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Conceptual inferences in design

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1. Introduction

People easily err in their design thinking [Perrow 1999, Reason 1990]. This is why it is vital to get as complete a scientific understanding of the design thinking process as possible. In this manner, it is possible to develop rational organizational and technical support processes for designers, and decrease design risks. However, elimination of design risks is not a trivial task, but requires many types of expertise.

Design thinking is a very versatile and complex process. Hundreds, if not thousands of people may work to reach a common design goal. Design processes can take decades and some design traditions such as houses or ships are thousands of years long. On a social level, the flow of new ideas is constant and in many fields, such as computing or mobile technology, developments may sometimes have rather chaotic forms. This means that it is crucial to eliminate human risks to improve a designers' control of the knowledge process in their work.

In many ways, design thinking is holistic. Individuals who design must understand multi-scientific concepts required in their field of work from materials, and from physics to engineering construction patterns and more recently from human behaviour. They have to be able to unify many different types of knowledge into working plans and objects. Design organizations have to be able to unify thoughts and efforts of large numbers of people into complex wholes [e.g., Bender and Blessing 2003, Kavakli and Gero 2003, Norman 2002, Pahl, Beitz, Feldhusen and Grote 2005].

The complexity of the design process makes it necessary to use many different scientific approaches. Cognitive science with its multi- and interdisciplinary ways of thinking provides a set of possible theoretical languages to make human aspects of design more explicit. This type of work in the field of design is relatively new [Simon 1969]. Consequently, the many possibilities of applying cognitive science are still relatively under researched. It is also possible to develop new cognitive scientific tolls of thought for the investigation in design processes. One such window of opportunity is opened by the study of conceptual inferences [Saariluoma 1997, 2002]. These ideas can be applied for example in requirement engineering as here, but they undoubtedly have many other functions in explicating and clarifying representational content in design thinking.

Engineers use such notions daily as system, cognition, function, and design but the understanding of these notions may be relatively shaky. They have different content for different people. Their content may vary between fields and even companies. When working with such problems, one should have a good idea about the content of the basic notions. This is why it is worth considering in detail the nature of conceptual analysis and its possible functions in design thinking [Saariluoma 1997, 2002]. The clearer and more explicit the structures are of the used concepts the better our understanding of the ongoing thought and other knowledge processes. It is much better to get a clear conception about what is meant and what is said than to rely on intuitive ideas about the contents of ill-defined knowledge.

2. Total contents, definition, individuation and essence of concepts

All the concepts have their own information content. They refer to something. The traditional way of thinking about the information content in concepts is to see them as classifiers. This is a metaphor in which the main function of concepts is seen to be in dividing sets of object into those which belong to area within some defined concepts and those which are outside their scope [cf. eg. Murphy 2002]. Ferrari belongs to automobiles but not to paintings or books. Classic taxonomies are naturally the best examples of classificatory view to concepts.

It is also possible to see the content of concepts from an alternative point of view which is equally functional in its origins. This can be termed as a constructor view to concepts [Saariluoma 1997, 2002]. In this approach, the content of concepts is decided on the grounds of what they add to representations. If we add the *possible* concept to the proposition “Mary comes tomorrow” its content essentially changes. This change provides us with information about the contents of *possible*.

The constructor view of concepts does not open a simple field of the problems, but classificatory view also has its complexities. The two views are obviously not contradictory but complementary. The idea of constructive content leads to a number of interesting additional properties of the content of concepts. One of them is the content attribute of concepts.

Each reference of a concept, i.e., an object or an event, mental or physical, has its properties. Consequently, each concept must have a representation for these properties. These content-elements of a concept can be called the attributes of the concept. Thus, a car has an attribute that it has an engine. This means that in the notion of a car we have entailed the notion of an engine as one of its many attributes. The notion of a conceptual attribute forms the very core of all conceptual analysis.

We can e.g. speak about the total content of a concept. This theoretical notion refers to the set of all the attributes of a concept, i.e., everything we can explicate from it. Naturally, the total content is a theoretical notion, comparable to infinite space. We cannot discuss it as a whole and this is why we normally make “compressions” to cope with the problems of content. The most important of them are definition and essence.

A set of interrelated issues with concepts should be clearly differentiated here. These issues are the definition, the use, and the essence of concepts. Definition refers to a set of attributes, which can be used to individuate a concept among a set of other concepts. Fear, for example, is a feeling with negative valence and will to escape or avoid. This definition expresses some critical characteristics of fear.

As is well known ever since Wittgenstein’s [1953] famous critique, at least, all the definitions are relative. The above definition of fear, for example, is not comprehensive. It does not make clear the difference between itself and angst, or mild horror, for example. We must mostly see concepts rather as sets of interrelated attributes than unique and unambiguously definable entities. For this reason definitions have rather a practical value than the power of making absolute differences.

Consequently, it is much better to discuss the individuation of concepts than their definition. Individuation means that a concept is differentiated in a context from all of its neighbors and its reference is made accurate. The concepts of fear and angst might provide an example. They are normally differentiated by the attribute that fear has a definable target but angst does not. The act of making the difference clear is individuation and its function is to give us a sufficient practical understanding of the content of a concept.

Individuation is not assumed to be absolute as is defining. Individuation is relative to a definitional context. This means that the individuation of a concept normally distinguishes it from a contextually definite set of concepts, i.e., definitional domain group, and not necessarily from all imaginable concepts. Indeed the criteria may be different in different contexts. This kind of slightly pragmatic position can be termed as contextual essentialism [Saariluoma 1997, 2002].

The contextual essentialism does not compel us from using the notion of eternally invariable essence. We can think that in a defined context the set of the most relevant attributes of a concept forms its essence. The essence of a geometric circle as a set of equal points far from a defined point is rational in plane geometry, but hardly true when investigating the shapes of circular rolls in paper mills. Consequently, the essence of a concept is, like definition, a way of characterizing the core content of a concept, but the contents of the latter always vary somewhat within context.

3. Conceptual inferences

An interesting property of attributes is that we can infer them from the notion. Thus knowing that something for example like a car we can infer that it has an engine. Saariluoma has called these kinds of inferences “Cartesian or conceptual” [Saariluoma 2002]. In Cartesian inference any true attribute of a concept is explicated.

The following notation can be used:

C → A,…., A**Error! Bookmark not defined.**

This formula simply means that one can infer any of the attributes (A) of a concept (C) from it. We may, for example, infer from the notion of “bottle” that it is an object and it has size and is intended to store materials (basically liquids). Usually it is also made of glass. Conceptual of Cartesian inference is interesting here, because it allows us to investigate the attributes of concepts.

The next question is naturally, when conceptual inference is valid. If one suggests that life is a characteristic of a stone, it certainly would be an invalid inference. The reason for invalidity of this inference would be that stones do not have the attribute of being living creatures. Thus, the criterion of the conceptual inference is whether the concept has the referred attribute or not. Conceptual inference is valid when it is true to say that the concept has the attribute, i.e., when the respective reference has the defined property. One might naturally think that under certain metaphorical conditions one could truly claim that “stones live”. A sculptor, for example, seems to make stone come alive. However, in a conceptual analysis one cannot interpret metaphors on the ground of wording. The word “life” in the context of a statue does not refer to living but to the human experience of the object. Conceptual inference is important because it provides us with a method of investigating the content of concepts. This means their use, individuation, definitions and the total content. This makes it possible for us to apply a conceptual analysis when investigating the use of concepts in design.

3. An example: The contents of a design process

A concrete example might best make the method understandable. Here, our goal is to model the notion of a building design to illustrate our approach.

Main attributes of design	Second level attributes
1. Goal	1.1 Client’s intention
- Client’s needs and their satisfaction	1.2 Definition of the goal-state
2. Agent	2.1 Agent types
- The designer & organization	
3. Target	3.1 Existing drawings and documents
- What is designed	3.2 Contextual knowledge
	3.3 Legal & social constraints
4. Resources	4.1 Funds
- The resources	4.2 Time
required by design	4.3 Equipment
5. Management	5.1 Process description
- The resources	5.2 Process control
required to manage	5.3 Inspections
the design task	

Figure1. The highest levels of design ontology for a one family house

The concrete example is made on the grounds of an imaginative family needing a larger house. In Figure 1, the highest levels of design ontology have been presented.

Here we suggest five major conceptual attributes for describing a design process. Design is seen here as an economic activity. It has a goal and like all economic activities it begins with the needs of the client. So the first level is intended to provide information needed in a detailed description of the clients needs.

The second level describes the designer. Obviously it is impossible to describe the design process without a description of the designer. All designs are made by a designer and this is why the description of a designing agent is required. The third major attribute of a design activity is its target. This means what is actually designed. Naturally, it is impossible to make a description of any design process without having a description of the target.

The fourth and fifth levels explicate the organizational point of modern design. Firstly, on the fourth level we discuss the resources required by design. On the fifth level the main focus is on the management and administrative dimension of the design. It expresses the available resources and methods of management.

These attributes have been selected because they are task-necessary. This means that by leaving one of them out it would necessarily provide a deficit representation of a modern design activity. On the other hand, it is possible to include these attributes into all the relevant information.

4. Analyzing next level of attributes

The analysis can naturally be extended to attributes. We must for the sake of brevity look at two examples. The first extended attribute is an agent. By agent we mean the person or group of people, who actually carry out the design process. The agent can be analyzed as is shown in Figure 3.

Main attributes	1st degree	2nd degree	terminals
2.1 Agent types	2.1.1 Individual	2.1.1.1 Profession	CAD-illustrator
	2.1.1.2 Social skills	Good	
		2.1.1.3 Task	Drawings
	2.1.2 Team	2.1.2.1 Member list	Member 1, 2, ...
		2.1.2.2 Competence	Good
		2.1.2.3 Atmosphere	Energetic
	2.1.3 Organization	2.1.3.1 Specialization	Home design
		2.1.3.2 Contractors	Lighting designer
		2.1.3.3 References	Designed 103 houses
		2.1.3.4 Finances	Solid

Figure 2. The sub-attributes of agent.

We resolve agent types into individuals, teams, and organizations, which is all relevant information about the designers, but in different ways. Individuals' competence and social skills are important, as is the task in the design team. The second child of an agent type is the team, i.e., the group, which carries out the task. It has such important attributes as a list of members, competence or atmosphere. They are all natural conceptual attributes of teams and obviously important for the management of the design organization. Our last attribute of the agent type is the organization. It is the widest of all and it may have numerous design tasks simultaneously, even though it has its own attributes. Here, we have taken specialization, contractors, references and finances as examples of possible attributes.

Obviously, there can be additional attributes, but this set demonstrates the method of developing a conceptual ontology.

The next example of extended attribute analysis is provided by the target. This attribute and its followers entail information about the actual target of the design. It has numerous important attributes but we constrain ourselves here to two: the existing documents and the actual plan. Typical additional attributes could be legal constraints or contextual knowledge.

Main attributes	1st degree	2nd degree	terminals
3.1 Existent documents	3.1.1 Drawings	3.1.1.1 House plan	Detail drawing
		3.1.1.2 Lot	Distances
		3.1.1.3 Electricity	Installation plan
	3.1.2 Requirements	3.1.2.1 Legals	Fulfilled
	3.1.3 Calculations	3.1.3.1 Strenghts	Approved design
3.2 New documents	3.2.1 Drawings	3.2.1.1 Houseplan	Detail drawing
		3.2.1.2 Lot	Coordinates
		3.2.1.3 Electricity	Lighting plan
	3.2.2 Requirements	3.2.2.1 Legals	Fulfilled
	3.2.3 Calculations	3.2.3.1 Strenghts	Approved design

Figure 3. The sub-attributes of target.

In Figure 3 we discuss the possible restoration and a new target. They represent alternative descriptions of the actual target, which in our case is a house extension plan. Here, we have taken such documents as drawings, requirements and calculations as examples. They represent very different types of documentation. They are all things, which are required when we describe the target of a design process. There could also be such information as risk analysis, social conditions, and materials. A complete representation of the target in building design is naturally a very large system of information, but the few attributes presented here should make the methodological point evident. This means, how the systems of conceptual attributes can be worked out.

These examples should be suffient. They illustrate how our relatively simple but non-formal infernetial schema allows us to investigate the structure of concepts. Naturally the analysis can be continued until the required accuracy has been achieved. No mechanical limits would make sense. The length of the analysis depends on the needs of the design process and problems.

5. Conclusions

The focus of our paper has been in methodology. We have outlined an approach to cope with the constructive content of concepts. It is basically cognitive science, but it is intended to help engineers in constructing computational ontology. In the wide spectrum of methods of requirement engineering conceptual analysis as defined here provides one additional tool [cf. Bray 2002] In a respective manner, any concept relevant in building ontology can be analyzed into their attributes and this information can be used in engineering knowledge management. Naturally, the example of design ontology is just one example. Practically there are unlimited numbers of possibilities for applying conceptual analysis in reflecting design thinking.

The main use for conceptual analysis is the improvement of conceptual accuracy in design thinking. It is important to get rid of relatively loose and inaccurate ways of understanding concepts. It is also important to get rid of the idea that definitions are very decisive in investigating design thinking. Research groups may often have different conceptions about the content of their concepts. Nevertheless, these problems cannot be solved by dictatorial definitions, but they presuppose a rational analysis of the contents. It is possible to dictate ontology, but it is impossible to dictate nature.

It appears very rational to think that the better we are able to structure the knowledge, the easier and more natural its use would be. We should be able to represent required knowledge very much in the way we think. Information structure should follow the conceptual structures of the targets. However, penetrating into complex webs of ideas and concepts required in engineering design is not a trivial problem. It presupposes adaptive use of interdisciplinary knowledge and the introduction of new types of expertise in engineering contexts.

Conceptual accuracy is also vital in generating new ideas. Concepts determine the limits of our thoughts. This is why it may be very difficult to see alternative ways of looking at designed reality unless we are able to see the limits of our conceptual glasses. If we are used to thinking that rolls in a paper machine must be of stone as was thought some decades ago, we can hardly get an idea of an extended nip –construction. It is vital to not only look at the designed object but also the content of concepts we use in designing these objects. In fact, this is a lemma of Kant’s famous Copernican revolution, which demonstrated that nature does not imprint its laws in our minds but our minds imprint the laws on nature. Indeed, what else is design but constructing pieces of nature into the form we need it to be.

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