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

A MODEL OF DECISION-MAKING KNOWLEDGE IN CONCEPTUAL DESIGN

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ABSTRACT

Systematic models for concept evaluation and selection have been proposed for decades to support decision making. However, in conceptual design, engineers do not always approach decision-making in a systematic manner as these models propose. The area of decision-making in conceptual design still does not seem to have many pieces of research that can serve as a theory base, especially in terms of understanding the role of knowledge in decision-making. The objective of this paper is to propose a model of the forms of knowledge involved in decision-making and their relationships. A coding system of decision-making in conceptual design that can be used to explore the role of knowledge in decision-making has been developed. The model shows that engineering designers make tentative decisions based on tentative knowledge. Knowledge plays a fundamental role, since decisions become validated as the knowledge does, and hidden assumptions are not proved wrong. The results have important implications on decision-making traceability and decisions storage.

Keywords: decision-making, conceptual design, design experiments, protocol analysis, knowledge

1 INTRODUCTION

Hatamura [1] points out that the reason why it is necessary to describe the decision process of inventing a technology is that just looking at an established technology does not allow people to reach a real understanding of it, to use it and to develop it further; but that, in fact, to enable such further steps, it is necessary to see the process of giving birth to the technology, especially the process of making decisions. This means that the inventor needs to record the mind process in a form that can be communicated to other people. In industry, decision-making traceability is becoming increasingly important, e.g. [2].

Another reason why it is important to describe the decision process is that it is necessary for researchers if they want to produce useful tools or guidelines to support designers.

To improve decision-making traceability and decision-making tools, we need to understand decision making, and in order to understand it, we must be able to analyse and describe it. There is much interest among researchers in providing support related to product knowledge to aid designers in making better decisions, but the role of knowledge in decision-making remains largely unexplored.

Systematic models for concept evaluation and selection have been proposed for decades to support decision making, e.g. [3]. However, in conceptual design, engineers do not always approach decision-making in a systematic manner as these models propose. The area of decision-making in conceptual design still does not seem to have many pieces of research that can serve as a theory base [4], especially in terms of understanding the role of knowledge in decision-making.

2 OBJECTIVE

The objective of this paper is to propose a model of the forms of knowledge involved in decision-making and their relationships. A coding system of decision-making in conceptual design that can be used to explore the role of knowledge in decision-making has been developed. The coding system is based on literature study and the analysis of a video-taped team-design experiment.

3 RESEARCH METHODOLOGY

The methodology has three steps:

- Definition of a coding system to analyse the relationship between knowledge and decision-making. It has been made by means of a literature study on decision-making in design and observation of a recorded design session to decide a way to code a team taking design decisions. Then, the coding system has been applied to this design session.
- Study of the reliability of the coding system. It has been applied by a third person for validation of its reliability. The coding system is reliable if the same results are obtained to a reasonable extent. The percentage of agreement is studied.
- Analysis of the protocol. Finally, the coded experiment has been studied. This analysis has resulted in the proposal of a model of decision-making knowledge.

4 DEFINITION OF THE CODING SYSTEM

4.1 State of the art of evaluation in conceptual design

In the literature, it is stated that when evaluating between alternatives, all of them should be developed to the same level and represented in an external form [5]. However, Ahmed and Hansen [6] have observed designers evaluating designs that had yet to be externalised. The designers did not externalise their design alternatives unless their evaluation had been successful; if not, they would generate another design alternative. Hence, evaluation is done between alternatives in a “synthesise and evaluate activity”.

In the same line of thought, Dwarakanath and Wallace [7] had observed, in an empirical study of design work within an experimental setting, that individual designers tend to apply a single-string solution-oriented approach, where alternatives are not considered unless the pursued direction in the solution space is recognised to be infeasible.

This is what Stacey et al. [8] call premature focus. They discuss that design is also characterised by modification of similar products, following habitual paths, and the description of new designs with reference to previous similar designs.

In this respect, Derelöv [9] contends that depending on the status of the design process, the alternative solutions are defined at different levels of detail. In the early phases when solutions are characterised by non-quantifiable, unclear and incomplete information, they are often addressed as concepts. Later in the process when solutions are more quantifiable, detailed and concrete, they are denoted as products. The difference in characteristics reflects the possibilities of conducting a systematic evaluation on each level respectively. Ullman [10] had already distinguished between concept and product evaluation. For the concept evaluation, the goal is to use the least number of resources on deciding which concepts have the highest potential for becoming a quality product. The difficulty is to choose on which concept to spend time developing when the information that the selection is based on is strongly limited. Product evaluation, however, is more about determining, with certain validity, the performance of the product, and comparing it with the specification, the performance being interpreted here as the measure of function.

It can be concluded that some authors in the literature have identified non-systematic evaluation behaviour in conceptual design. We argue that in conceptual design, evaluation can be non-systematic and one central reason for this is the lack of knowledge; problems are not always sufficiently clear or defined to enable the application of systematic rules to evaluate solution proposals uniformly, and make a selection. For instance, Nidamarthi et al. [11] observed solution generation alternatives with subsequent evaluation for the purpose of clarification of the problem during early stages of design. In such cases, using a systematic procedure might take excessively long in absence of adequate information. Instead, premature focus on concepts has been observed, meaning that designers have been seen not going through a process of considering many solutions to select the best, but considering one or few solutions (based on previous ones) that are perceived as potential carriers of the pursued objectives. This paper focuses on the relationship between knowledge and decisions in non-systematic decision-making.

4.2 What is *making decisions in conceptual design*?

4.2.1 To “decide” understood as the activity of selecting

In literature, two views of decision-making have been found. In the first view, to “decide” has been understood as to “select”. In this line of thought, decisions have been grouped into three types [1]:

- Go or no go. There is only one choice to begin with and the decision is whether or not to do it.
- Single selection. One option is selected from multiple choices.
- Structured decisions. It is the state with multiple nodes, each with multiple choices, and selecting one option at each node leads to a structured route.

Derelöv [9] discusses two possible evaluation approaches, which can be applied to Hatamura's single selection and structured decisions:

- Exclusion of improper solutions. It focuses on the limitations of a solution, e.g. their shortages or disadvantages.
- Selection of fittest solutions. A common interpretation of this approach is the systematic comparison of the solutions with characteristic criteria, which have often been derived from the design specification.

In the first case, a comparison is more complicated. The alternative solutions could be derived from different base-technologies, each with their own set of problems. This indicates that the basis for the evaluation might originate from the solution, rather than from the task [9, 11]. In the second case, solutions are most of the times evaluated on the same basis, with the same criteria. A comparison is, in other words, relatively easy to execute. However, as discussed in the previous section, this systematic approach does not seem to be applicable in all cases of conceptual design, and *it is not applicable to the case being studied in this paper*.

4.2.2 Decision-making understood as a way of seeing the whole design activity

In the second view, a number of authors consider decision-making as a way of seeing the whole design activity. The decision-making process is considered to take place over a period of time that finishes when the decision has to be taken or when engineers feel there is sufficient certainty in the decision; but not at a distinct moment during that period. Hansen and Andreasen [4] contend that engineering designers make a tentative decision based on the available information. As new criteria and clarifications emerge, which to a satisfactory level support the tentative decision, it will be considered verified, and "the decision is made". According to them, during the decision process there are several decision-makers, and there are many stakeholders, which act as decision-makers influencing the design process and its outcome.

In accordance with this view of decision-making, Andreasen and Hansen point out that *to evaluate*, *to validate*, *to navigate*, and *to unify* are sub-activities, which result in a basis for making a decision. Hansen and Ahmed [6] have developed an encoding system of decision-making activity, which distinguishes the following sub-activities within the activity of decision-making:

- Specify: a statement concerning compilation of design criteria. This sub-activity sets the criteria for the decision. It is the engineering designer's task to compile stakeholders' goals and translate these goals into product design specifications.
- Evaluate: a statement concerning either the value of a design alternative, or the alternatives with respect to the current criteria.
- Validate: a statement whether a design proposal is "fit for purpose" with respect to identified product life concerns, e.g. manufacturing, distribution, or use.
- Navigate: a statement regarding the progression and feasibility of the design work, i.e. which activity to do next or in which direction to go next.
- Unify: a statement concerning the current design solution or design activity in relation to the totality of the product or process.
- Decide: a verbally expressed decision.
- Other: statements which do not belong to any of the first six categories.

Badke-Schaub and Gehrlicher [12] also assert that the decision making process includes a number of activities such as analysing, evaluating, and selecting, mainly in a group context. It is interesting to note in the work of [4] the implicit emphasis of the role of knowledge in decision making. However, the activities proposed by [4, 12] do not fulfil the objective pursued in this paper - of studying the role of knowledge in decision-making. A new coding system is necessary, and is proposed next.

4.3 Initial observations of the design experiment

The design experiment consisted of a group of three engineers generating ideas for a tubular map case allowing for one-by-one removal and insertion of maps. The three participants were at that time

Engineering Design PhD students with training in systematic design and with experience in mechanical engineering designing of 5, 10 and 15 years. However, they did not have any experience in packaging design. First, the designers were given the initial requirements of the problem along with technical and market data and two exemplars of map cases. During 40 minutes, the problem was read individually, the designers could use the exemplars, and the doubts of the initial requirements were clarified. Then, the designers were given new instructions by the facilitator to start the team design activity. It was recorded and lasted for another 40 minutes. The protocol analysis in this paper is made on these 40 minutes of team design.

When analysing the decisions taken in the experiment, the first thing that draws the attention is that most of the decisions are made without the designers being conscious about it. The designers embarked upon the decision-making process by identifying solutions, specifying required functions, and changing direction intuitively. Decisions got manifested through the designer's actions and inactions, and not through explicitly uttered decisions. We call these decisions *implicit decisions*.

However, there were moments in which designers appreciated a potential risk in an idea for which they did not have an immediate answer, and brought the decision-making activity to the conscious world. In team design, this becomes even more evident because designers may not agree on the directions to take, and consequently have to take decisions regarding ideas to reach consensus. The action of consciously deciding is, therefore, a design action in which designers explicitly discuss whether they should go or not for an idea, or about whether an idea is good or bad, or better or worse than another one, or about which idea they should select. We call these decisions *explicit decisions*.

An example of implicit and explicit decision-making is given next:

- From 05:16 to 08:00, a solution proposal was developed consisting of a map case with a side sliding system to roll up maps concentrically (Solution S1 in Figure 1).
- From 08:00 to 08:10 a solution was proposed consisting of a case prepared to roll up maps independently (Solution S2 in Figure 1).
- From 08:10 to 14:53 the designers discussed whether or not to reject Solution 2.
- From 14:53 to 15:51 the designers created a third solution consisting of a big storage file, which is flexible and can be rolled up (Solution S3 in Figure 1).

We consider that from 08:10 to 14:53, the designers were taking an explicit decision, whereas in the rest of the time above they were taking implicit decisions.

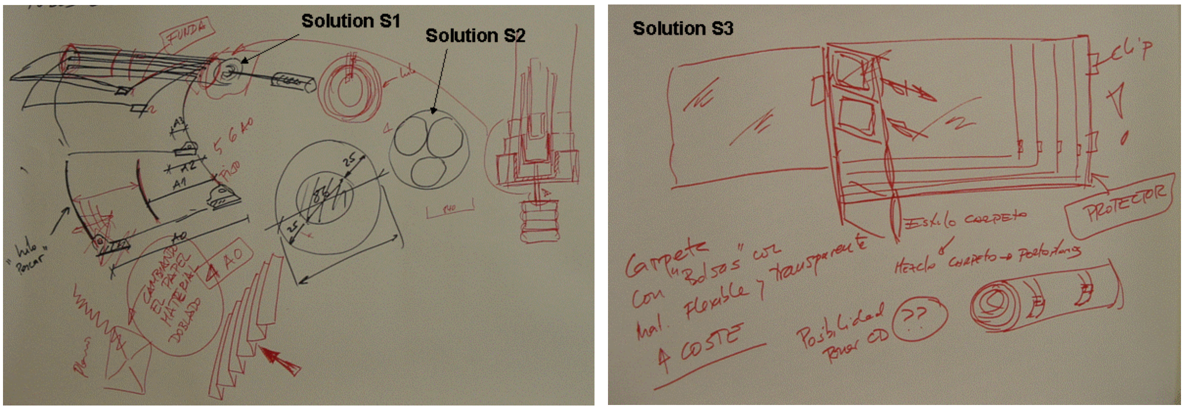
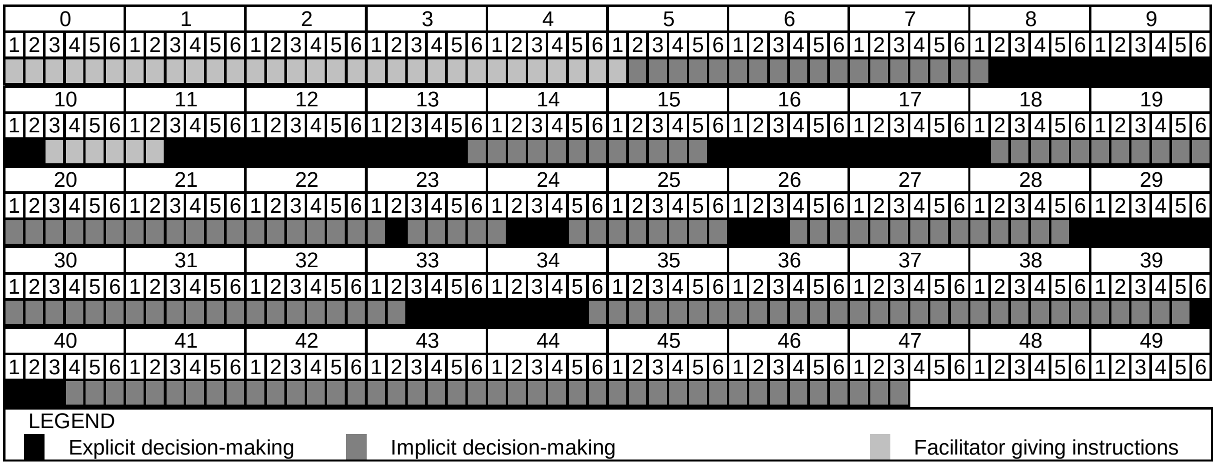


Figure 1. Solutions S1, S2, and S3

An explicit decision in team design is uttered and can be coded. It can also be easily distinguished from other activities in a session. For this reason, the coding system defined here is used only for those moments during which decision-making is taken to the conscious world because it can be coded. The objective, then, is to define a coding system that allows studying the role of knowledge in explicit decision making in conceptual design.

In Table 1, the alternation between explicit decision-making (highlighted black) and implicit decision-making (highlighted dark grey) is represented. Five horizontal blocks, with three rows each, can be observed. The first row represents the minute in which the activity is taking place. For example, "8" represents what was going on from 08:00 to 08:59. The second row divides the minutes in intervals of 10 seconds. There are, then, 6 intervals in each minute. As it can be observed from the table, the total time that the engineers were recorded was about 47 minutes and 30 seconds, out of which 41 minutes and 20 seconds were dedicated to designing, the rest (6 minutes and 10 seconds) being dedicated to the instructions that the facilitator gave to the team. During 72% of the 41 minutes and 20 seconds of designing, engineers were observed taking implicit decisions. During 28% (11 minutes and 30 seconds) of the time, the decisions were explicit.

Table 1. Alternation between explicit decision making and implicit decision making in the design experiment



The decisions that were explicitly discussed in the design experiment are listed next:

1. Decide to go or not for solution 2 (during minute 8 to minute 13).
2. Decide whether a solution is bad or not because it will damage the maps (during minute 15 to minute 18).
3. Choose the best two among three alternatives (during minute 23).
4. Decide which parameters of the tube (colour, texture, size, etc.) should be made customisable (during minute 24).
5. Decide whether a solution is bad or not because it does not allow identifying the maps when these are inside the tube (during minute 26). To solve this initially tentative decision, they do an activity that is later called in the coding system *biasing solving*, which means that they refine the solution to bias the decision. The final decision taken is that the solution is good.
6. Decide whether they can dispense with a lid or not (during minute 28 and 29).
7. Decide to go or not for a solution because it is very similar to another one, which is, indeed, better (during minute 33 to minute 34).
8. Decide whether to continue or not with a solution because it is too heavy and too sophisticated (during minute 39 to minute 40).

4.4 Definition of the coding system

During explicit decision-making, designers have been observed doing mainly two things:

- Uttering decisions. The decisions are most of the time tentative, as proposed by [4]. We will distinguish between tentative and validated decisions.
- Uttering knowledge. The knowledge is normally used to bias the decision towards one side. Sometimes the knowledge is also tentative. Other times what they do is to validate knowledge or to access validated knowledge.

Besides uttering decisions or knowledge, the designers in this experiment have been observed doing two more things: refining a solution to bias the decision towards one side, and posing questions whose answers will help to take the final decision.

Consequently, the coding system proposed here comprises of the six following activities, which are found during explicit decision-making:

- Tentatively deciding (**TD**). As suggested by [4], it has been observed that engineering designers make tentative decisions based on the available information.

  Decision 1 is plotted in Figure 2 to show an example of a tentative decision. The decision consists of whether to go or not for solution 2. The team had been defining a solution (S1) for some time, when one of the team members proposes a second solution (S2). One of the other two members wanted to reject this solution, and a decision of whether to do it or not was taken.

- Uttering tentative biased knowledge (**TK**). It implies uttering tentative knowledge that is biased towards a tentative decision.

  In decision 1 (Figure 2), tentative knowledge is used to support the tentative decision of rejecting solution 2. The tentative knowledge used is that the concentric distribution, like in solution S1, allows for more maps than solution S2.
- Posing decision-oriented questions (**PQ**). In order to go from a tentative decision to a final decision, designers have been observed to sometimes pose such questions whose answers are expected to support a tentative decision.

  Two examples of this kind are found in decision 1 (Figure 2). One of the questions is “how many A0 maps can be introduced in solution 2?” This question is made with the intention of obtaining an answer that shows that the number of maps that solution 2 allows for is small.
- Validating knowledge or accessing already validated knowledge (**VK**). This is the action of accessing or creating knowledge that all the team members recognise as valid.

  The question posed in Decision 1 (Figure 2) regarding the number of A0 maps that can be put inside a map case is answered with the validated knowledge of four A0 maps. The validation is carried out by the team at some point during the design session, by taking an A0 map, rolling it up as much as possible, measuring the resulting diameter, estimating a suitable size for a cylindrical case to be carried by a person, and calculating the number of rolled up A0 maps which can be contained in the cylindrical case.
- Biasing solving (**BS**). This is refining an already proposed solution in order to influence a pending decision.

  In Decision 1 (Figure 2), Solution 1 is further developed addressing a few issues used to convince the rest of the team about how good solution 1 is that Solution 2 should no longer be considered. The addressed issues are: S1 can have some threads which allow one to take out maps independently; in S1 the remaining space in the middle can be used for the turning technology that allows extracting and introducing the maps; and in S1 the remaining space in the middle can be used to store things.
- Validating decisions (**VD**). This is the action of confidently deciding whether or not to reject an idea, or stating whether an idea is better than another. The decision is considered valid.

  In the case of decision 1, the team does not utter a final decision about it, but since they never talk again about Solution 2, it is assumed that the group implicitly decided not to go for it.

5 STUDY OF THE RELIABILITY OF THE CODING SYSTEM PROPOSED

The reliability is studied with the help of a third person, who is an experienced researcher in the physical chemistry field. The coding system is considered reliable if the same results are obtained to a reasonable extent by other individuals. Other authors doing similar reliability studies obtained a percentage of agreement of 70% and 80% fits, e.g. [13], and solved the difference doing an arbitration discussion to create a better understanding of the data by discussing it among the coders. Here, it is necessary to study the reliability in two respects:

- On one hand, it has to be checked whether explicit decision-making can be differentiated from implicit decision-making or not.
- On the other hand, it is necessary to study the percentage of disagreements in the coding of the activities.

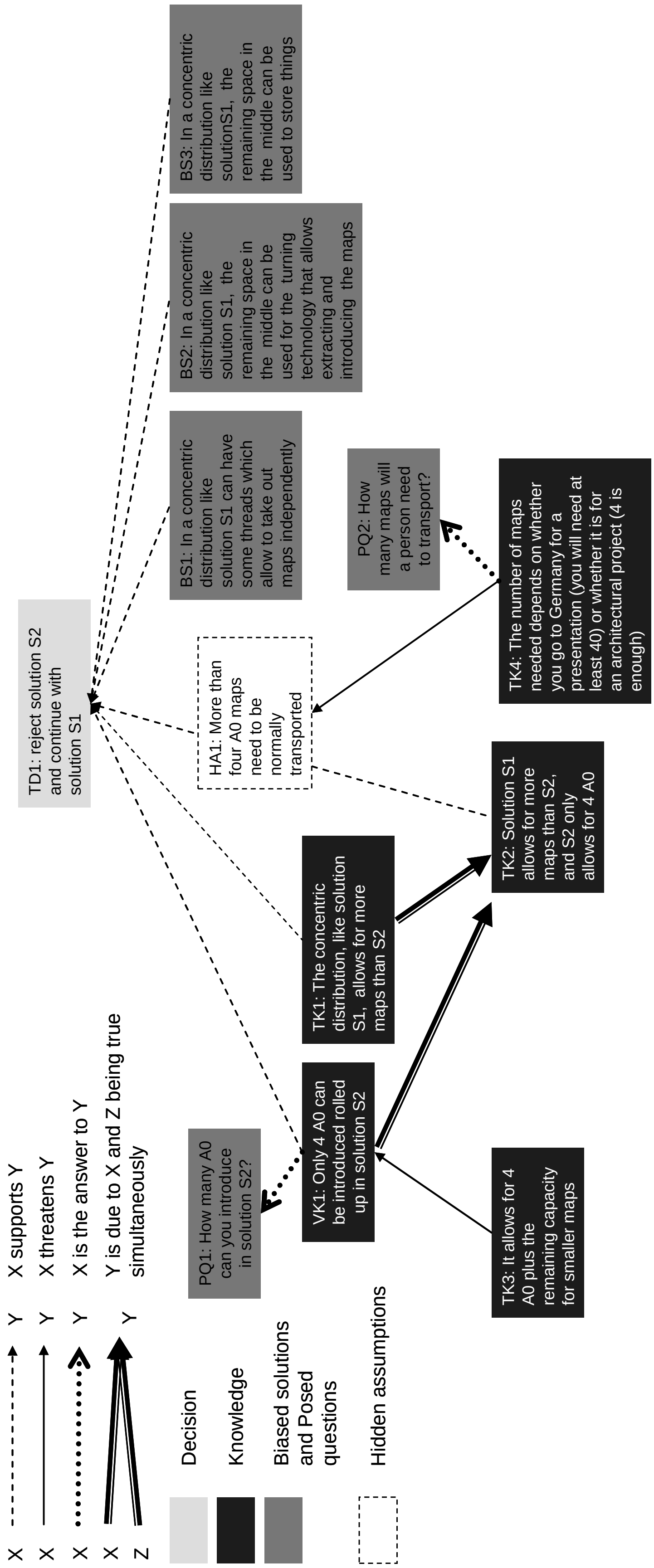


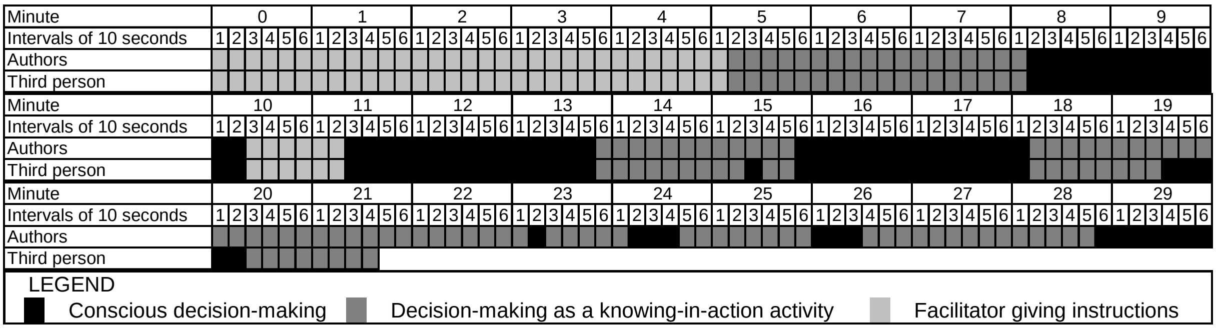
Figure 2. Explicit Decision 1

5.1 Can conscious decision-making be easily differentiated from unconscious decision-making?

The third person was given explanations of the coding system and the experiment for about one hour. He was working on the identification of the explicit decision making and the coding system in the experiment for about 6 hours in a row. During his coding activity, one of the authors was sitting with him to solve potential problems with the understanding of the events in the video. He had a copy of the whole conversation transcribed, and some drawings that were made by the designers during the experiment.

The third person studied the first 22 minutes and 40 seconds of the experiment, which included the coding of 14 minutes and 30 seconds of designing, obtaining the result that appears in Table 2. There is a 93.5% (14 minutes and 30 seconds) of the time equally coded by the authors and the third person (measured in intervals of 10 seconds), and 6.5 % of the time (1 minute) coded differently. This is quite a high match compared to the percentage obtained by other authors [13].

Table 2. Comparison of the alternation between conscious and unconscious decision-making as coded by the authors and by a third person



5.2 Are the activities of the coding system unambiguously coded?

The reliability of the coding system for the two decisions considered explicit decisions by both, the authors and the third person, have been studied. The coded activities for the first decision last for 4 minutes and 40 seconds. Table 4 reflects the comparison between the codifications by the authors and by the third person. The coded activities for the second decision last for 2 minutes and 2 seconds. The percentage of agreements between the authors and the third person are shown in Table 3.

Table 3. Percentage of agreement/disagreement between the authors and a third person in the codification of two conscious decisions

	Agreement [seconds]	Disagreement [seconds]	Agreement (%)	Disagreement (%)
Decision 1	245	35	87,5%	12,5%
Decision 2	110	12	90,2%	9,8%
Total	355	47	88,3%	11,7%

The percentages of disagreement are not excessively high compared to what other authors have got.

What was going on in the design experiment in the four occasions of disagreement between coders in Decision 1 (Table 4) is presented next:

- 08:40-08:43 [One of the designers says regarding Solution 2]: “It is not that I had not thought about it as a possible solution… But…It seems interesting to discuss about it”.
- 09:49-09:55 [The same designer says a bit later]: “There are two ways. One is to have all the maps in a concentric way…”.
- 10:10-10:13 [The same designer continues saying a bit later]: “The other way is to put small cases inside the case”.
- 12:22-12:27 [Again the same designer]: “Regarding what you said before. You were talking about putting them like this”.

In the four occasions the authors considered these comments as tentative decisions, while the third person considered them as tentative knowledge. In these four occasions, the designers were referring to solutions that had previously been mentioned. This could be the explanation as to why the third person considered them already as knowledge. The important thing to note is that, this difference does not change the validity of the code, as substantial overlaps exist between coders in each event of the design session.

Table 4. Comparison between the codifications by the authors and by a third person of the explicit Decision 1

Minute	8																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors											TD	TD	TD	TD	TD	TD	TD	TD	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD
3rd person												TD	TD	TD	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD
Minute	8																													
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Authors	TD	TD	TD	TK	TK	TK	TK	TK	TK	TK	TD	TD	TD	TD	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
3rd person	TD	TD	TD	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
Minute	9																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
3rd person	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
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Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	PQ	PQ	PQ	PQ	TD	TD	TD	TD	TD	TD	TD	BS	BS	BS	BS
3rd person	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	PQ	PQ	PQ	PQ	TK	TK	TK	TK	TK	TK	TK	BS	BS	BS	BS
Minute	10																													
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Authors	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD	TD	TD	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ								
3rd person	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TK	TK	TK	TK	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ								
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Authors	VK	VK	VK	VK	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	TK
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Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK										
3rd person	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK										

LEGEND

TD Tentative decision	TK Tentative knowledge	PQ Posing questions
VD Validated decision	VK Validating knowledge	BS Biased solving

6 ANALYSIS OF THE RESULTS FROM THE DESIGN EXPERIMENT

Once the explicit decisions were coded, the relationship between the different activities has been studied. As an example of the type of analysis, Decision 1 is used here. In Figure 2, the knowledge is highlighted black and the decisions light grey. Biasing solving (BS) and posing decision-oriented questions (PQ) are highlighted dark grey, and hidden assumptions (HA) are white. The relationships between the activities are mainly of the following types:

- X supports Y. This happens when the objective of an activity is to support one of the options of a decision. For example, in Figure 2, the tentative decision of rejecting solution S2 is supported by the validated knowledge VK1, the tentative knowledge TK1 and TK2, and the biasing solving activities BS1, BS2, and BS3.
- X threatens Y. This happens when an activity, normally uttering tentative knowledge or posing decision-oriented questions, threatens a decision, other knowledge, or an assumption. Assumptions are normally hidden in the relationship between knowledge and decision, as shown in Figure 2 in the relationship between the tentative decision TD1 “reject S2 and continue with S1” and the tentative knowledge TK2 “S1 allows for more maps than S2, and S2 only allows for four A0”. The assumption hidden is that “more than four A0 maps need to be normally transported” and therefore four A0 are not enough. This assumption gets threatened by the decision oriented question “how many maps will a person need to transport?”, whose answer threatens the assumption.

Therefore, knowledge can support or threaten decisions, but it can also threaten the relationships between other knowledge and decisions by discovering hidden assumptions (HA).
Other secondary relationships are:

- X is the answer of Y. Knowledge was used to answer the decision-oriented questions.
- Y is due to X an Z being true simultaneously.

7 PROPOSAL OF A MODEL OF DECISION-MAKING KNOWLEDGE

The model of decision making knowledge proposed here is shown in Figure 3. It shows that in the context of a problem and a solution finding activity, engineering designers make tentative decisions (TD) based on tentative knowledge (TK). Knowledge plays a fundamental role, since decisions become validated (VD) as the tentative knowledge does (VK), and hidden assumptions (HA) are not proved wrong.

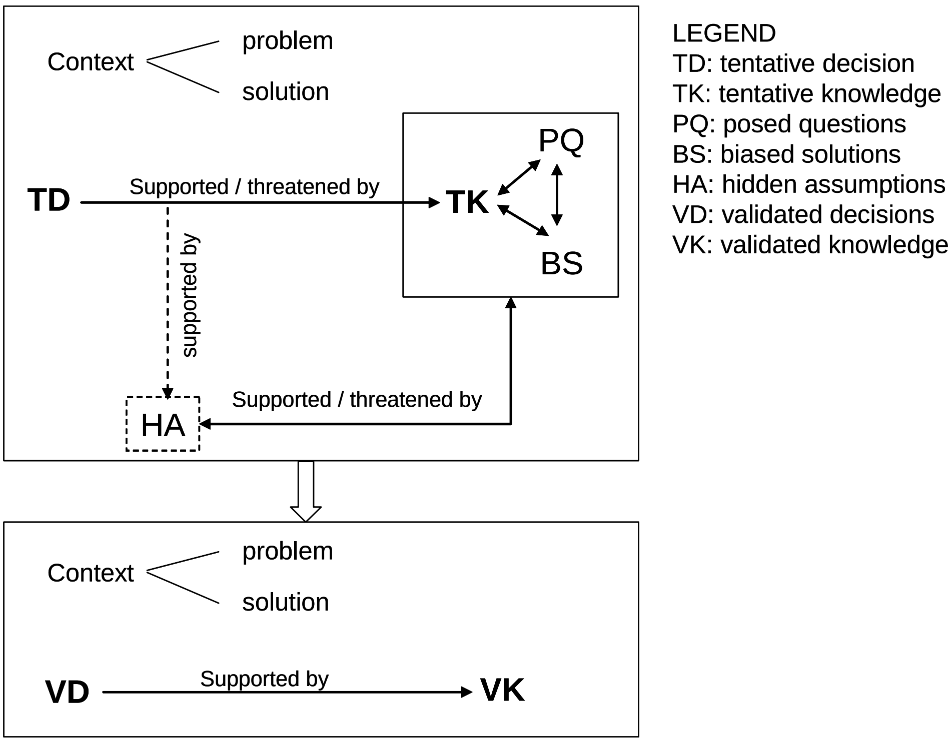

Figure 3. Model of decision-making in conceptual design

Tentative knowledge gets manifested, not only by explicit tentative knowledge, but also by the implicit intentions contained in posed questions (PQ) and biased solutions (BS). The interplay between TK, PQ and BS is responsible for supporting or threatening hidden assumptions and tentative knowledge as a process of validation of knowledge and decisions. Note that hidden assumptions can be made about TK, BS, PQ, and also about the relationships between them.

As an example Decision 1 (Figure 2) is used:

- Context:
  - **Problem**: finding solutions for a tubular map case which allows for one-by-one removal and insertion of maps.
  - **Solution**: solution S1 with maps rolled up concentrically (Figure 1) and solution S2 with maps rolled up independently (Figure 1).
- Decision: “reject S2 and continue with S1” **supported by**:
  - “S1 allows for more maps than S2” (TK1)
  - “Only four A0 maps can be introduced rolled up in solution S2” (VK1)
  - “Solution S1 allows for more maps than S2, and S2 only allows for 4 A0” (TK2),
  - “S1 can have some threads which allow to take out maps independently” (BS1),
  - “In S1 the remaining space in the middle can be used to store things” (BS2),
  - “in S1 the remaining space in the middle can be used for the turning technology that allows extracting and introducing the maps” (BS3).
- Decision: “reject S2 and continue with S1” **threatened by**:
  - “S2 allows for four A0 maps *plus* the remaining capacity for smaller maps” (TK3) because it partially invalidates one of the pieces of knowledge (VK1) on which the decision was based,
  - “How many maps will a person need to transport?” (PQ2) because it uncovers the possibly false hidden assumption made in the relationship between TK2 and TD1 that more than four A0 maps need to be normally transported,
  - “The number of maps needed depends on whether you go to Germany for a presentation (you will need at least 40) or whether it is for an architectural project (4 is enough)” (TK4) because it threatens the assumption made in the relationship between TK2 and TD1 that “more than four A0 maps need to be normally transported” (HA1).

From this example, it can be observed that posed questions (PQ) and biased solutions (BS), can be considered to have knowledge seeking purposes with the intention to support or threaten the decisions, and that hidden assumptions are a for of knowledge that can get externalised or not. Therefore, it can be concluded that the knowledge in decision-making can take various forms:

- Tentative knowledge
- Posed questions
- Biased solutions
- Hidden assumptions

8 IMPLICATIONS

The paper provides a preliminary model of the forms of knowledge in decision-making and the relationship between knowledge and decisions. The model needs further development. Once maturity is reached, the model could be used as the basis to support designers in decision-making. So far, several options of support to designers in decision-making have been identified:

- To provide them with tools to validate knowledge or with validated knowledge.
- To provide them with tools that help them finding hidden assumptions.
- To provide them with tools that help them detailing solutions to enable decisions to be validated.

It can also be said that to increase the traceability of decisions in a company, it is necessary to record:

- The decisions taken.
- The context of the problem being solved and the solution.
- The knowledge behind the decisions taken, and the degree of validity (or certainty) of this knowledge.
- The assumptions made in the relationship between knowledge and decisions, if these can be externalised.

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ACKNOWLEDGMENTS

Gratefully acknowledged financial support has been provided by the Spanish Ministry of Public Works (Ministerio de Fomento), project C 54/2006, and by Bancaixa-Universitat Jaume I, project 05I006.37/1. The engineers in the design experiment are warmly thanked for their participation. Special thanks to the colleague who helped in analysing the reliability of the coding system. The experiment was possible thanks to the support from Lennart Karlsson, Graham Thompson, and Rosario Vidal.

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