers considered the user including; usage (i.e. application, user), user interface (ergonomic) and safety. Similar aspects and other aspects that were considered leading to identification of requirements was found in the protocol study by Chakrabarti *et al.* [Chakrabarti *et al.* 2004]. The study also observed two approaches of requirements search that occurred repetitively during the design process these were:

- Aspect to source
- Source to aspect.

These approaches occurred in the problem domain e.g. the specification developers begin by considering safety aspect then they identify end user as the source. Furthermore they start with end user and start to consider ergonomic aspect. Figure 3 shows the approach of requirements search during the design process for a project.

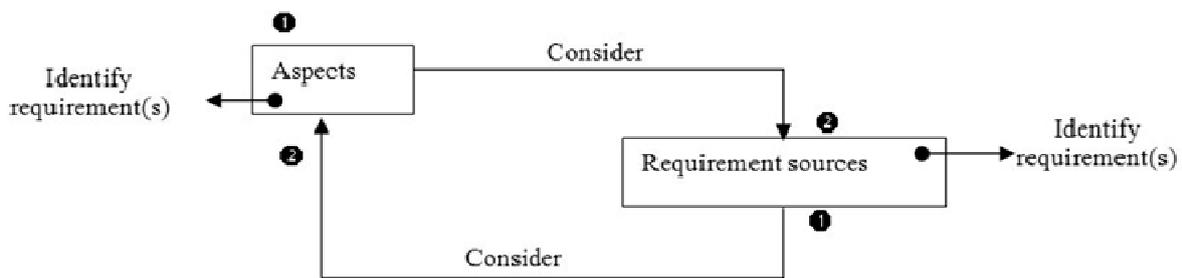


Figure 3. Approach of requirements search for a project

The study investigated the sources of requirements during the design process. The result shows that twelve sources of requirement that the design engineers were referred to can be classified into two major sources that were:

- Human: Client, end user, market analysis, colleagues, expected solution, designer's own requirement.
- Artifact: Semi developed specification, proposed solution, existing product, previous project, design guideline, user guidelines.

Table 6. Sources of requirements during the design process

No.	Main source of requirement	Source of requirement	Instance	Total Instance
1.	Human	Client	6	31
		End user	4	
		Marketing	2	
		Colleagues	11	
		Expected solution	3	
		Designer's own requirement	5	
2.	Artifact	Semi developed specification	1	19
		Proposed Solution	5	
		Existing product (prototype, previous product)	8	
		Previous project	3	
		Design guidelines	1	
		User Guidelines	1	

The major source of requirements during the design process was human as shown in Table 6. The study of Romer *et al.* and Wootton *et al.* also discovered similar results about the sources of requirements i.e. colleagues, customer, document, other departments (i.e. sales department, marketing and manufacturing) [Romer, et al., 2001] and customer, user, supplier, written material (i.e. book,

trade journal, technical manual)[Wootton, et al., 1997]. In another study [Romer, et al., 2001] found task clarification was performed by discussion with colleagues (80%), customer (60%) and by document analysis. Furthermore, market analysis, analysis of legal defaults and consulting other departments involved in product development (e.g., sales department, marketing, and manufacturing) were also reported. This result has highlighted the importance of communication and knowledge sharing between design engineers with other stakeholders in order to develop a good specification. Furthermore by considering all aspects and sources (origin) of requirements continually along the design process, may result in a reduction in the number of changes in requirement. However attention should be given to ensure that new requirements that were identified at least appear in the right stage of the design process i.e. requirement about function appear at conceptual design stage. This is important because if the requirement is needed in the conceptual design stage emerges at the embodiment stage then the design engineers may need to do more design iteration.

4.4 Roles of specification

As the role of specification during the design process influences it’s development, this also formed part of the investigation. The specification plays a vital role in the product development process and was found to have various roles including :

- Guidance to designers
- Identify trade-off between requirements
- A checklist e.g. during milestone meeting
- Evaluation of solutions to select the one that is most suited to the specification
- An agreement within the design team, and as an agreement with the client e.g. company-supplier agreement on fulfilling the design task.
- To trace the likelihood of change propagation.
- Product overview

Figure 4 shows the roles of specification for a project and the number of instances for each role. Specification was frequently used during the design process mainly to guide the design engineers to search for the feasible solutions. This result is supported by the finding of a previous case study [Romer et al. 2001] with respect to the starting phase of product development, they found 84% of the interviewees reported analysing the requirement before developing solution. Similar roles i.e. guidance, verify solution and an agreement was also found in previous study [Nijhuis and Roozenburg, 1997].

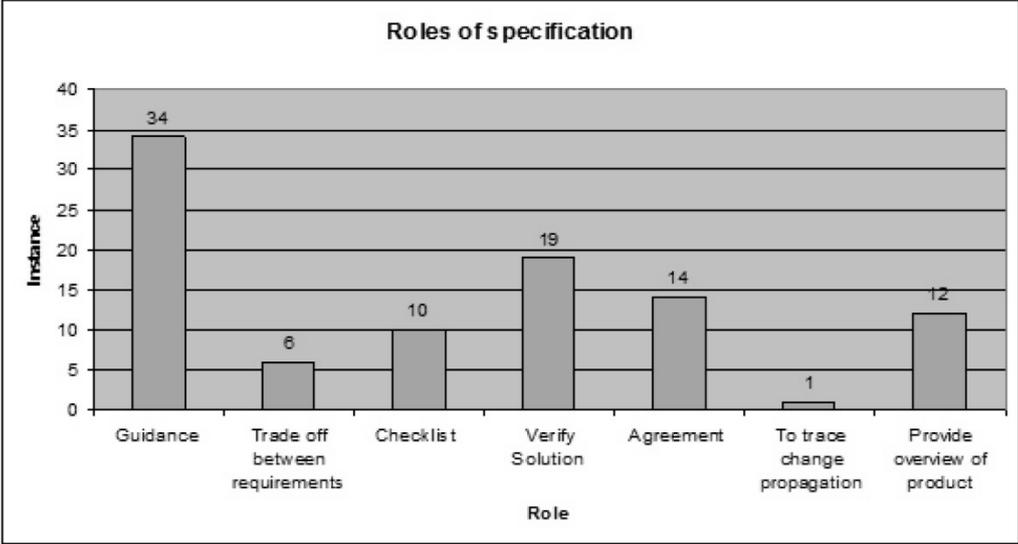


Figure 4. Roles of specification during the product development process

The specification design should reflect how the specification is used during the product development process. Based on this study the design engineers used the specification for: guidance to execute the design tasks, to identify conflict between requirements so they can do requirements trade-off, as a checklist e.g. during milestones meeting, to verify solution, agreement within design team or with client, to trace change propagation likelihood and serve as product overview before they proceed with their design tasks. However, the majority of specifications were used as a mean to guide design engineers to execute the design tasks into advance stage. The similar usages of specification were also found in another study [Nijhuis and Roozenburg, 1997] where it was used as: a guidance, verify solution and an agreement. This result highlighted some important notes; firstly, the developers of specification should be aware of the roles of specification as it being designed to ensure that it is really useful and of benefit to design engineers to execute their design tasks. Secondly, further research to characterize specification based on it usages is essential as the specification has multiple roles in the product development activities.

5. Conclusion

The study has been carried out by interviewing six design engineers in a consultancy company. The themes of interviews were about the creation of specification and roles of specification during the design process. The study investigated consultants viewpoints about specification development in the business to business context. Since the interviews were open ended and the participants were allowed to expand the discussion, the study also uncovered a few additional aspects which were helpful to understand the topic of the study.

The results of the case study assist in obtaining an insight into the development of specification in the customer-client context from the consultant viewpoints. It was clear that a specification is a central element in the product development process as it provides vital information for design engineers to execute the design tasks i.e. for concept generation and solution evaluation. However due to it multiple roles in the product development environment as were found from this case study, the specification could be developed in response to it usage i.e. in what context it will be used. For example, as a guidance to design engineers to execute the design tasks the requirements in this specification should be difference to the requirements in the specification that will be used for tendering in the customer-supplier context even for the same project. Providing specific type of specification to the right application helps to avoid design engineers with being overwhelmed with information and leading to the specification not being used during the design process. Thus in the design process methodology, support such as a method to identify requirements that the design engineers need to execute their design tasks maybe essential.

Acknowledgement

I would like to thank Institute of Product Development (IPU) for participation in the studies, UTeM and MOHE for the funding.

References

- Andersson, F., "The dynamic of requirements and product concept management: a product modelling approach", PhD Thesis, Chalmers University of Technology, Goteborg, Sweden, 2003.*
- Chakrabarti, A., Morgenstern, S. and Knaab, H., "Identification and application of requirements and their impact on the design process: a protocol study", Research in Engineering Design, Vol. 15, pp22-3,. 2004.*
- Darlington, M.J. and Culley, S.J. "A model of factors influencing the design requirement", Design Studies, Vol. 25, pp329-350, 2004.*
- Hansen, C. T. and Andreasen, M.M., "Specifications in early conceptual design work", ICED 07, Paris, August 28-31.*
- Hubka, V. and Eder, W.E., "Theory of technical system: a total concept theory for engineering design", Springer-Verlag, Berlin, Germany, 1988.*
- MacDonald, S. and William, C., "Beyond the boundary: an information perspective on the role of the gatekeeper in the organization", Journal of Product Innovation Management, Vol. 10, pp417-42, 1993.*
- Nijhuis, K.J. and Roozenburg, N.F.M., "Evaluating the use of product design specifications in dutch product development practice", ICED 97, Tampere, Finland, August 19-21.*

Pugh, S., "Total design: integrated methods for successful product engineering", Addison-Wesley Longman Ltd., Essex, UK. 1997.

Romer, A., WeiBhahn, G., Hacker, W., Pache, M. And Lindemann, U. "Effort-saving product representations in design-results of a questionnaire survey", Design Studies, Vol. 22, pp473-491, 2001.

Ulrich, K.T. and Eppinger, S. D., "Product design and development, 3rd Edition", McGraw Hil Inc., NY. USA. 2000.

Wootton, A.B., Cooper, R. and Bruce, M., "Requirements capture: where the front end begins?" ICED 97, Tampere, Finland, August 19-21.

Mohd Nizam Bin Sudin
Technical University of Denmark
Department of Management Engineering
2800 Kgs. Lyngby, Denmark
Telephone: +4545254153
Telefax: +4545255677
Email: mnbs@man.dtu.dk
URL: <http://www.man.dtu.dk>