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A SURVEY OF CONTEXT MODELING : APPROACHES, THEORIES AND USE FOR ENGINEERING DESIGN RESEARCHES.

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Abstract

This paper provides a survey on recent researches in various areas concerning context theories and context modeling. Context issues are introduced in the field of engineering design researches. A framework is proposed to take into account context representation in engineering design model and two examples are detailed.

Keywords: context, engineering design models, sketches capitalization, decision-making capitalization, concurrent engineering.

1 Introduction and objectives

Our goal is to point out the main issues where the concept of context could be useful for engineering design researches, especially concerning modeling activities of complex systems and formalization of phenomena from the real world. The impact of context theories upon engineering theories, especially in modeling design have to be identified.

By a review of the literature from a span of disciplines, we aim at giving a first answer to the following questions : What is context? Can we find model to represent context, and how? How can we identify and recognize context? Can we acquire and model contextual knowledge [1] ? Is context representation necessary ? As soon as context is a key issue in engineering design researches and applications, a framework intended to support context representation is proposed and examples based on this framework are given.

This paper is organized as follows : the next section identifies some engineering design issues where context modeling is required. Section 3 exposes context definitions and approaches found in the literature. In section 4 our propositions for engineering design are drawn out and two example of context representation are proposed. Section 5 concludes our work and open perspectives.

2 Context and engineering design research issues.

Context is often perceived as "that which surrounds, and gives meaning to something else". In most systems' models, in the engineering design field, the context is infrequently assessed, or is simply defined by which surrounds models and make them valid [2].

This is quite true and could be sufficient in a stable environment. But, nowadays, companies are evolving in a highly competitive and changing environment and organizations have to adapt their structure and their processes to achieve success. Consequently the complexity of the models needed to represent systems is growing. Hence, the notion of context becomes crucial and the need for understanding and modeling such phenomena is rising.

- Communication and collaboration : design processes require more communication and interaction between people geographically distributed, in an asynchronous way of working, from various cultures and organizations. Consequently we need methods and tools to take into account the context of these communications and interactions in our models.
- Environment and evolution: the organizational development of firms is more dynamic and more linked to the environment. Consequently the notion of context is linked to the notion of validity or even of verity [3] of models. For instance, an electric-motor cost model have to be linked to materials market price evolution to be valid.
- Knowledge and information : a lot of work has been done to integrate knowledge in order to support design activities and to manage information flows of design. Context is need to provide designers with the right information at the right time.
- “Globalization” reveals that most engineering design needs are generic all over the world. We have to think our tool more generic than in the sequential engineering.

The notion of context is tacitly linked to several aspects of researches in engineering design. Several example of research methodologies that need to take into account the concept of context can be found.

Empirical studies of engineering design are seeking to understand and to model design activities and heuristics of designers. Descriptive models integrates non-formal design factors that explicitly make reference to human characteristics (knowledge, emotion, group characteristics... [4]) and environment characteristics (availability of information, customer requirements, availability of a technology,...). Psychology of design, groups studies, decision-making studies, usually make reference to these factor linked to concept of context.

Prescriptive models are also concerned by context issues. Thus, general prescriptive design methodologies have to be adapted when deployed in specific domain area. Detailed information is necessary to determine which factors are required. Context understanding will lead to the success of the methodology use.

As far as design methodology are generally materialized by tools to support design, tools specifications have to take into account context. This is particularly true for tools enforcing collaboration and communication between designers that require mutual understanding.

As an illustration, Table 1. expose three of the questions and directions for future empirical engineering design researches [4].

Table 1. Empirical engineering design research perspectives [4] and link to the concept of context

Question ([4])	*Links to context*
How can a general design methodology be transferred to different branches and products	What was the context of the modeling, what was the context of validation. What are the factors to take into account ?
Which are the most effective ways to assure information availability for the concerned persons in the process	What is the context necessary to interpret information? Which factors are necessary to identify the context of the person in the process ?
How is the influence of information and communication technologies on the designers' action and thinking	What is the context of interaction and collaboration ? How tools can simulate context of human collaboration.

3 Context definitions, approaches and models

3.1 Definitions and approaches.

The study of context spans a lot of discipline [5], Philosophy, Communication, System Science, Linguistic, Artificial Intelligence, Industrial Engineering. The objective of this section is to understand its different meanings and what were the main evolutions of the representation of this concept in people mind. The first definitions (in French language) are based on the Latin word *contextus* (to weave), context is defined as “the part of a text that surrounds a word or sentence and determines its meaning” (1754, Encylopédie, t4). The modern definition was initiated by *Kant* (Critique of pure Reason), context is defined as the circumstances in which an event occurs. Consequently, in order to understand related information, we must have context factors explicitly assessed. Nowadays this definition is widely used in natural language, people are familiar with the notion of social context, economical context and so forth.

The main contributions in context modeling are proposed by the CONTEXT conferences (1997, 1999, 2001, 2003). This is an interdisciplinary community with contribution from artificial intelligence, linguistic, natural language processing, knowledge engineering, philosophy and system modeling. Several definitions can be found:

- The semantic definition has to be taken into account for engineering design studies that have to consider information: “the semantic context is what gives the evaluation of the terms once their linguistic role has been disambiguated” [6]
- The modeling context definition : “context is a stand-in for those factors that are not explicitly included in the simple models we learn, or to put it positively, those factors that we use to recognize when a model is applicable“ [7]
- The “objective” or “metaphysical” context [6] “is a set of features of the world <time, place, speaker,...>
- The subjective or cognitive context [6] is a “set of assumption on the world (+rules)”

More than definitions, approaches of context modeling are proposed. We present here, the synthesis made by *Edmonds*. In [7] two conceptions and two main approaches for context representation are proposed. Then in the next section, 3 examples of context modeling are presented.

Table 2. Edmonds proposition

Point of view	*Internal approach*: Context can be considered as the result of an individual learning process. Hence he can be empirically studied. For instance experienced designers know and recognize context of design problems to find an solution [8]
	External approach: Context can be represented as modeled heuristics, abstracted from individuals' constructs.
Type of approach	*Top-down approach* is where one attempts to lay down general principles (encoded variously as axioms, rules, algorithms, etc.) based on current or a priori thought.
	Bottom-up approach involve attempting to induce models of context from the details of the learning and inferential processes as they might occur in practice,

3.2 Cognitive context

The first proposition comes from Artificial Intelligence and is held by *Mc Carthy* [9]. In this theory of cognitive context, context is defined as a set of assumptions on the world and rules. It is linked to the notion of verity an is based on two propositions :

- $ist(c, p)$: proposition *p* is true in context *c*
- $value(c, e)$: is the value of *e* in context *c*.

The purpose of this representation is to introduce context as a formal object. The main consequence on engineering design modeling is the compatibility. If a design model is valid in a context A (one company, one country, ...), and if the context B share rules, strategies and information with context A (same kind of company, same country, ...), it is possible to navigate between contexts and the design model would be valid in context B.

In this case, context is simply not taken into account due to the supposed and tacit context compatibility. Difficulties arise when contexts are not compatible or when it's difficult to evaluate contexts' compatibility. This is why context representation is required in models.

3.3 Strong Contextualism

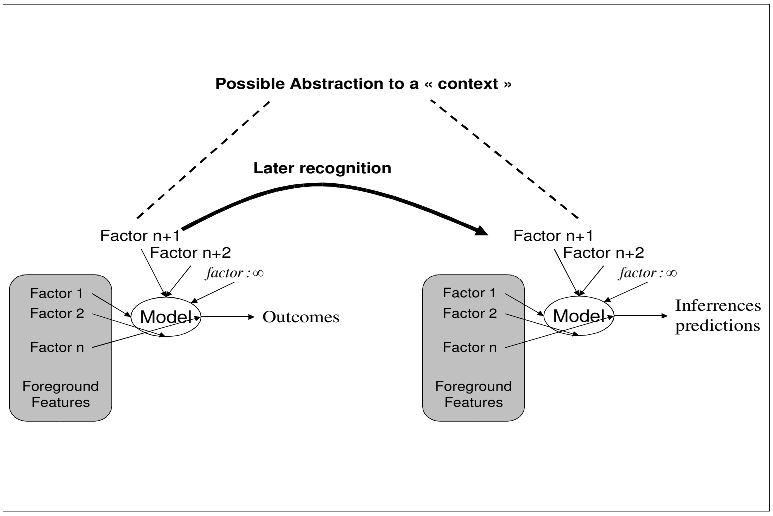

Figure 1: Edmonds proposition

Edmonds [7] introduce context as "the abstraction of those elements of the circumstances in which a model is learned, that are not used explicitly in the production of an inference or prediction when the model is later applied, that allows the recognition of new circumstances where the model can be usefully applied". This definition is illustrated by figure 1. Context emerges from heuristics and is linked to the possibility of the transference of knowledge "via fairly simple models from the circumstances where they are learned to the circumstances where they are applied". As an illustration, engineering design models, especially those resulting from empirical design studies can not include all the causal factors. Researchers have to make a choice and produce partial models. The potential reuse of those models is determined by those three factors:

- Factors not included in the model are so constant that they can be ignored, the model is valid in any case.
- Factors not included in the model are not constant but those background features are "recognized" as identical to those learned so that the model can be used.

- Factors not included in the model are not constant and not learned. The model is not valid in another context.

The main issue in engineering design researches is coming from the difficulty to recognize a context as similar to the learned context of the model.

3.4 Context, collaboration and information

The construction of a sentence corresponds to a set of instructions formulated in term of variables, which provide a sense to the statement. Exchanged information is then an abstracted entity, a theoretical object which consists of linguistic components and rhetoric or context components [10]:

- The linguistic components build the significance of information starting from instructions. They are characterized by the clearness of their formalism more or less structuring which leaves the possibility of having or not various possible interpretations. For instance, industrial designs formally described the geometrical shape of a part and leave only few little possible interpretations. On contrary, talks can be interpreted in several ways according to the receivers.
- The context or rhetoric components bring a sense to information by addition of contextual information. This construction is characterized by the facility to identify information context. For instance, an industrial design associated with a cartouche not have to, in theory, require the possession of other information for its understanding.

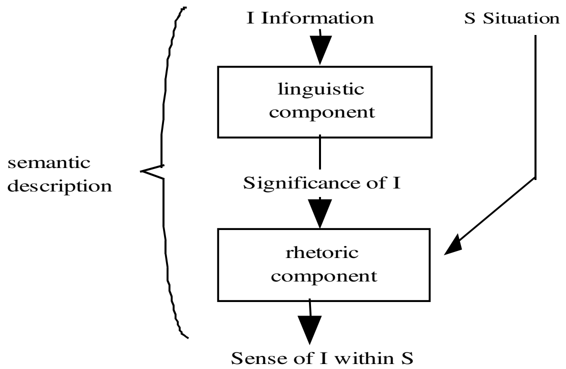

Figure 2: Instructional design of the significance of information

According to instructional semantic description (Figure 2), we agree that an Information System is structuring when information has one and only one significance (with clear linguistic components) and a well defined sense (with accurate rhetoric component).

The properties of this structuring enable us to define *Structured-Information* (*SI*), *Semi-Structured-Information* (*SSI*), and *Non-Structured-Information* (*NSI*) [11].

Characteristics of the *SI*:

- Linguistic components of the *SI* are generally imposed. The employed formalisms are accurate and logic. They leave little place to interpretation (example: an industrial design, etc),
- Rhetoric components of the *SI* are also imposed. They are clearly defined and have to be indicated to validate information (example: an industrial design is associated with the name of the designer, the product, the part, the date, etc.).

The transmitter has not the choice of the *SI* type (design, text, etc) and rules concerning the container, the content and the circulation of the *SI*. Consequently all the receivers have, thanks to the *SI*, necessary and sufficient information to carry out their tasks. The context is imposed.

Characteristics of *SSI* :

- Linguistic components of the *SSI* are little formalized. They can take the shape of texts, tables, graphs, etc. They could be hardly understandable by all but more easily for direct receivers (for instance: graphs without legend, design without industrial formalism, etc).
- Rhetoric components could be parsimonious. Indeed, the transmitter knows the receiver and adapts the level of granularity of the rhetoric components according to the supposed knowledge of the context that the receiver has (example: meeting reports are not always easily interpretable by a person who did not take part to the meeting).

The *SSI* are stored less longer than the *IS* because the context is not always associated with information, they can thus quickly become not useful.

Characteristics of *NSI* :

- The *NSI* are very little formalised. The formalisation of the linguistic components employed depends on the degree of complicity between transmitters and the receivers, which can leave place to a multitude of interpretations.
- The rhetoric components can be very light if they ensure a sufficient degree of relevance for the comprehension of information by the receiver (example of a verbal message which can be relevant according to the transmitter and of the receiver: 'we do as we talked').

The *NSI* are essentially volatile, because even if it is possible to preserve a piece of information of a talks (' we do as we talked'), it is sometimes more difficult to remind the context.

4 Proposition for integration of context representation in engineering design.

4.1 A three layered context representation

Context representation is an important factor that has to be taken into account in engineering design models. This concept is helpful and leads to robustness of design models. We introduced (Section 3.) definitions and approaches concerned by context modeling. Each of these examples can be used in engineering design researches but when one is confronted to context modeling there are no guideline and rule to integrate this concept in modeling activities.

The purpose of this section is to propose a framework in order to support context modeling in engineering design researches. This framework contains: (i) a categorization of contexts based on three levels; (ii) a guideline to determine which level of context is necessary; (iii) a proposal for identification of those three levels and their integration in models.

The three levels of context are:

- The first one is the local context called *explicit context*. We are able to formalize it and that can be seen as new inputs or constraints to our models (e.g. project constraints, like planning delay,…). This context is simply represented by additional factors, input parameters of models. It is similar to the *objective context* (See section 3.1).
- The second level of context is the *implicit context*. We are not able to fully formalize it. This context is not a set of explicit factors or parameters. It is a set of rules linked to the

cognitive context (See Section 3.2). This context is learned by actors can be recognized (See Section 3.4)

- Then, the third level of context is the *overall context.* It concerns the surrounding context which is complex and hard to recognize. It includes human comportment, history, culture, education feelings of the involved people and the environment dynamics, ...

We propose recommendations in order to handle and to represent the three levels of context identified above. These recommendations ought to be generic but aimed particularly at supporting empirical studies and descriptive modeling in engineering design.

- *Explicit context*: This context is represented by additional parameters to our models. In order to identify such parameters one have to check what are situations in which the model can be wrong and list all the relevant parameters. For instance, an engine cost model can be false in the future if the price of the aluminum body is fixed. Consequently, the market price have to be added as an *explicit context*. It is represented by *SI* (See 3.5)
- *Implicit context*: This context is knowledge that be partially represented by information. It can be partially elicited by various techniques such as knowledge engineering techniques (semantic networks, data-mining) or empiric observations. The main purpose is to provide actors with non-formal representation that help to recognize context when its necessary. It can be represented by *SSI* (See 3.5) or *NSI*.
- *Overall context:* This context can not be represented it can only be learned by actors. How could we handle it ? Human beings have a common context (common factors and shared characteristics, biology education, moral, ...) that allows us not to assess this level.

The level of required context representation depends of the models' purpose. Table 3 summarize our proposal.

Table 3. Required level of context

No context	If models have to be used in the same situation as they were produced, the context issues are void.
Explicit Context	If the models don't integrated human interactions or processing and have to be used in various situations, *explicit context* have to be considered.
Implicit Context	If models integrate human interactions, information and knowledge processing, implicit and tacit context have to be considered.
Overall Context	As soon as it can not be represented or assessed, this level is never required because it is made of all the underlying principles of the world. Nevertheless, we have to keep in mind that it is possible to find a context where verities are false.

In the next sections, two example of this framework application are proposed. The purpose of the first one is to illustrate how to choose level of context that have to be considered . The second one deals with concurrent engineering and sketch capitalization and propose an implicit context modeling.

4.2 Application to decision-making capitalization

The first example deals with context modeling and capitalization of decision-making processes. These processes are decomposed in activities where the context plays a fundamental role.

This short example concerns the context of the evaluation of alternatives within a set of criteria. In order to capitalize this decision, we use the QOC representation as a descriptive model applied to software design. The example concerns the choice of a software interface [12] (See Figure 3). *Q* represent the question, *O* the available options, and *C* the criteria used for evaluation. The boxed option is the resulting choice, and the dotted lines represent a negative evaluation (a pull-down menu is poor in term of speed of access and good in term of user orientation).

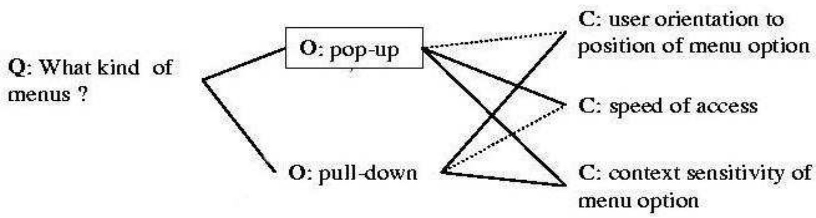

Figure 3. QOC [11], A descriptive decision-making model.

According to the proposed framework, in this case, we need an implicit context representation. Hence, this model have to be reused in the future, by actors who were not implied in this decision-making process and decision-making is highly linked to human interactions. Options are evaluated under criteria by subjective evaluation. And the design rationale built and understood by the project stakeholders is constrained by the context of interaction between actors in group decision.

Consequently, in this case, in order to integrate context representation, experiments have to be conducted. *NSI* or *SSI* have to added to this model in order to represent underlying knowledge in criteria evaluation.

4.3 Application to sketches capitalization.

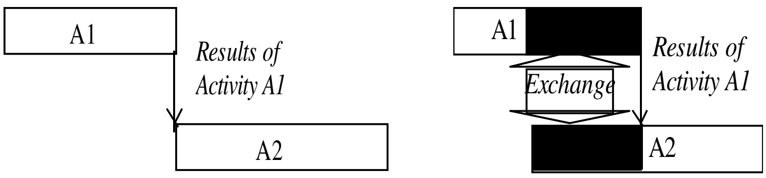

Figure 4. Comparison between Sequential Engineering and Concurrent Engineering

Most of the information exchanged in sequential engineering are results of the different tasks. Actors who are responsible of the next task can trust it. In CE, actors of the design have to exchange conjectures [13] that allow the others to work simultaneously [10]. The actors have to discuss ideas, drafts of solutions etc… These information are partially true, and have to be updated often. The nature of information is mostly *NSI*. That's why, some enterprises promote the exchanges by design teams, then CE relies on so-called Integrated Teams.

This second example concerns the capitalization of non-structured information from sketches [13]. Indeed, we propose specifications of a communication tool that supports and structures numerical drafting and treatment for capitalization of those drafts connected to messages in the group understanding within Integrated-Team. With this aim in view, we use the notion of intermediary objects to describe all the objects or documents that appear or are used in the process. So, we focus on the role of sketches in the group understanding. In agreement with previous work allow us to analyze the role of sketching in the emergence process of new solutions of design. Objects can have different uses in the design that we can connect with the structure of the information. Indeed sketches are generally Non Structured Information that can play the role of conjecture while official drawings (Structured Information) transmit decisions from a group to another.

Sketches are much more difficult to interpret because the linguistic components are not predefined and the context components are seldom joined to the sketches , indeed there are mostly oral. Context in this case in implicit context and overall context. This section presents an implicit context modeling and use, based on intermediary objects and GNSI.

The first quality of a sketching device for designer seems to allow fast freehand sketch. Previous studies have highlighted that the cognitive tasks of manipulating the sketching tool have to be minimized [13]. Even if we can expect that the actors will learn the tool. That is why the tool is based on a simple blackboard techniques and uses a digital table with an electronic pen. Indeed, when the designer needs formal drawing he will mainly use CAD or Structured information tools. Sketches are just *GNSI* and support fuzzy and partial definitions of elements. The functions that we offer are not supposed to help the drawing process but to partially structure *GNSI* in order to capitalize and treat them in the knowledge process. We are at the moment unable to manage a knowledge treatment directly on sketches. The principle we develop here is to characterize *GNSI*, track the steps of the building process and to associate textual and symbolic information that the data-mining techniques used by MICA are able to treat. At the moment, a designer creates a new sketch, he creates a properties file containing the legend of the file, type of the *GNSI* created and all the textual annotations contained. All this textual information is able to be treated by the MICA data-mining process

Indeed, we have experimented a retrieval system that allows fast and reliable search for black and white sketches [14]. Efficiency is achieved by organizing the sketches in a nested hierarchy of clusters and by allowing the user to provide relevance feedback. Reliability is achieved by extracting shape information that is invariant to some or all affine similarity transformations and by combining different features for performance maximization. The system has been used to determine relative strengths of different shape features in the particular context of aeroplane sketches. Among four features tested were Fourrier descriptors, difference chain code histograms and two variants of coocurence matrices. Fourrier descriptor achieved the best evaluation results with average precision values of up to 68 %. We implemented a genetic algorithm to determine the optimum weigt set for this particular sketch base and found that performance can be increased by another 10% by simply combining Fourier descriptors and difference chain codes with a weight ratio of roughlu 3:1. Further studies are currently undertaken to evaluate the robustness of these results under different datasets.

Even if the technology exists, it is most of the time difficult to "understand" the meaning of the sketches that is why the MICA-Graph. tool offer the possibility to add specific skill symbol or annotation. However, we haven't experimented it yet in an industrial environment.

5 Conclusion

In this paper we underlined needs for context representation in engineering design researches. We proposed a survey of context definitions and approaches. This led us to propose a framework to support context modeling in engineering design research. This framework was illustrated by two example. As a conclusion, we would like to propose perspectives for further researches in context modeling. The framework presented in this paper is a first proposal. In-depth studies have to be made in order to identify in details the guidelines for context modeling in all design activities. The *implicit context* is the more critical and the more difficult to handle. Research works have to be conduced in order to identify all the existing representation in other disciplines that could be used in engineering design context.

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