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A MODEL OF DESIGNING AS THE INTERSECTION BETWEEN UNCERTAINTY PERCEPTION, INFORMATION PROCESSING, AND COEVOLUTION

S. V. Lasso, P. Cash, J. Daalhuizen and M. Kreye

Keywords: uncertainty perception, information-processing theory (IPT), co evolution

1. Introduction

A number of fundamental perspectives on designing have been described in the literature, in particular problem/solution coevolution and information use. However, these different perspectives have to-date been modelled separately, making holistic description of design activity difficult. This paper takes the first steps towards linking these disparate perspectives in a model of designing that synthesises coevolution and information processing.
How designers act has been shown to play an important role in the process of New Product Development (NPD) (See e.g. [Badke-Schaub and Frankenberger 2012]). Modelling design activity in NPD is typically done in one of three ways; object-, subject- or process oriented. First, it can be modelled by focusing on the object of design: the product. Second, it can be modelled by describing the social interaction and knowledge exchange between actors. Third, design activity can be modelled by describing the steps and phases that entails a specific design activity [Bedny and Harris 2005].
In all aspects and stages of the NPD process, uncertainty plays a key role both within the project itself as well as in relation to the project environment [Huang et al. 2015]. In order to resolve uncertainty, both individuals and teams need to engage in decision making. In the case of decision making in a team, there is also greater scope for uncertainty, since personality and cognitive style influence decision making [Dewberry et al. 2013] and every person has a different perception of uncertainty. This difference can for example lead to a lack of agreement on the best solution. In NPD projects information is used to minimize the uncertainties inherent to innovation [Stockstrom and Herstatt 2008], [Huang et al. 2015], however, it is important to accept that there are uncertainties that can not be minimized and are inherent to the project itself [Ullman 2009].Thus, in NPD, the designer's activity is impacted by a wide range of variables.
First, uncertainty is significant both inside and outside the project (as in the market for example), and is perceived and acted upon by the designer. Uncertainty perception can be connected to personal characteristics and cultural background, as well as experience and domain specific knowledge. The designer may perceive uncertainty arising from the design of the artefact, from the market, from consumer use, from prototyping, and others.
Second, the designer's perceived uncertainty is the motivation to start a process of collecting, exchanging, and integrating knowledge. This has been formalised in Information-Processing Theory and more generally described by authors such as Aurisicchio et al. [2013] who describe design as an information transformation process. Here the aim of the activity is to reduce the perceived uncertainty

through identifying and integrating external information and knowledge within the design team. For example, when perceiving uncertainty the designer might seek new information online, process this information, and share with their team in order to assess e.g. opinion, after that they process this knowledge and information together with their interpretation, giving a context to it and finally analysing if the new knowledge is helpful.

Third, the designer's perceived uncertainty might also be the motivation to start a process of synthesizing information and ideas into new design propositions through the process of simulation. That is, design work is characterised by an iterative process between problem and solution space, also termed *design coevolution* [Poon and Maher 1997], [Dorst and Cross 2001]. This describes how problem and solution coevolve over time and have a mutual effect on one another, helping the designer to resolve high levels of uncertainty [Christensen and Ball 2013].

Thus in resolving NPD projects two fundamental processes are the manipulation and evolution of the problem and solution spaces [Christensen and Ball 2013], and the transformation of information [Aurisicchio et al. 2013]. However, prior research has traditionally modelled these perspectives separately; making holistic description of designer activity difficult. Thus, the aim of this paper is to propose a model that links design coevolution and information processing via uncertainty perception. This brings us to the following question: How are coevolution, information processing, and perception of uncertainty connected?

The paper is structured in the following way. First, it presents the definitions and literature review of Uncertainty Perception, Information Processing, and Coevolution highlighting connections between them. The proposed model is then presented and explained. The paper closes with conclusions, limitations, and suggestions for further studies, including testing of the model itself.

2. Uncertainty perception

Walker et al. [2003] defined uncertainty as "any departure from the unachievable ideal of complete determinism". This is differentiated from risk by Blau and Sinclair [2001] using a metaphor about weather. Here, uncertainty is the possibility of rain, it cannot be changed; and risk is the possibility of being caught in the rain with no umbrella, it is a consequence. Thus, even when effectively managing the uncertainties within an innovation project there is always the risk of problems or failure.

Focussing on the sources of uncertainty, Ullman [2009] describes information uncertainty as having three sources: human cognition, environment, and variation.

The *human cognition* source can have five causes. The first is limited knowledge, as uncertainty comes from a lack of knowledge and the more knowledge one has the fewer uncertainties they will have. The second is approximations, related to the models that are made, which are not true representations of reality. The third is the viewpoint differences across the various team members. The fourth is terminology imprecision and the misuse of terms. The last is disagreement amongst team members.

With respect to the *environment* source, Ullman [2009] states that it is driven by the organization itself, with two main causes. The first is other projects, where one project can depend on others. The second is organization priorities and procedures, where companies alter a project according to changing priorities.

The last source is *variation* with four causes: statistical, aging, environment, and measurement of errors. The first is connected to the random nature of the behaviour of things. The second is related to the variation of time, as for example the duration of things. The third is about the environment and how it can change things, as for example the weather. The fourth is connected to statistical mistakes when doing measurements.

Other frameworks exist in the literature, such as Walker et al. [2003] who focus on three dimensions of the uncertainty: location, level, and nature of uncertainty (epistemic and variability); Kreye et al. [2011] who classified uncertainty in five layers: nature, cause, level, manifestation and expression; or De Weck Olivier et al. [2007] who focus uncertainty related to the internal or to the external world of the individual. However, an exhaustive review of uncertainty is not necessary for this work because although there are multiple types and sources of uncertainty, they can only influence activity after they are perceived. As such, the proposed model in this paper will focus on the designer´s perceived uncertainties as they form the driver for the designer’s activities and decisions.

It is important to notice that uncertainty perception is distinct from the sources of uncertainty in that each person has a different perception due to personal and cultural characteristics [Doctor et al. 2001]. Uncertainty perception is a process that happens in the designers' work, and finding a way to deal with high levels of perceived uncertainty in a productive way can be challenging, especially during decision making.

It is important to better understand how the designer deals with uncertainty perception in a NPD project since, new product development is both relevant to overall business success and highly uncertain [Hjalmarson et al. 2007], [Stockstrom and Herstatt 2008]. Thus there is a need to understand how designers act and can subsequently be more effectively supported/managed in this context.

Perception of uncertainty is connected with the two reasoning systems explored by Sloman [1996] and Osman [2004], where one system is intuitive and the other is analytical. Both systems work together when dealing with uncertainty perception and decision making. They are also influenced by personal characteristics [Kreye 2015]. Personal characteristics are a filter through which designers see and perceive uncertainty, as each person has different background and individual characteristics, each has a different filter to see, perceive and deal with uncertainty.

Perception of uncertainty can be personal or shared with the team, and influences the activity and decisions taken in a project. It is the perception of uncertainty that drives action related to information or design; therefore, it is relevant for the designers work to know what processes the uncertainty perception drives as well as how the designers deal with these processes in reality. Specifically, uncertainty perception is linked to information processing since it triggers the search for new information and knowledge; and to problem/solution coevolution through interaction with the artefact, once the problem brings the motivation and the uncertainty.

3. Information processing

For the designer, information is a key part of their work, since without it they can not progress the project. When seeking for information, which includes both acquisition of information and information processing, the designer gains knowledge. According to Dervin [1998], knowledge is value. It gives value by providing answers that can minimize the designer’s uncertainty and through those answers allows him or her to progress the project towards completion.

While seeking for information, the designer will select and collect new information from multiple sources. For example, when a designer is motivated to design an artefact to hold rainwater, he or she might be uncertain about how rainwater could be collected in an appropriate way. The designer might seek information via various sources like internet, articles, and books in order to help them progress the project.

After finding information, the designer must process and internalise it. Here, the designer will process the new information in terms of in how it might help to come to a solution. The designer's background, previous knowledge and personal characteristics, etc. will influence the way the information is processed and give context to it. As a result, the processed information might help the designer to see one or more solutions

The information processing concepts have been brought together by Cash and Kreye [2014] in their information-processing cycles. The cycle starts when a designer has a problem (or perceives uncertainty); the individual seeks information, through acquisition and processing. In the first case, the individual will acquire new information through books, Internet or other sources and will collect this new knowledge with their existing knowledge.

During processing, the individual will interpret the new knowledge, learn and give a context to it. It is possible that the new knowledge will not be enough and they will go back to information seeking. It is also possible that the new knowledge will alter his/her notion of the problem and make them go back to give a new perspective on it, which can also alter the information that they will seek next. After seeking information, finding it and interpreting, the individual can pass to the knowledge exchange with his/her team, which can be informal, formal, implicit or explicit. When exchanging knowledge with others, team members typically experience high levels of uncertainty, as they perceive the situation from different, idiosyncratic perspectives. Going back to the example, the designer would share with his/her colleagues his/her findings and ideas for the water collection artefact and would gain feedback on it.

This feedback, after being processed, can lead to him/her perceiving new uncertainties, or to change the problem or the solution.
According to Ullman [2009] decisions can be made by individuals or the team. Product development decisions are typically complex as not all the possibilities are known and not all information is available. As a result, there is often disagreement between team members. . Thus, uncertainty perception can drive a process of information seeking, processing, and exchange influencing both activity and decision making as illustrated in Figure 1 (adapted from [Cash and Kreye 2014]).
Here we explicitly extend this framework by adding problem and solution to the more general conceptualisation of uncertainty previously used by Cash and Kreye. This further links the model into the design domain and gives a significantly refined comprehension of it. The connection between the iterative loops was also added, since it is relevant to know how the loops are connected, relate to, and interact with each other.

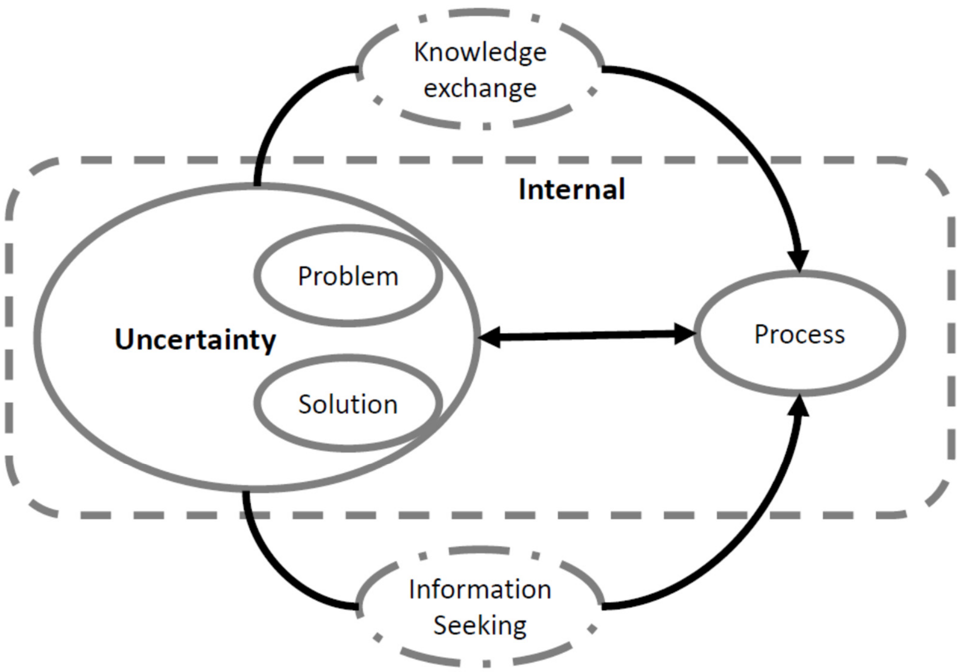

Figure 1. Information processing and uncertainty

4. Coevolution of problem and solution

The concept of coevolution originated in biology where it is used to describe the mutual development of one species in response to another; their interaction and adaptation [Janzen 1980]. Taking this concept out of biology, Maher and Poon [1995] researched the fitness function in the problem-solution process. They worked with two spaces: the problem space and solution space.
In design, it is necessary to develop the solution, yet it often involves the reframing of the problem as well (see e.g. [Dorst 2011]). This process implies that the problem is not something fixed but will evolve as the solution space is being explored.
Dorst and Cross [2001] have shown that as a solution is being developed, it can change the view of the problem, often triggered by the introduction of 'surprise' solution spaces. This complements the notion of Maher and Poon [1995] of the problem/solution as an interactive process and not static and finite, with only the movement from problem to solution. Thus in design, coevolution refers to the process a designer starts with an idea for the problem and develops the solution. The new solution then alters the first idea of the problem. They use ideas and information to better understand these spaces and subsequently try to find a solution and test it to see if it is a fit solution. If not, they start to look for

another solution or problem formulation, as an interactive process [Maher et al. 1996], [Maher and Poon 1996], [Maher 2000].
As a result of the flexibility of the problem-solution process, it is possible to have coevolution transitions including problem to problem (when the problem creates a new problem), problem to solution, solution to problem (when the solution changes the problem) and solution to solution, only finishing upon finding of an appropriate solution or several solutions.
Wiltschnig et al. [2013] describe a change in the definition of the problem as an effect of the solution, which can happen for numerous reasons, such as an inaccurate understanding of the problem itself, lack of prior knowledge, and new technology in the market. Linking these back to uncertainty and its subsequent perception, it is possible to link the coevolution of problem and solution to a designer's uncertainty perception at a fundamental level.
In particular, simulation plays a key part in the coevolution process. Simulation in design is described as a practice by which a designer brings certain elements of an idea to life, in order to be able to evaluate its value in relation to the design goal. Simulation is a key element of the design cycle, as it can be seen in Figure 2.The basic design cycle consists of the following basic activities: analysis, synthesis, simulation, evaluation, and decision. With simulation, the designer can bring to reality his/her ideas and see their interactions and connections, which allows him/her to have a better understanding of both problem- and solution space and help in his/her decision making process.

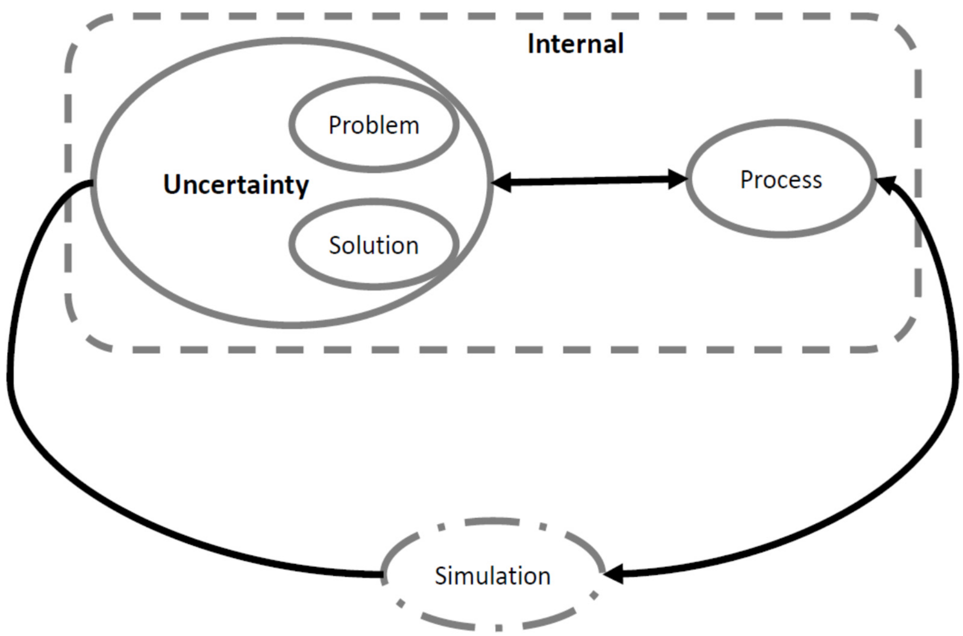

Figure 3. Coevolution and uncertainty

Thus as with information processing, the perception of uncertainty is part of the coevolution process as it influences its progression and drives designers to synthesize, simulate and evaluate ideas. As this process unfolds, new uncertainties might arise in the mind of the designer as the problem- and solution spaces interact with each other. In addition, when carrying out simulations, new uncertainties can be perceived. This is driven by new perspectives that emerge when the designer tries to put his/her ideas into reality and compares them to what they initially thought about the problem or expected from the solution. From the example used above, one simulation would be to make a simple prototype of the rainwater holder, which would give the designer insights that after being processed can alter their perception of the problem, the solution, the uncertainty associated with the design.
As coevolution happens, new knowledge is built within a person or a team [Rosenman and Saunders 2003]. The process of coevolution is fundamentally linked to uncertainty perception, particularly in the

problem and solution domains. This is simplified and illustrated in the model in Figure 2, which was built by linking the expanded coevolution conceptualisation (problem, solution, and uncertainty) to simulation. Again, connections between these elements were identified in order to characterise their interactions and relationships.

5. A model of the design process

In design, information processing and coevolution occur simultaneously and influence the designer's perception of the design task and the developed artefact. Thus, to acquire a more comprehensive understanding of the design process, the three constructs of uncertainty perception, information processing, and coevolution can be integrated to better depict their interdependencies and roles in the design process. It is possible to see in Figure 3 that the proposed model is a development that brings together the various elements highlighted in Figures 1 and 2, in order to link and integrate these constructs and their interactions. In this context, it is possible to see uncertainty as a common link between the two processes described in Sections 3 and 4. This section describes the proposed model and discusses the implications for research and design practice.

5.1 The proposed model

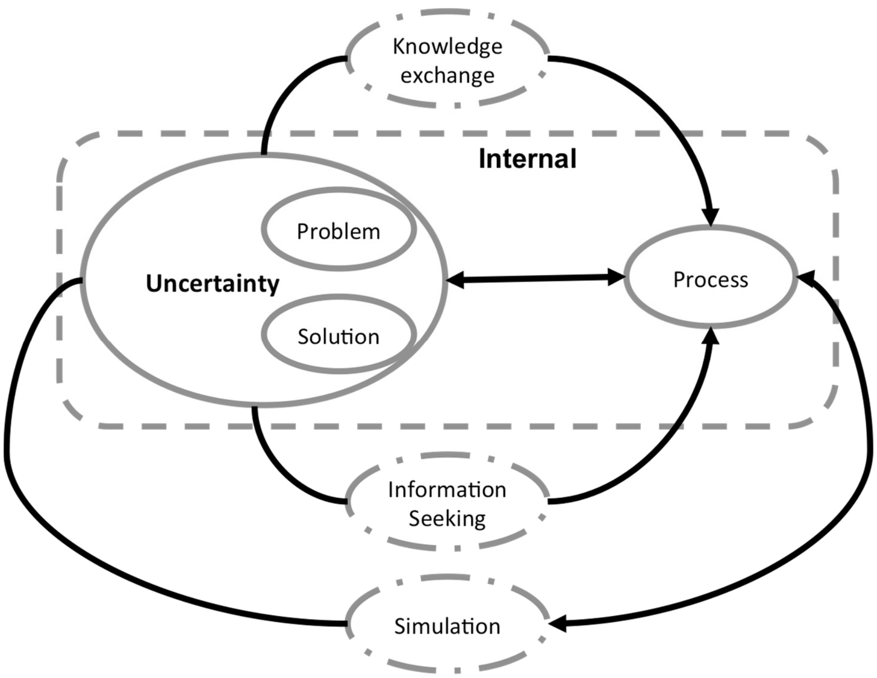

Figure 3. The proposed model integrating coevolution and information processing cycles

In this model, the process starts with uncertainty perception – as in the example of the rainwater holder artefact. Uncertainty perception can be seen as one of the motivations or triggers for the process to start. Uncertainty perception refers to the designer's understanding when perceiving in his/her project something that they feel unsure about, lack knowledge on or which raises unexpected questions. In the example of the designer building the rain water holder, perception of uncertainty can come from e.g. the structure of the artefact, which might make the designer question which structural form would hold more rainwater.

Uncertainty, problem, and solution are clustered since they are all aspects of the designer's perception and they are all altered over the course of the design process. The way that they are perceived differs between individuals and is influenced by many factors, including gender, age, culture, and personal background, and is connected intrinsically to the individual With respect to information, two loops can happen: information seeking and knowledge exchange.

The designer can seek information to better understand the problem and solution, also trying to reduce his/her uncertainty perception based on multiple sources as books, internet or even previous experience; and/or they can exchange knowledge with their team or colleagues. These loops can happen sequentially or in parallel and both provide new information for the designer by feeding into the processing stage.
In the processing stage, the new information (either acquired or exchanged) is processed by the designer to see if it will be used or not based on their interpretation and prior knowledge. Based on this, the designer's perception of the problem, solution, and overall uncertainty can change. In processing new information, the designer can have insights about his/her perceptions as well as developing a new point of view or opinion, thus creating a recurring loop between processing and the cluster of uncertainty, problem, and solution perception.
Finally, with respect to coevolution the simulation loop can be seen as an interaction with a prototype, a draft, a drawing, or any attempt to bring ideas and insights into reality. This loop can again give the designer new perceptions of uncertainty, problem, and solution, by allowing them to explore the artefact and generate a different point of view. Again, simulation leads back to processing, since its result need to be processed for the designer to know if the simulation was satisfactory, if it changes his/her perception of uncertainty, problem or solution or if he needs to be improved.

The model in context

The model can be seen as a learning process if in each loop the designer will learn and reduce or modify his/her uncertainty though the interaction with the external world, the designed artefact, and information that is being sought and processed. Thus the model shows the internal world of the designer and the external world interacting through knowledge exchange, information seeking, and simulation; with these interactions affecting designer's internal world.

The model over time

The cyclical loops proposed by the model can happen several times until the designer finds a suitable solution, reduces his/her uncertainties or decides to accept the uncertainty that is within the design/project. The process can start at any loop point and can also finish at any loop point, having no specific start or finish.
Further, the loops can happen simultaneously or sequentially, and one loop does not exclude the other, as all of them can happen in the cycle or not. In the case of the designer and the rainwater holder, as they seek information, they can also talk to their colleagues about the project, thus doing the information seeking and knowledge exchange in parallel.
It can also happen that the designer does the information seeking and after processing, the new information acquired decides to do a simulation and not share the knowledge, thus not completing the knowledge exchange loop.

The model in practice

In practice, it is possible to see the proposed model as the foundation for design process management tools similar to other fundamental conceptualisations of design work, such as CK Theory. In particular, the illustration and connection of the process loops point key implications for designers. For example, it is possible to use the model to help balance design work (iterations through the loops) and to guide reduction of designers' uncertainty perception. Further, by helping to better understand the design process itself it helps the designer to understand and reflectively improve his or her own design work.

5.2 Implications for research

The proposed model, seeks to help improve the understanding of uncertainty perception and how it drives fundamental aspects of design work.
Thus combining information processing and coevolution brings together parts of the designer's activities and has previously been mapped separately. Thus, this model gives a broader vision of the designer's processes and interactions.
The proposed model also brings together aspects of design and information theories that have previously been considered separate via the unifying concept of uncertainty perception.

This highlights significant potential for further research in the role of uncertainty perception as a driver for design activity and as a possible means for creating more cohesive design theory.
Finally, the model extends both information processing and coevolution frameworks to develop a new perspective on design work. This opens the possibility for further study of design activity and management based on assessment of external uncertainty and its perception within the design team.

5.3 Implications for design practice

When linking coevolution and information processing it is possible to better support NPD projects, via a unified focus on uncertainty perception. Also, by mapping the designer´s interaction, and loops of seeking, exchange, and simulation, it is possible to achieve a broader understanding of the designers' work, his/her interactions with the external world, and how knowledge is created to minimize his/her uncertainty perception.
This can point to potential management strategies built round supporting uncertainty reduction and facilitating all three loops, by balancing them. For example, if information seeking is more used in the process, balancing it with knowledge exchange and simulation could make the process more efficient. However, further work is needed in order to offer concrete guidance in this context.

6. Conclusions

This paper proposes a model of designing as the intersection and interaction of uncertainty perception, coevolution and information processing. The proposed model contributes to design, management, and new product development research by linking two aspects of design work through uncertainty perception in one model, with the internal world of the designer in the centre.
The proposed model thus provides a more complete vision of design work by bringing together fundamental process elements previously discussed separately.
Future research is needed to test the model first via qualitative exploration of its role in a designer´s real world work, and then quantitatively based on derived hypotheses. Further, due to the core role of uncertainty perception there is a need for future research on how this perception differs depending on the designer´s e.g. background, gender, age, and culture. These were not added to the current model because further work is needed in order to identify all of the influencing factors and their relation to uncertainty.

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Sarah Venturim Lasso, PhD student
Danish Technical University (DTU), Department of Management Engineering- Technology Innovation Management
Diplomvej 372, 2800 Kongens Lyngby, Denmark
Email: salas@dtu.dk