INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

SPECIFICATIONS IN EARLY CONCEPTUAL DESIGN WORK

Claus Thorp Hansen and Mogens Myrup Andreasen
Department of Mechanical Engineering, Technical University of Denmark

ABSTRACT
In early conceptual design the design team is working in an uncertain situation, where the understanding of a need is limited and not much is known about the solution space. In this situation the design team has to both analyse need and explore solution space. Thus, the team has to formulate design specifications, which express attractive product goals, and has to synthesise the product idea.
The authors of this paper see a challenge to enhance and improve our understanding of the nature of design specifications as a means to support the synthesis of a product idea. In this empirical study we analyse the structure and content of design specifications during early ideation activities, where initial design specifications are formulated and a product idea is synthesised. We have analysed specification documents of 19 teams of novice designers.
Our analysis indicates that a productive product design specification in early conceptual design consists of few specification statements, which express value, important aspects of product context and articulate key functions. A product design specification, which contains a lot of specification statements about product properties, is not productive to support the synthesis of a product idea.

Keywords: Goal specifications, innovative ideation, empirical study

1 INTRODUCTION
In industrial practice there is a need for an effective goal-oriented product development process, where the design team synthesises an attractive solution within given resources and time. However, product development is a complex multidisciplinary task encompassing synthesis and problem solving, where there does not exist an infallible procedure, which leads the design team to an attractive solution. An important activity in a product development process is to formulate a product design specification because it defines the target to be met. In this paper we use the term a product design specification for a specification document, which contains a set of specification statements. A specification statement can be formulated as a fixed requirement, minimum requirement, demand, criterion, or wish.
In a previous paper [1] we observed that influential textbooks in product design and development in their descriptions of the product design specification as a means to articulate design goals share a common underlying assumption, namely that it is meaningful to interpret an understanding of need and problem into a product design specification *before* actually searching for solutions. However, empirical studies of design work have shown results, which compromise this assumption. Researchers have observed at least two distinct different design strategies, namely a solution driven versus a problem driven design strategy. Another observation is that designers generate specifications *during* the design process. An empirical study in industrial practice showed that for some issues is it hard to state design specifications.
We see a challenge to enhance and improve our understanding of the nature of design specifications as a means to support the early ideation activities to synthesise a product idea, or in other words as a means to support the design team in exploring the solution space. Our overall research questions can be formulated as: what is the content of a product design specification, which is productive in supporting a designer or design team to synthesise a product idea? And which specification elements articulate the explorative nature of the ideation task? Our research work is based on an empirical

approach. We have analysed the specification documents of 19 teams of novice designers, focusing on the structure and content.
The structure of the paper is the following: In section 2 we describe our findings from the literature in detail, and we describe the material we are analysing. In section 3 we formulate hypotheses and research method. In section 4 the analysis is described. The analysis result has some implications for conceptual design work, which are described in section 5. Finally, the paper finishes with conclusions.

2 SPECIFICATIONS TO SUPPORT SYNTHESIS

In this section we will describe the textbooks' understanding of the product design specification and compare this understanding with empirical studies of design work. We identify a gap between the textbooks' understanding and the outcome of the empirical studies, and this gap is our motivation to ask for an enhanced and improved understanding of the nature of design specifications as a means to support the synthesis of a product idea.

2.1 Related work

In a previous paper [1] we observed that influential textbooks in product design and development ([2], [3], [4], and [5]) in their descriptions of specifications as a means to articulate design goals share a common underlying assumption, namely that it is meaningful to interpret an understanding of need and problem into a product design specification *before* actually searching for solutions. The common idea is that a design process starts with an analysis of need and problem, and based on the analysis a set of specification statements are formulated. Thereafter, a search for solutions begins. Thus, the key function of the specification statements becomes to evaluate alternative solutions. Roozenburg & Dorst [6] propose five requirements for specifications to be functional: comprehensive, complete, operational, non-redundant and minimal, and Roozenburg & Dorst assume that specifications can be analysed with respect to these requirements before the search for solutions begins. However, we see no reason to believe that it is possible to analyse a product design specification with respect to these requirements unless solutions are known. As an example let us focus on the requirement of completeness, i.e. all specifications are present in the product design specification. Roozenburg & Dorst write that, "Completeness is crucial since working with an incomplete performance specification is like solving the wrong problem. However there is no simple test for completeness. It is largely a matter of experience with comparable problems." Andersson [7] also discusses completeness of a product design specification, and he states that it is an issue under debate. Andersson argues that the problem definition, in which design specifications are formulated, is dependent on many issues (e.g. customers and other stakeholders) and not absolute, and Andersson writes, "In the light of bounded rationality, the completeness is a criterion that is basically unachievable, but nevertheless worth aiming for, since missed requirements can cause major iterations in a development project." By this small example we have shown our reservation regarding the idea that a design team can and shall analyse a product design specification with respect to the five requirements proposed by Roozenburg & Dorst before searching for solutions. The design team has to know several solutions and evaluate these solutions' consequences in order to determine whether the product design specification fulfils the requirements or not.
The authors of this paper have more than 15 years of experience in teaching engineering design and product development at the Technical University of Denmark. We teach students in the study programmes mechanical engineering and design & innovation, and we teach undergraduate students as well as master students. Based on our teaching experience we acknowledge that the textbooks' descriptions of specifications are teachable and to a certain degree productive, e.g. a careful analysis of need and problem leads the design team to a certain focus on the core of the task, i.e. a focus on which criteria are hard to satisfy and/or which functions are central to realise. However, design situations are more complex than the underlying common assumption indicates.

There are several design strategies

Firstly, a design strategy does not necessarily begin with an analysis of the need and problem. In order to understand how architects perceive complex design problems, and how they synthesise desired solutions Lawson [8] develops an experimental situation, which models a design situation. The experimental material consists of four pairs of coloured blocks and a rectangular plan. The two members of each pair of blocks have identical shape, but different to all other blocks. The vertical

surfaces of the blocks are either blue or red, and the two blocks in a pair have different patterns of blue and red. The rectangular plan consists of a grid of three by four bays and the blocks and bays follow the same dimensional module. In the experiment the subject was asked to arrange one block from each pair on the plan to cover all twelve squares, and the subject was asked to maximise the amount of either blue or red showing around the outer vertical face. Not all possible combinations of blocks would be allowed each time, and a configuration rule requiring certain blocks to be present for a combination of blocks to be accepted as valid would be determined before each experiment. The subject was not told the actual configuration rule, but was allowed to ask if a combination of blocks was acceptable or not, which was answered by 'yes' or 'no'. The subject was asked to reach a best solution possible by asking as few questions as he could.

A number of students were asked to act as subjects and Lawson's analysis of the subjects' approaches to carry through the experiment shows two distinct strategies. Some students were selecting the block in question in order to discover the structure of the problem, i.e. to identify the configuration rule. Thus, these students use a problem-focused design strategy. Other students were carrying through the task by generating a sequence of high scoring combinations until one proved acceptable, i.e. a solution-focused design strategy.

Kruger & Cross [9] report a protocol study of nine experienced industrial designers performing a design task individually in a laboratory setting. The experiments were conducted as 'think –aloud' protocol studies, and the sessions were videotaped. The time allotted for each session was 2.5 hours. Kruger & Cross use the protocols to identify four cognitive strategies, which they characterise as follows:

1. Problem driven design, where the designer characteristically pays attention to careful reading the design assignment. The designer's focus is on understanding and defining the given problem.
2. Solution driven design, where the designer quickly scans the assignment for basic requirements. The design problem remains ill defined, and on this basis the designer generates solutions.
3. Information driven design, where the designer spends a lot of time reading the assignment and gathering information. The strategy while reading the design assignment is to look for pointers to other information sources.
4. Knowledge driven design, where the designer carefully reads the design assignment, and compare it to his knowledge about similar problems. Those aspects that seem new are explored through gathering information.

The timing of generating design specifications

Secondly, Restrepo & Christiaans [10] report a study of the information seeking behaviour of designers. In an empirical study four teams of design students have to design a luggage carrier for bicycles, and the study shows the relationship between information seeking behaviour and the generation of design requirements. Restrepo & Christiaans write, "Whilst teams 1 and 4 developed the list of requirements throughout the entire session, teams 2 and 3 finished the list of requirements before starting the development of the concept. In fact, team number 2 did not succeed in completing a concept because they spend too much time on the list of requirements." The behaviour of team 2 is a worst-case example with respect to Andersson's statement that the design team shall aim for a complete product design specification although completeness is unachievable.

The difficulty in formulating design specifications

Thirdly, for some issues it is hard to formulate design specifications in technical terms. Almefelt et al. [11] report an empirical study carried out in industrial practice, where they followed a product development project from early concept phase to industrialisation in a Swedish automotive company. The case studied was the development of a passenger car cockpit, which is a major sub-system of a car and has multi-technology content. The research method encompasses a product study, a study of documents and a number of interviews. With respect to formulating design specifications in technical terms Almefelt et al. write, "However, even if the design and organisation of the requirements documents were perfect and the content appeared to be complete, the fact remains that some issues are really difficult to state requirements for. The ability to specify technical requirements is seen as good, while more abstract issues, such as perceived tactile feeling in controls and aesthetic values, are said to

be more difficult to capture in a requirement." Thus, for product properties related to aesthetic values and user feeling it is difficult to formulate specification statements in measurable, technical terms.

Our motivation for this research work

We see a gap between the influential textbooks' understanding of the product design specification and the outcome of empirical studies of design work. The textbooks assume a problem-focused design strategy, where the design team firstly analyses need and problem then formulates the product design specification and thereafter initiates a search for solutions. However, empirical studies of design work have shown several design strategies, and that specifications can be generated during the design process, and finally that for a number of issues it is hard to formulate specifications in clear, technical terms. This gap is our motivation to ask for a better understanding of the nature of design specifications, and in this paper we will focus on design specifications as a means to support the synthesis of a product idea.

2.2 Our data material

Our research work is based on an empirical approach. We have analysed the design specification documents of 19 teams of novice designers. The novice designers are first semester undergraduate students of the design & innovation study programme at Technical University of Denmark. The 19 design teams are two cohorts, namely the 2004 cohort with 9 teams of 5-7 students and the 2006 cohort with 10 teams. The design task is formulated by the teacher, who is not an author of this paper, as a 'what if'-question. In 2004 the design task was: "What if cars were not allowed to enter the centre of Copenhagen? What means of transportation could be an attractive alternative?" And in 2006 the design task was: "What if the fruit outdoor-market in centre of Copenhagen was to be improved? Can you design more attractive market spaces?" Thus, the design task has an open formulation like a design brief, where a need is not identified and a problem is not specified. It is each design team's task to identify a need and formulate their problem.

In the first project phase each design team collects information based on a socio-technical approach ([12], and [13]), where the design team identifies a relevant actor-network and collects information from the actors. For human actors, e.g. the authorities of Copenhagen, interest groups, citizens and users, the information collection is based on observations of actors in action and interviews. For non-humans actors, e.g. legislative requirements with respect to traffic safety, hygienic when selling fruit and working environment, the information collection is carried out by a discourse analysis of documents. Also, information about existing socio-technical solutions is collected.

The result of the information collection activity is the design team's understanding of the actors' needs, certain design possibilities, the context, certain limitations, and the design team's articulation of what they see as project goal and its argumentation, i.e. a formulation of the design problem. Based on the identified need and formulated problem each design team has to formulate a set of specification statements, and collect these statements in a design specification. In order to prepare the students to write a design specification the teacher gives a short introductory lecture. The teacher describes the design specification document as *the way* to articulate the design goal, which is a good product, and he describes specification statements as either requirements or wishes. The teacher does not describe ways to structure specification statements in a design specification document. Finally, he shows a couple of examples. Then the student design teams begin writing the design specification document. For many teams it is a frustrating process. The team members have to agree upon important goal elements to include into the design specification and imagine feasible solutions. Many teams make unsystematic experiments with different types of statements, e.g. criteria and open questions, and structuring principles of the design specification document. By the end of the writing process each design team hands in their design specification document to the teacher, and the next project phase, which is the synthesis of three design concepts starts. The data material for our analysis consists of the 19 design specification documents handed in.

3 RESEARCH METHOD AND HYPOTHESES

The examination of the 19 design specification documents is carried out in two phases: In the *encoding phase* the documents are read and recorded into an encoding scheme. In the *analysis phase* the encoding schemes are analysed and a number of observations with respect to the structure and content of design specifications are formulated.

The encoding of each design specification document is carried out in four steps:

1. The number of specification statements is counted.
2. The design team's structuring of the design specification document is recorded.
3. Each specification statement is recorded with respect to its object.
4. Specification statements, which express value, are identified.

According to Ericsson & Simon [14] an encoding should be based on a theory. Whereas the two first steps of the encoding are self-explanatory, the two last steps require a thorough discussion. In order to record a specification statement with respect to its object and to determine whether a specification statement expresses value or not, we need a theoretical foundation. The theoretical foundation for the chosen encoding is described in the next two subsections.

The specification object

Since the student design teams collect information based on a socio-technical approach, which involves input from many sources, we expect that specification statements are not narrowly focused on technical properties, but reflect a composite need and problem. Thus, the specification object is a complex entity. As a first step in building a model of the specification object we apply Olsson's [15] normative model of problem analysis. According to Olsson there are four elements to be considered in formulating a problem situation. Firstly, there is *a process*, e.g. a transformation, an action, an activity, or a task, and the design team can ask: what is the process? What does the user want to do? Why? When? Secondly, there is *a result*, e.g. a product or a solution, to be synthesised by the design team. Thirdly, the design team has to consider *the surroundings* in which the solution will be applied or operated. Based on our socio-technical thinking we interpret Olsson's term surroundings as *the context*. And as the fourth element *the human beings*, who are exposed by or exposing the result in its use. Our second step in building a model of the specification object is based on the observation that Olsson is missing a systems theory view upon a problem situation. A core element in systems theory [16, 17, and 18] is the distinction between structural *characteristics* and behavioural *properties*. A system's structure is designed by determining its characteristics, whereas the behaviour of a system is how it reacts to input and how human beings perceive its properties. We expect to find not only specification statements related to properties of the four elements of a problem situation, but also specification statements related to the elements' characteristics. This expectation is based on the observation that in some cases customers and users of consumer products prefer products having certain product characteristics, e.g. the white earphones of an iPod. Thus, we expect that the student design teams during their information collection activity will meet human actors asking for certain structural characteristics as well as properties, and therefore design teams will formulate specification statements related to characteristics and specification statements related to properties of the process, the product, the context, and the human beings. As the third and last step in building a model of the specification object we have to expect some specification statements will be related to product life issues, e.g. maintenance and disposal, and some specification statements will be related to general factors such as legislative requirements. With respect to specification statements related to product life issues or general factors we do not make a distinction between structural and behavioural attributes, because this is not relevant for our analysis. By this discussion we have established our model of the specification object, i.e. a model in which we can encode any specification statement with respect to its object. An overview of the model is given in table 1.

Table 1. We expect we can encode any specification statement with respect to its object.

Object of specification	Structural attributes (characteristics)	Behavioural attributes (properties)
Use process	Use process structure	Use process properties
Product	Product structure	Product properties
Context: Socio-technical system surrounding and interacting with the product	Socio-technical system structure	Socio-technical properties: Social properties Image, experience
Humans interacting with the product	Interaction, way of use	Use value Product qualities
Product life issues	-	-
General factors	-	-

Specification statements expressing value

In order to determine whether a specification statement expresses value or not, we have to explain our understanding of the concept of value. Fishburn [19] writes that the word "value" is used in four different ways in his book on decision and value theory, viz. to indicate a numerical quantification, to describe the possible realisations that a variable can assume, to denote a qualitative impression or expression of worth, importance, or desirability, and to denote a quantification of the concept of worth. In our examination of design specification statements we understand "value" as an expression of worth or desirability, where the worth or desirability is seen from the viewpoints of identified human actors. Thus, the specification statement from a 2004 document "fun for kids to be transported" is identified as a specification statement expressing value.

Hypotheses

Upon the completion of the encoding phase, the encoding schemes are analysed and a number of observations with respect to the structure and content of design specifications are formulated. The overall research questions are: what is the content of a product design specification, which is productive in supporting a designer or design team to synthesise a product idea? And which specification elements articulate the explorative nature of the ideation task?

We base our analysis of the following hypotheses:

1. During the synthesis process the design team gradually determines all product characteristics. However, the product idea, which gives the product its identity and raison d'être, can be identified by few characteristics, mainly concerning use, value, experience, and function.
2. The merit of a product is carried by all characteristics, but the value elements, which provide the product idea an identity and *a difference that matters* [20, 21] are realised by few characteristics dependent on context and existing product solutions known on the market. Such value elements can be of technical, aesthetic, usability, or pleasing nature.
3. If the design team shall use value imaginations as a means to control the synthesis of a product idea, then the team has to formulate a small set of specification statements pointing to value creating aspects; other specification statements have to be seen as generating noise and disturbance at the present stage of the synthesis process.

4 ANALYSIS

After having carried out the encoding, the encoding schemes are analysed. Figure 1 shows the encoding scheme of design team 1, cohort 2006 where the design task was: "What if the fruit outdoor-market in centre of Copenhagen was to be improved? Can you design more attractive market spaces?" In the analysis phase each encoding scheme is read and observations are made to provide answers to our research questions. With respect to the analysis method two comments have to be made:

1. The first author of this paper carried through the analysis of the design specifications documents of the 2006 cohort, and the second author analysed the documents of the 2004 cohort. Then, we discussed and summed up the observations.
2. The way we determine whether a specification statement supports the design team to synthesise a product idea or not, is based on our experience and intuition. We take the role as designers, and check whether we can imagine a solution or an exploration for solutions based on the current specification statement. As an example, the specification statement "a landmark of Copenhagen" from the encoding scheme shown in figure 1 is seen as supporting an exploration for solutions. As designers we could look for landmarks of Copenhagen, and we could identify the city bike system of Copenhagen, where during summertime anyone can borrow a bike for free. Or we could look for landmarks of other cities, e.g. Paris having the Eiffel tower and New York being the big apple, and use this as inspiration. But a specification statement like "long lifetime" does not support an explorative search of desirable product ideas.

4.1 Some observations

In this section we describe the observations we have made during the analysis. We describe four observations, namely an observation regarding specification statements, which support the synthesis of a product idea, an observation with respect to specification statements, which do not support synthesis of a product idea, an observation regarding inconsistency in design specification documents, and finally an observation regarding ambiguous specification statements.

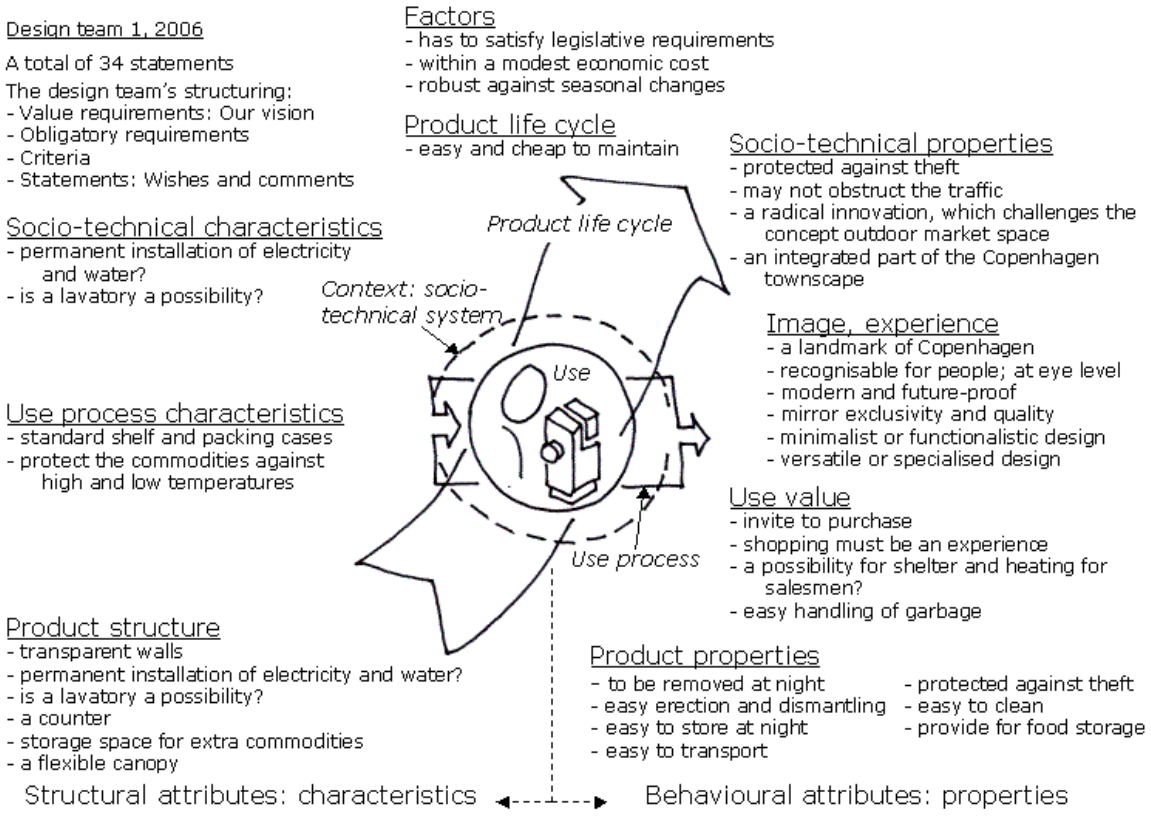

Figure 1. The encoding scheme of design team 1, cohort 2006.

Observation 1: Supportive specification statements

We have observed two types of specification statements, which we consider being supportive for a designer or design team during the activities to synthesise a product idea, namely specification statements expressing value and specification statements related to required function.

Specification statements expressing value

In the design specification document of design team 1, 2006 the first specification statement "a radical innovation, which challenges the concept of outdoor market spaces" articulates a high ambition, and the statement is supported by several value statements: "a landmark of Copenhagen", "an integrated part of the Copenhagen townscape", "invite to purchase", and "shopping must be an experience". By this set of specification statements the design team has formulated a good basis for several explorations to search for a new and attractive product idea.

The document of design team 6, 2006 contains a short introduction, which articulates the team's focus and design intention: "Our focus and interest will be mainly within the development of canopies for stalls." The design object seems to be rather narrow, but the intention is supported by three specification statements expressing value: statement no. 4 "to function in the Copenhagen townscape", statement no. 11 "an open stall with a good possibility to display the commodities; the customers have a possibility to look/walk around", and statement no. 19 "the stall has a radiation and atmosphere (warm-heartedness)". We believe these three specification statements open up for good analytical observations and synthesis-oriented explorations of the solution space. As an example, we will focus on the statement "to function in the Copenhagen townscape". The design team could consider e.g. what are the characteristics of the Copenhagen townscape? Which elements and expressions work within the townscape today, and which do not? Then, the design team could identify all possible types and forms of canopies, and use this as a source of inspiration for sketching new proposals. Similarly, the statement "the stall has a radiation and atmosphere (warm-heartedness)" forces the team to sketch ideas of a warm-hearted stall.

The design team 8, 2006 formulates an introduction in which it is stated, "Our vision/goal is to create a market stall, which is pleasing and functional. It has to be appealing to as many people as possible,

both salesmen, customers, and those, who focus upon the overall townscape." This articulation of the design team's intention contains important elements with respect to value, namely *pleasing* and *appealing*, and mentions that different human actors' viewpoints have to be taken into account. The formulated design intention is not broken down to any value statements, except one, in the design specification document. In case the solution is to be based on a semi-mobile stall, then "it would be fine if the stalls look like each other – to create a 'calm' streetscape". Why this value statement should not apply if a non-mobile or a fully mobile stall solution were to be developed is difficult to understand. We allow ourselves to assume, that is would probably have been beneficial for the design team to formulate some value statements to unfold their design intention in order to inspire and control several explorations into the solution space.
The three examples show the worth of specification statements expressing value as a means to support the design team's activities to synthesise a product idea. Our understanding of a specification statement expressing value was based on the notion of worth or desirability seen from the viewpoints of identified human actors. Our observations have shown that this seems to be a very good way to define 'value statement' in a design specification document. An emphasis on several viewpoints, e.g. salesmen, customers, and authorities, and various surroundings, e.g. the townscapes of Copenhagen, Paris, or New York, inspires the team to explore the situation of the product idea from several perspectives, giving the design team a possibility to "create something new by combining existing elements", which in fact is a common definition of creativity [22].

Specification statements related to required function

We observe that statements related to function are also supportive during the activities to synthesise a product idea. The 2004 cohort worked on the design task: "What if cars were not allowed to enter the centre of Copenhagen? What means of transportation could be an attractive alternative?" Public transportation by bus, tram or train, or individual transportation based on a bike or another kind of human powered vehicle (HPV) are feasible solution alternatives. All the 2004 student design teams decide to focus on designing a HPV. This might be due to the facts that travelling distances within the centre of Copenhagen are relatively small and that there do exist the Copenhagen city bike system during summertime, where anyone can borrow a bike for free for short rides within the centre of Copenhagen; a quite popular service.
In the design specification documents of the 2004 student design teams we found a few specification statements related to required function, which could be supportive during the activities to synthesise a product idea. Design team 1, 2004 writes, "shall the product be able to climb stairs?" Design team 2 writes, " the product shall be applicable when shopping – a lock function to secure the purchased items while the user visits other shops."
The design teams can initiate explorations into the solution space in order to find solutions, which realise the required functions. If attractive solutions are found, and if these solutions can be build into an integrated whole, e.g. a HPV, which can take the user and his purchased items from street level to his apartment, then this integrated whole might constitute an attractive product idea, which is worth developing.

Observation 2: Non-supportive specification statements

During our analysis we have observed many specifications statements, which are not supportive during the ideation activities to synthesise a product idea. In fact it seems to us that some design teams see the design specification document as a memorandum, where every thought has to be noted. However, a lot of these statements, although formulated requirements, criteria or wishes, do not support ideation, or will not be relevant before a certain detailing, or will not be relevant at all due to the nature of chosen solutions.
Design team 2, 2004 writes about their human powered vehicle, "the product shall as far as possible be produced by environmental friendly materials." Teams 3, 4, and 9 have formulated specification statements related to maintenance, e.g. minimal maintenance and easy to repair. Design team 7 writes, "it has to be durable, robust and financially realistic with respect to materials and production."
Design team 4, 2006 writes about their market stall, "resistible to Danish weather: rain, wind, heat, frost." Design team 5 writes, "be proof against Danish weather conditions", "easy to use", and "robust structure."

The Copenhagen outdoor fruit market obviously has attention from the authorities. In the design specifications we find statements with respect to hygienic and fire safety. Design team 2 writes, "the fire department: rescue routes, selection of materials, distance between stalls." Design team 4 writes, "legislative requirements with respect to food must be satisfied; handling of food and hygienic".
The common denominator of all these examples is that the specification statements do not support or inspire explorations into the solutions space, unless the product idea is known. It does not make sense to search for a stall, which is "easy to use" or having a "robust structure", unless the design team has determined relevant product characteristics. For example, is "easy to use" related to erection and dismantling of a mobile stall solution, or is "easy to use" related to displaying and selling fruits from a cargo container stall? Likewise, a "robust structure" could be a core issue for a mobile stall solution, whereas a cargo container stall is born with a robust structure.
This observation indicates that specification statements related to product properties, product life factors, or legislative requirements, are not productive during the early ideation where focus is to synthesise a product idea. However, when the product idea has been synthesised the design team has to consider these specification statements carefully, because some specifications will be important in order to detail and develop a product, and some will not be relevant.

Observation 3: Inconsistent specification documents

As we wrote earlier the design specification document of design team 1, 2006 contains a good basis for synthesising a new and innovative product idea: the specification statement "a radical innovation, which challenges the concept of outdoor market spaces" is supported by the value statements: "a landmark of Copenhagen", "an integrated part of the Copenhagen townscape", "invite to purchase", and "shopping must be an experience".
However, the design specification document of this team also contains a number of specification statements with respect to product structure: "transparent walls", "a counter", "a flexible canopy" and with respect to product properties: "to be removed at night", "easy erection and dismantling" and "easy to transport". These specification statements are problematic, because they point towards the conventional solution in use at the Copenhagen outdoor fruit market. We doubt it is possible to satisfy the ambitious specification statement "a radical innovation, which challenges the concept of outdoor market spaces" based on a set of specification statements pointing to the conventional solution.
The example shows clearly an inconsistency: On the one hand we find value statements supporting explorations for an innovative and challenging product idea. On the other hand we find specifications pointing to the conventional solution. It is probably not easy for the design team to navigate in the solution space based on this set of design specification statements.

Observation 4: Ambiguous specification statements

During the encoding phase we realised that some specification statements were ambiguous with respect to their object. The encoding scheme shown in figure 1 contains three examples: specification statement "protected against theft" can be seen as related to a product property or related to a social property. The specification statements "permanent installation of electricity and water?" and "is a lavatory a possibility?" can been seen as related to either product structure or socio-technical system structure. Are ambiguous specification statements a problem? Roozenburg & Dorst [6] propose non-redundancy as one requirement for specifications. Thus, according to their line of thinking ambiguous specification statements should be avoided. However, if the design team realises that "protected against theft" can be related not only to a product property, but also to a socio-technical property, then two explorations into the solution space are possible. The design team can search for robust technical solutions, which makes it difficult to break into the stall, or the design team can search for socio-technical solutions based on surveillance, e.g. a corps of guards, an agreement between the salesmen to look after not only their own stall, but also the neighbours, or video surveillance, which may decrease the motivation and courage of a burglar to carry through his project.
The ambiguous specification statements "permanent installation of electricity and water?" and "is a lavatory a possibility?" with respect to structural properties, namely product structure or socio-technical system structure, contain an important condition for implement these solutions. If the design team decides on installation of electricity, water, and lavatory in the stall, then the socio-technical system shall deliver access to the electricity network, water supply, and sewer. Thus, also in this case the ambiguous specification statements contain important information.

The specification statement “the stall ought to be easy accessible” of design team 4, 2006 is also ambiguous: easy to locate and come up to a certain stall, or easy to enter the stall? It can be difficult for the design team members to agree on a common understanding of the specification statement, and thereby to reach consensus on a shared goal, unless an open discussion is taken. However, the ambiguity of the statement could also during explorations into the solution space result in surprising possibilities and exiting solutions.

5 IMPLICATIONS ON CONCEPTUAL DESIGN WORK

Our analysis of the design specification documents written by 19 teams of design students during their first semester design project at the Technical University of Denmark has given some interesting and surprising results. We formulated two overall research questions: what is the content of a product design specification, which is productive in supporting a designer or design team to synthesise a product idea? And which specification elements articulate the explorative nature of the ideation task? Our analysis indicates that a productive product design specification in early conceptual design, where the design team has to synthesise the product idea, consists of few statements expressing value, articulating key functions, and important aspects of the socio-technical system in which the solution shall be used. Ambiguous specification statements should not necessarily be avoided during the early ideation activities to synthesise a product idea. They might very well in the ambiguous formulation open the design team’s eyes for unforeseen possibilities and solutions. However, a product design specification, which consists of a lot of specification statements about product structure, product properties, product life issues, or legislate requirements, is not productive in supporting the synthesis of a product idea in the early search. The analysis also showed that based on a design specification document containing inconsistent specification statements it is difficult for the design team to navigate in the solution space, because the specification statements point in different and conflicting directions.
An important factor regarding the validity of the analysis is related to the way we determine whether a specification statement supports the design team to synthesise a product idea or not. We took the role as designers, and checked whether we could imagine a solution or an exploration for solutions based on the current specification statement. But we were not the designers, the student design teams were. Thus, in order to make a more proper justification of our analysis result a comparative study of the student design teams’ synthesis results from “good” and “bad” specification behaviours would provide strong evidence. It is unfortunately not possible for the authors to carry through such a comparative study because our data material does not contain the design concepts synthesised by the student design teams. Such a comparative study will be made next year when the 2007 cohort of first semester undergraduate students of the design & innovation study programme at Technical University of Denmark is carrying through the design project.
Although we realise that the analysis results are preliminary and not yet fully justified, we will use the results to formulate instructions to design students about the content and structure of a design goal formulation, which is supportive during the ideation activities to synthesise a product idea. Some instructions are briefly outlined here:

1. Formulate several value statements. Describe “the good product” seen from the different, important human actors’ viewpoints.
2. Formulate statements related to required functions; i.e. describe what the product has to do. A product with improved and enhanced functionality is often considered superior in the eyes of human actors.
3. Try many different ways to interpret and satisfy a specification statement. Any specification statement may by accident be ambiguous in its formulation. If you are lucky the ambiguity results in surprising possibilities and exiting solutions.

Further, it is always important to minimise the risk of inconsistencies in a design goal formulation, because it is difficult for a design team to navigate based upon inconsistent statements. Two means to reduce the risk are given here:

1. The design specification document could be supplemented with a verbal problem formulation or design brief, where the team formulates their overall design intention. A problem formulation could contain the following elements: the perceived need, the chosen design perspective and task, the design goal to obtain, and an outline of the design approach. Such a verbal problem formulation would be an invaluable tool for the design team to identify and keep focus on the task, the product’s raison d´être, and key specification statements. In this way the confusing

inconsistency could evaporate.

2. Our second proposal is based on the idea that it must be possible to structure the specification document so the inconsistency problem decreases. The design team 2, 2004 has created an interesting structuring: “requirements”, “criteria”, and “considerations to be treated later”. This structure has a nice property. The design team can write down all specification statements based on a simple heuristic, namely specification statements with respect to product structure, product properties, product life issues, or legislative requirements shall be classified as “considerations to be treated later.” Thus, these specification statements are neither forgotten nor disturbing the team’s explorations for a product idea.

It is our intention that the teacher can use these instructions in next year’s design project. We expect this will help the design teams to articulate their design goal formulation in a form, which will prove supportive during the ideation activities to synthesise a product idea.

6 CONCLUSION

In this paper we have presented an empirical study of design specification documents. The purpose of the study was to enhance and improve our understanding of the nature of design specifications as a means to support a designer or design team during the early ideation activities to synthesise a product idea. Our empirical study consists of a literature study and an analysis of design specification documents of 19 teams of novice designers. In the literature study we observed some differences between the influential textbooks’ descriptions of the product design specification’s structure and content as a means to articulate design goals and support the design team in reaching the goal, and the outcome of empirical studies of individual and team design work. The empirical studies have identified complexities in design work, which have not been taken into account in the textbooks’ descriptions. We analyse the structure and content of design specifications during early ideation activities, where initial design specifications are formulated and a product idea is synthesised.

Our analysis indicates that a supportive product design specification ideally seen should consist of few specification statements, which express value, important aspects of socio-technical context, and articulate key functions, in order to support the ideation activities to synthesise a product idea. Many specification statements about product properties, which are typically found in a product design specification, do not support the designer or design team in exploring the solution space until the product idea is known. Ambiguous specification statements are not necessarily a problem for the design team. On the contrary, ambiguity of a specification statement could during explorations into the solution space result in surprising possibilities and exiting solutions.

The contribution of this paper enhances and improves the knowledge within our research community on the nature of design specifications as a means to support the ideation activities to synthesise a product idea. Our empirical study indicates, that the formulation of a mindset about product design specifications to support innovative ideation should emphasise few specification statements expressing value, the socio-technical context, and key functions, if the designer’s or design team’s focus is to carry through explorative searches into the solution space in order to synthesise a product idea. Requirements for design specifications documents such as comprehensive, complete, operational, non-redundant and minimal are not relevant at this early stage of the design process.

The authors believe that this paper contains an interesting supplement to design theory, and we have established a first justification of our empirical study. The next steps in our research will be to make a comparative study of the cohort 2007 student design teams’ synthesis results from “good” and “bad” specification behaviours as a means to provide a stronger evidence for the analysis result, and to formulate a set of instructions based on the insights obtained so far. This set of instruction will applied in next year’s first semester design project, and it will be interesting to study the effect on the design teams behaviour as a means to justify our results from a design practice perspective also.

REFERENCES

[1] Hansen C.T. & Andreasen M.M. Towards a theory of product design specifications. In *Proceedings of NordDesign 2004 Conference*, Tampere, August 2004, pp. 9–20, (Tampere University of Technology, Product Development Laboratory and The Design Society).

[2] Pahl G. & Beitz W. *Engineering design*, 1984 (The Design Council & Springer-Verlag, London).

[3] Roozenburg, N.F.M. & Eekels J. *Product Design: Fundamentals and Methods*, 1995 (John

Wiley & Sons, Chichester).
[4] Cross N. *Engineering Design Methods. Strategies for Product Design*, 3rd edition, 2000 (John Wiley & Sons, Chichester).
[5] Ulrich K.T. & Eppinger S. *Product Design and Development*, 1995 (McGraw-Hill Inc., Singapore).
[6] Roozenburg N.F.M & Dorst K. Some guidelines for the development of performance specifications in product design. In *Proceedings of International Conference on Engineering Design 91*, Zürich, August 2001, pp. 359 – 366, (HEURISTA).
[7] Andersson F. *The Dynamics of Requirements and Product Concept Management. A Product Modelling Approach*, 2003, PhD-thesis, Chalmers University of Technology, Sweden.
[8] Lawson B.R. Cognitive Strategies in Architectural Design, *Ergonomics*, 1979, 22(1), 59-68.
[9] Kruger C. & Cross N. Solution driven versus problem driven design: strategies and outcomes. *Design Studies*, 2006, vol. 27, no. 5, pp. 527 – 548.
[10] Restrepo, J. & Christiaans, H. Design requirements: Conditioners or conditioned? In *Proceedings of 14th International Conference on Engineering Design*, Stockholm, August 2003, (CDROM) pp. 1-10, (Design Society).
[11] Almefelt, L., Andersson, F. et al. Exploring requirements management in the automotive industry. In *Proceedings of 14th International Conference on Engineering Design*, Stockholm, August 2003, (CDROM) pp. 1-14, (Design Society).
[12] Bijker W.E. *Of Bicycles, Bakelites, and Bulbs. Towards a theory of Sociotechnical Change*, 1997, (MIT Press, Cambridge, MA).
[13] Latour B. *Pandoras Hope. Essays on the Reality of Science Studies*, 1999, (Harvard University Press, Cambridge, MA).
[14] Ericsson K.A. & Simon H.A. *Protocol Analysis – Verbal Reports as Data*, 1996, (A Bradford Book, MIT Press, Cambridge, MA.).
[15] Fredy Olsson K.G. *Systematic engineering Design*, [in Swedish], 1976, PhD-thesis, Lund University of Technology, Sweden.
[16] Klir J. & Valach M. *Cybernetic Modelling*, 1967, (Iliffe Books, London).
[17] Chestnut H. *Systems Engineering Methods*, 1967, (John Wiley, New York).
[18] Hall A.D. *A Methodology for Systems Engineering*, 1962, (Van Nostrand, Princeton).
[19] Fishburn P.C. *Decision and Value Theory*, 1964, (John Wiley & Sons, Inc., New York).
[20] Hansen C.T. & Andreasen M.M. The content and nature of a design concept. In *Proceedings NordDesign 2002*, Trondheim, August 2002, pp. 101-110, (Department of Machine Design and Materials Technology & Department of Product Design Engineering, NTNU, Trondheim).
[21] Hansen C.T. & Andreasen M.M. A Proposal for an enhanced design concept understanding. In *Proceedings of 14th International Conference on Engineering Design*, Stockholm, August 2003, (CDROM) pp. 1-10, (Design Society).
[22] Chakrabarti A. Defining and supporting design creativity. In *Proceedings of the DESIGN 2006 - 9th International Design Conference*, Dubrovnik, May 2006, volume 1, pp. 479 – 486, (Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb & The Design Society, Glasgow).

Contact: C. T. Hansen
Technical University of Denmark
Department of Mechanical Engineering
Engineering design and product development
Nils Koppels Alle, building 404
DK-2800 Kongens Lyngby
Denmark
Phone: +45 45 25 62 73
Fax: +45 45 93 15 77
e-mail: cth@mek.dtu.dk