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## VISSER: DESIGN AS CONSTRUCTION OF REPRESENTATIONS

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### Abstract

In this chapter, we present our own approach to design, as we have described it in *The Cognitive Artifacts of Designing*: from a cognitive viewpoint, designing is constructing representations.

What is this link between design and representations? Designing consists in specifying an artifact, for example a machine tool – not in its implementation, its fabrication in the workshop. The result of design is a representation: the specifications of the machine tool. These representations are also artifacts, that is, entities created by people – they are "man-made as opposed to natural" (Simon, 1969/1996). Artifacts may be physical (machine tools, buildings, cars, or garments) or symbolic (software, social welfare policies, route plans, or any procedure); they may be internal (mental representations) or external (drawings, mock-ups). The term thus pertains not only to material objects. The antonym of an "artifact" is a "natural" – not an "immaterial" entity.

After a presentation of our definition of design, this chapter presents three types of activities designers perform on representations, namely generation, transformation, and evaluation. In special subsections, we review the use of knowledge in design, and how collaborative design proceeds through interaction. In the last two divisions of this section, we discuss activities that are specific to collaborative design.

## VISSER: DESIGN AS CONSTRUCTION OF REPRESENTATIONS

In this chapter, we present our own approach to design, as we have described it in *The Cognitive Artifacts of Designing* (Visser, 2006).<sup>1</sup>

### DEFINITION OF DESIGN

Definitions are representations: They focus on *aspects* of the object they aim to cover—even if their authors imagine that their focus is the object's *essence*. In our following review of definitions, we restrict ourselves to cognitive aspects of design.

Even considered from such a perspective, the characteristics of design that are selected as essential may still differ. Our focus on the activity of design further orients our view. Definitions may thus focus on characteristics whose relevance we do not deny, but that do not inform us about cognitive aspects of designing. An example is the definition by Moran and Carroll (1996):

"The primary goal of design is to give shape to an artifact—the product of design. The artifact is the result of a complex of activities—the design process" (p. 1).

Many definitions of design focus on the result of the activity, that is, the artifact product, ignoring the nature of the activity. In their *wording*, they may use references to actions, such as "specifying," "defining," or "creating," but not detail any activity in developments of the definition. Another characterization by Moran and Carroll (1996, p. 13) considers design as "the process of creating tangible artifacts to meet intangible human needs" (p. 2), to which the authors add, "creating and constructing" are "the defining acts of design." There are authors, such as Stacey and Eckert (2003, p. 164), who view designing as "modeling." Both are positions close to ours, but they present no further specification of the cognitive aspects of the activity. Other authors, often from AI-

<sup>1</sup> This paper is entirely composed by quotes from our book *The Cognitive Artifacts of Designing* (2006), Hillsdale, NJ, USA, Lawrence Erlbaum Associates.

related communities, consider design as a constraint-satisfaction activity, but propose methods without any cognitive underpinnings (see Darses, 1990, for a cognitive-psychology discussion of this approach).

Designers are not to produce the artifact product, but its specifications. We consider essential to distinguish between these specifications and the artifact product itself. A group of definitions seems to neglect this difference. They qualify design, for example, as "the creation of artifacts that are used to achieve some goal" (Mayall, 1979, in his *Principles in Design*, referred to in Atwood, McCain, & Williams, 2002).

For authors focusing on the specifications, design consists of producing plans or descriptions, or still other forms of representations of the artifact product (Archer, 1965/1984; Brown & Chandrasekaran, 1989; De Vries, 1994; Hoc, 1988; Jeffries, Turner, Polson, & Atwood, 1981; Kitchenham & Carn, 1990; Schön, 1988; Whitefield, 1989). Applied to software design, for example, this means that design leads to a plan that allows transformation of these specifications into executable code (Jeffries et al., 1981; Kitchenham & Carn, 1990). Many empirical studies of "software *design*" focus, however, on elaboration of executable code—that is, coding—rather than design.

According to most definitions, the artifact product has to meet certain requirements, that is, accomplish certain functions, fulfill certain needs, satisfy certain constraints, allow attaining certain objectives, and possess certain characteristics. Designing is thus usually defined—even if implicitly—as a goal-oriented activity—even if this goal is not fixed, or preestablished.

After a presentation of our definition of design, this chapter presents a characteristic of design that we consider essential, that is, its creative nature.

### OUR DEFINITION OF DESIGN

Globally characterized, from our viewpoint, design consists in specifying an artifact (the artifact product), *given requirements* that indicate—generally neither explicitly, nor completely—one or more functions to be fulfilled, and needs and goals to be satisfied by the artifact, under certain conditions (expressed by constraints). At a cognitive level, this specification activity consists of constructing (generating, transforming, and evaluating) representations of the artifact *until they are so precise, concrete, and detailed* that the resulting representations—the "specifications"—specify explicitly and completely the implementation of the artifact product. This construction is iterative: Many intermediate representations are generated, transformed, and evaluated, prior to delivery of the specifications that constitute the final design representation of the artifact product together with its implementation. The difference between the final and the intermediate artifacts (representations) is a question of degree of specification, completeness, and abstraction (concretization and precision). A similar view is expressed by Goel (1995), who writes: "Design, at some very abstract level, is the process of transforming one set of representations (the design brief) into another set of representations (the contract documents)" (p. 128).

Our focus on the activity and the intermediate representational structures should not lead to forgetting the central role of both the requirements as source and the implementable specifications as goal, that together steer both activity and representations. There are other activities that construct representations (especially, the interpretation of semiotic expressions), but due to their having other types of inputs and outputs than design, the underlying activities differ as well (cf. Hayes-Roth, Hayes-Roth, Rosenschein, & Cammarata, 1979, August's distinction between generation and interpretation problems [...]).

In our core definition, we qualify design as *construction*, rather than transformation of representations, because "transformation" may convey the connotation of the representations to be transformed, being *given* [...]. "Construction" is more general: [...] It involves both generation and transformation activities (and it also requires evaluation).

### DESIGN REPRESENTATION CONSTRUCTION ACTIVITIES

Many recent studies concern representational structures in design, especially external representations, but the cognitive activities and operations involved in their construction and use have not been the object of much research. Publications mention activities such as "transformation," "(re)interpretation," and "restructuring and combining." Generally, they describe the results that are obtained, but rarely make explicit the underlying cognitive activities or operations.

We distinguish three types of activities on representations, namely generation, transformation, and evaluation. These activities, their underlying operations, and related activities and operations are discussed in the following

subsections. In special subsections, we review the use of knowledge in design, and specific aspects of collaborative design.

### PROBLEM REPRESENTATION, SOLUTION GENERATION, AND SOLUTION EVALUATION: THREE STAGES IN DESIGN AS PROBLEM SOLVING

From a problem-solving perspective, design has often been described as proceeding through three stages, namely construction of problem representations, solution generation, and solution evaluation. A related, less high-level model sees these stages occurring in iterative cycles that, progressively, lead from the abstract, globally specified problem to its concrete, detailed implementable solution. None of these two models renders the actual design activity. The three stages correspond nevertheless to fundamental design activities, which are completely intertwined—and not at all consecutive, as stages are supposed to be. The perspective we have adopted, namely to consider design as the construction of representations rather than as problem solving, leads us to consider these three activities as construction of representations, even if they may involve different types of input and output representations.

### USING KNOWLEDGE IN DESIGN

Knowledge is a central resource in the construction and use of representations. The importance of knowledge holds for most professional domains, but it is of course particularly critical in an activity that essentially consists in representational activities. Design requires general, abstract knowledge and weak, generally applicable methods, but designers also need domain-specific knowledge and the corresponding strong, knowledge-intensive methods. We suppose that satisficing, for example, requires more domain-specific knowledge than does optimizing. This also holds for the exercise of creativity, which is so important in design. In addition, knowledge is a key element in the exercise of analogical reasoning—which may, in turn, be related to design creativity (but see Visser, 1996).

[...] In the presentation of the SIP approach, [references to the role of knowledge] were very general, because this problem-solving view insists mainly on generic knowledge and weak methods. In the SIP approach to problem solving, one searches for solutions in the "problem space," going "from one knowledge state to another, until the current knowledge state includes the problem solution" (Simon, 1978, p. 276). [...]

In our presentation of the SIT view, knowledge did not play an important role neither, but for different, nearly opposite, reasons. SIT-inspired researchers have identified and described in detail much domain-specific knowledge. They insist on the role of "knowledge-in-action"—which they oppose to school knowledge, whose role is of course not denied, but ignored in their research. SIT-inspired studies have provided us with extremely rich descriptions of situations that were often so unique that presentation of the knowledge identified would have been rather anecdotal. One may notice that it is undeniably difficult to find a level of description of interest to many different people (researchers, practitioners, students, general public), with different backgrounds and interest in different domains. Furthermore, SIT-inspired researchers emphasize that there is more to design—and other professional practice—than knowledge (cf. Bucciarelli, 1988).

[....]

Yet, without knowledge, no representation! Knowledge is necessary—but of course not sufficient—for the construction of representations. Without knowledge, no interpretation, thus neither the possibility to look at a project in a way different from one's colleagues, nor that of seeing things differently than one did during a previous project!

The operative and goal-oriented character of representation results from an interaction between one's knowledge and experience, and the situation one is in.

Nonalgorithmic activities—necessary in, for example, creativity, satisficing, (re)interpretation, and qualitative simulation—require knowledge. In order to proceed to complex calculations, a designer, of course, also needs knowledge, but of a sort that can be learned in school. The knowledge that is very important in design is not gained through formal education, but through experience. Designers may acquire such knowledge because of their work on many different types of projects, and their interaction with colleagues who have other specialties (see Falzon & Visser, 1989).

Knowledge determines if a design task constitutes a problem for someone. Working with ill-defined problem data is only possible if one has specific knowledge (in addition to generic knowledge, of course).

Furthermore, knowledge is a critical resource underlying most strategies. If simulation via representations works, it is thanks to one's knowledge. Reuse is, by definition, impossible without knowledge (it is not a components library that makes knowledge superfluous). Handling constraints (especially constructed constraints) would be hard without it.

The domains from which this knowledge comes are not only the application domain and that of design methods, but also the underlying technical and theoretical domains (mathematics, science, engineering)—and even non-technical domains. In our carrying/fastening device study (Visser, 1995), we showed the importance of common-sense knowledge (in the design project examined, this was the knowledge of cycling). Additionally, designers, one may hope, also draw on ergonomics and knowledge of social, political, economic, and legal aspects of the artifact and its use. As designers generally are not expert in all these different domains, the need of design projects for wide-ranging knowledge requires collaboration between professionals from various domains.

With respect to knowledge of different abstraction levels, designers of course use much generic, abstract knowledge (first principles, general-purpose knowledge, weak methods). However, the reuse of specific knowledge related to particular past design projects plays an essential role in design (Visser, 1995). In our carrying/fastening device study (Visser, 1995), we observed how the knowledge of cycling is not theoretical, school knowledge, but the result of personal experience in cycling, with or without a backpack, on a mountain bike or other bicycle. We showed how this episodic knowledge (Tulving, 1972, 1983) grounded in personal experience may be used in various ways (both in the construction of representations used for the generation of solution ideas, and in the evaluation of solution proposals). In this study, we also showed the importance of human informants besides non-human information sources. We observed how designers often use colleagues as informants—and how colleagues present themselves as such without being requested explicitly (Berlin, 1993; Visser, 1993).

These are only a few examples, mentioned in order to indicate the importance of knowledge in design.

*Expertise and knowledge.* [...] There are at least three types of research on expertise. The comparison between experts and novices in a domain, that is, studies on *levels* of expertise, is the classical paradigm in studies on interindividual differences in this domain (Chi, Glaser, & Farr, 1988; Cross, 2004, 2004 Ed.; Expertise in Design, 2004; Glaser, 1986; Glaser & Chi, 1988; Reimann & Chi, 1989). Experts have also been studied in clinical studies, leading researchers to identify particular characteristics of particular experts (Cross, 2001, 2002).

We have proposed to distinguish also different *types* of expertise (Falzon & Visser, 1989; see also Visser & Morais, 1991). We analyzed how experts in the same domain may exhibit different types of knowledge, and observed that this knowledge is also organized differently between the experts. We attributed these differences to different task experience (workshop vs. laboratory in the context of the aerospace industry). Our analysis of previous studies by colleagues who compared experts showed, in addition to the role of one's task, the importance of the representation that one constructs of one's task. The comparison between the two experts examined led us to qualify the knowledge of one expert's as "operative" and that of the other as "general." "The two experts differ in the same way as a teacher differs from a practitioner, in the same way as an epistemic subject differs from an operative subject" (Falzon & Visser, 1989; see also Visser & Morais, 1991).

## GENERATION AND TRANSFORMATION OF REPRESENTATIONS

[...]

*Generation.* A representation is never generated "out of nothing" (*ex nihilo*, from scratch). We consider it difficult, if not impossible, to decide if an idea or drawing (or other representation) is "new." In accordance with Goel [...] we consider that design always consists in *transformation* of representations. We qualify the construction of representations as "generation" [...] if its *main* source is one's memory—something that will be difficult to observe for an external observer. We insist on "main," because memory will never be the only source. By definition, the state of a design project (requirements and their follow-up included) will influence a designer. In addition to this influence, there will be other contributions "from the outside world."

Designers will interpret the input to a design project, that is, the requirements and other data that they receive or collect (e.g., reference documents, similar artifacts), in order to generate a first representation—which may consist of an ensemble of representations: For example, one or more related mental and external representations.

Generation may be implemented by different types of processes and operations: From the "simple" evocation of knowledge from memory to the elaboration of "new" representations out of mnemonic knowledge entities without a clear link to the current task (e.g., through analogical reasoning and other nondeterministic leaps; Visser, 1991).

[....]

The distinction between generation by evocation and by elaboration of course does not correspond to a clear-cut opposition, but is an analytical distinction that refers to a continuous dimension. Elaboration of a representation always uses mnemonic entities, which will have been evoked from memory [...]. We have illustrated this idea elsewhere by observations from our composite-structure design study (Visser, 1991).

Schema instantiation is a form of knowledge evocation that has received much attention in software-design studies. Schemata have indeed been the main framework for the analysis of knowledge representation in cognitive software-design research (Détienne, 2002).

Generation of representations may use operations and other activities, such as information gathering.

*Transformation.* We propose to distinguish transformation activities according to the type of transformation between input representation  $r_x$  and output representation  $r_y$ . We distinguish the following forms. Transformation activities may

- *duplicate* (Goel, 1995), that is, replicate or reformulate  $r_i$ .
- *add*, that is, introduce new information or "small alterations" (Van der Lugt, 2002) into  $r_i$ .
- *detail*, that is, break up  $r_i$  into components  $r_{i1}$  to  $r_{in}$ .
- *concretize*, that is, transform  $r_i$  into  $r_i'$  which represents  $r_i$  from a more concrete perspective.
- *modify*, that is, transform  $r_i$  into another version  $r_i'$ , neither detailing, nor concretizing it.
- *revolutionize* (Visser, 2009), that is, replace  $r_i$  by an alternative representation  $r_j$ , neither detailing, nor concretizing it (corresponding to Van der Lugt, 2002's "tangential transformations", i.e. "wild leaps into a different direction").

[...] [We] consider that both transformations into different versions (through modifying) and into alternative representations (through revolutionizing) constitute "lateral" transformations. [...]

Many activities play a more or less direct role in these different types of transformation. Some examples (varying between operations and activities) are interpretation, association, brainstorming, reinterpretation, confrontation, articulation, integration, analysis, exploration, inference, restructuring, combining, drawing (sketching, drafting, and other forms), hypothesizing, and justifying. In this book, we comment on only some of them.

[....]

Even if it is too simplistic to qualify "analysis" as a first design "stage," analyzing indeed corresponds to a central activity in the initial phases of a design project. Constraints analysis is essential to disambiguate design requirements. Analyzing the current design state may be a way to introduce detail or concreteness in the project. "Analysis" has, however, a logical undertone, which causes that it can certainly not be the only—or even the main—activity in the initial design phases. Other, more nonalgorithmic activities will also be required, such as interpretation, association, brainstorming, and exploration.

Analogical reasoning occurs in all three representational activities. We have mentioned it in different contexts: As a factor of opportunism, in creativity-requiring activities, as a way to tackle ill-defined problems by interpreting them, and as a possible form to generate "interesting" design ideas. It is also the reasoning form that underlies reuse, which plays an important role in design.

We observed its role in different studies, several examples of which have been presented in this book. [...] [We] described analogical reasoning used by the mechanical-design engineer in our functional-specification study (see Table 6.1). Using analogies, he took advantage of representations that he was constructing and using for his current design actions, to design analogically related design objects. A completely different use of analogy has been observed in the composite-structure aerospace design study [...]. There, the designer especially employed analogical reasoning in the conceptual-design stage. When elaborating conceptual solutions to design problems, he and his colleagues frequently were observed to be reminded of extradesign domain objects that implemented concepts (principles, mechanisms) that they judged potentially useful for development of a solution to the current design problem. The following example (from Visser, 1996) illustrates this use of analogy that we analyzed as contributing to the innovative character of the design project (other examples are presented in Visser, 1991).

*Example.* When the composite-structure designer and his colleagues are developing, in a discussion, "unfurling principles" for antennas, they come up with ideas such as an "umbrella" and other "folding" objects. They proposed, for example, a "folding photo screen," a "folding butterfly net," and a "folding sun hat," all related to the target by analogical relationships.

Different forms of inference are of course also used in design. Induction is used much more frequently than deduction. Goel (1995) identifies only 1.3% "(overt) deductive inferences" in his observations. In our composite-structure design study (see Table 6.1), neither did we notice any overt form of deduction.

The articulation, combination, and integration of representations play a particular role in collaborative design. So do inform, comment, and request. Such activities are discussed in the subsection *Construction of Interdesigner Compatible Representations*.

Restructuring and combining representations are often mentioned as components of the creative process (Verstijnen, Heylighen, Wagemans, & Neuckermans, 2001; Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998). Verstijnen et al. show that restructuring and combining are two separate constituents of creativity that function differently. In distinct ways, each can lead designers to introduce new information in the current design representation—something that is useful in generation and transformation of representations.

Restructuring is qualified by the authors as "getting free from an original conception" (1998, p. 545). Verstijnen et al. claim that "mental imagery" operations (i.e., operations on mental images) may lead to discovery of new ideas—but only under certain conditions. Some operations cannot be performed "within mental imagery alone" and other operations "are much easier to perform externally" (p. 522).

It is difficult to restructure completely mentally an existing external representation (i.e., a drawing, in Verstijnen et al.'s experimental studies)—for novices, it is even impossible. It is facilitated if one is allowed or encouraged to sketch—but this facilitation only holds for experienced designers. However, combining (synthesizing) parts of a representation can be performed mentally by only using mental imagery. In that case, "no additional value is obtained from sketching" (Verstijnen et al., 1998, p. 535). One may indeed suppose that the two operations—restructuring and combining—impose different loads on mental processing.

Yet, inventors (such as Kekulé, an example presented by Verstijnen et al.) seem to be able to restructure exclusively "in their head." Verstijnen et al. (1998, p. 546) formulate the interesting hypothesis that "extraordinarily creative individuals" may be able to "construct analogies within imagery, for which others, in more mundane cases, require a sketch" (1998, p. 546). Indeed, what an external representation such as a sketch allows a person is to restructure their image (i.e., an internal representation) in analogy to that external representation. This inspires in Verstijnen et al. (2001, p. 1) the idea that "with no paper available or no expertise to use it, analogies can be used to support the creative process instead of sketches" (2001, p. 1)—but perhaps only in "extraordinarily creative individuals" (the addition is ours).

As tools for reinterpretation, activities such as restructuring and combining may thus be used to come up with new ideas. Drawing (i.e., sketching, drafting, and other forms of drawing) may also be a tool for other activities. Besides restructuring, it may serve, for example, analysis, and simulation. It may also fulfill interactional functions, such as informing or explaining. It can even have several functions simultaneously: For example, simulation, explanation, and storing. The relatively unstructured, fluid, and imprecise drawings that sketches are, may give access to knowledge not yet retrieved and may evoke new ways of seeing [...]. Unforeseen views on the design project in progress are supposed to open up unanticipated potentialities for new aspects or even completely new directions.

## EVALUATION OF REPRESENTATIONS

According to design methodologies, the generation and evaluation of solutions are two different stages in a design project. Many empirical studies have shown, however, that designers intertwine the two. The participants in the technical review meetings that we studied (D'Astous, Détienne, Visser, & Robillard, 2004) were supposed to follow a particular method in which design was not supposed to occur. They came up, however, with alternative solutions; that is, not only were they recording the underlying negative evaluations, but they also proceeded to design.

Evaluating an entity consists in assessing it vis-à-vis one or more references (Bonnardel, 1991a). In the context of design, evaluation may occur when a representation is presented by its author, or interpreted by colleagues, as an "idea" or "solution proposal." Colleagues may interpret a representation as a solution proposal without its author presenting it explicitly as such, and they may evaluate it without its author explicitly requesting them to do so (Visser, 1993).

*Terminology.* The terminology around "constraints" and "criteria" is still under debate in the domain of cognitive design studies. Bonnardel (1989) reserves the term "constraints" for operative evaluative references and "criteria" for conceptual references, whereas we use "constraints" for generative references that steer solution genera-

tion and "criteria" for critical evaluative references guiding solution evaluation (Visser, 1996). Other distinctions have also been proposed.

According to the source of an evaluative reference, researchers distinguish different types of evaluative references (Bonnardel, 1991a; Ullman, Dieterich, & Staufner, 1988):

- Prescribed constraints, which are given to the designer or which the designer infers from the problem specifications.
- Constructed constraints, for which designers mainly use their domain knowledge.
- Deduced constraints, which designers infer based on other constraints, the current state of the design project (the problem solution), and design decisions made during their design problem solving.

Depending on the type of reference used by a designer, researchers distinguish three evaluation strategies (Bonnardel, 1991b; Martin, Détienne, & Lavigne, 2000, 2001), all three of which we qualify as "comparative":<sup>2</sup>

- Analytical evaluation: A solution is assessed vis-à-vis a number of constraints.
- Comparative\* evaluation: Various solution versions or alternatives are compared with each other.
- Analogical evaluation: A solution is assessed using knowledge acquired in relation to a previous solution.

In an analysis of negotiation patterns between participants in multidisciplinary aeronautical-design meetings, Martin et al. (2000; 2001) show that if such evaluation does not lead to a consensus between the different partners, arguments of authority may be used.

Evaluative references are forms of knowledge. As expected, designers' expertise in a domain influences their use of these references (D'Astous et al., 2004).

Given that, in a collaborative design setting, designers may have different representations of a project, proposals are evaluated not only based on purely technical, "objective" evaluative criteria. They are also the object of negotiation, and the final agreement concerning a solution also results from compromises between designers (Martin et al., 2000, 2001). In addition, not only solution proposals, but also evaluation criteria and procedures undergo evaluation (D'Astous et al., 2004).

The preceding discussion concerned different forms of evaluation by comparison, that is, with respect to evaluative references. This type of evaluation is possible if the form of the representation that is to be evaluated allows such a comparison. For example, if one knows already the performance measures of the artifact. This is often the case in engineering, where "objective" measures of artifacts are possible (e.g., measures of their future performance).

The evaluation of other types of artifacts may be based on simulation. The result of such simulation (e.g., a certain behavior displayed by the artifact) may constitute the input of comparative evaluation.

Evaluation has functions at both the action-execution and the action-management level of the design activity. The classical solution evaluation occurs at the action-execution level and leads generally to the selection of one proposal—possibly after one or more iterations. At the action-management level, evaluation affects the progress of the design process. Depending on the results, design may be pursued in different ways. Designers, thus, evaluate not only solutions, but also their possible design process, its progression, and direction (Visser, 1996).

## COLLABORATIVE DESIGN THROUGH INTERACTION

Collaborative design takes different forms and refers to the various representation-construction activities presented earlier. Besides the functions that representations play in both individual *and* collective design settings (mainly cognitive offloading, reminding, keeping track, storage, communication, organizing, reasoning, and discovery), various aspects of the externalization possibilities of representations provide additional functions specific to collective design. These functions go together with different cooperative activities, which vary according to the phases of the design project. During distributed design, when the designers' central activity is coordination in order to manage task interdependencies, representations of course play a role. Yet, it is in co-design that they have a particular function, due to its collaborative setting.

<sup>2</sup> We therefore label the specific evaluation mode that is called "comparative evaluation" in the literature, as "comparative\* evaluation" in order to distinguish it from the more general "evaluation by comparison," of which it is only one particular form and that also includes the analytical and analogical evaluation modes.

In collaborative-design situations, individual design plays of course also an important role (as we have emphasized at different occasions in this text, see also Visser, 1993; 2002). Yet, an essential part of collaborative design, especially during co-design, takes place—that is, advances—through interaction. This apparently unequivocal statement—it may even seem tautological—conveys characteristics of design thinking that we consider essential.

Indeed, the different forms that interaction may take in collaborative design—especially, linguistic, graphical, gestural, and postural—are, in our view, not the simple *expression* and *transmission* (communication) of ideas previously developed in an internal medium (such as Fodor's "language of thought"). They are more and of a different nature than the trace of a so-called "genuine" design activity, which would be individual and occur internally, and which verbal and other forms of expression would allow sharing with colleagues. On this issue, we do not concur with Goldschmidt (1995) when she writes that "thinking aloud and conversing with others can be seen as similar reflections of cognitive processes," which we can accept as "equal windows into the cognitive processes involved in design thinking" (p.193).

Notice that, in these collaborative contexts, a fundamental part is played by other factors than cognitive ones (representations, knowledge). These are especially emotional factors, and social, institutional, and interactional factors, such as the roles of the different design participants (formal, static roles that depend on one's predefined function in the design project, and informal roles that emerge and evolve depending on the interaction, see D'Astous, Robillard, Détienné, & Visser, 2001; Fagan, 1976; Herbsleb et al., 1995; McGrath, 1984; Seaman & Basili, 1998).

In the following and last two divisions of this section, we discuss activities that are specific to collaborative design.

### CONSTRUCTION AND USE OF INTERMEDIARY REPRESENTATIONS IN COLLABORATIVE DESIGN

Many notions referring to the interdesigner intermediary function of representations in collaborative design have been proposed in the literature, such as "intermediary objects," "coordinative artifacts" (Schmidt & Wagner, 2002), "entities for cooperation" (Boujut & Laureillard, 2002), and "boundary objects" (cf. also Star, 1988's boundary objects, discussed below).

Emphasizing the material setting and the artifactual nature of these entities that are essential in designers' interaction, Schmidt and Wagner (2002) emphasize that, in cooperative work, their main role is not informative, but coordinative: They contribute to a more or less effortless and fluent coordination and integration of individual activities in coordinative practices.

For architects, a particular form of coordinative artifacts is "layered artifacts." They are a tool that architects use "for communicating things that need to be taken account of or changed." Schmidt & Wagner (2002) describe that architects construct them by "making annotations on a document, e.g., putting a red circle around a problem, adding details (correct measures, material), marking a part of a drawing with a post-it with some instructions for changes, corrections (e.g., in pencil directly on a plan), sketching either directly on a plan copy or on transparent tracing paper. . . ."

Layered artifacts facilitate coordination between activities (and the people who are responsible for them). They, for example, provide a collective or individual space for experimentation and change. The CAD drawing itself is a layered artifact, which builds on a particular mix of codes for functions and materials and has been tailored to a particular division of labor." (Schmidt & Wagner, 2002, pp. 10-11)

The benefit of visual expression in creative collective activity has been examined by Van der Lugt (2002). One of the supposed specific contributions of visual expression to idea generation in a collective setting is that, through conversation with the drawings of colleagues, people may build on each other's ideas. Van der Lugt shows that sketching using brainsketching tools indeed contributes to creative activity in idea-generation groups, but not as expected: It especially supports reinterpretation of one's own ideas, and so stimulates creativity in *individual* idea generation. Reinterpretation of ideas generated by other group members is not enhanced. Collective working is thus not the panacea for all complex processes. Individually conducted activities in collective settings may sometimes lead to "better" results. The visual expression in a collective setting may nevertheless improve integration of the group process, by facilitating the access to previously expressed ideas.

Van der Lugt emphasizes that his results may be specific to the techniques and tools examined, and thus cannot be generalized to other sketching and idea-generation tools. Indeed, in another study on sketching tools, using a

different technique (visual brainstorming), Van der Lugt (2000) observed a breakdown in the idea-generation process.

Another communicative situation in design projects is the interaction between people involved in design and in implementation. Eckert's study of knitwear design (presented in Stacey & Eckert, 2003) constitutes an interesting example of the difficulties that these situations may bring about.

The knitwear designers examined by Eckert use "technical sketches" in order to communicate their patterns and garment shapes to the machine technicians who are to implement the knitwear designs in garments. In addition to a freehand drawing part (the actual sketches), these documents comprise a short verbal description and a set of dimensions (Stacey & Eckert, 2003, p. 157). These technical sketches are supposed to clarify the designer's specifications, but "are often excessively imprecise or ambiguous." The technicians tend to ignore the actual sketch part, and "rely mainly on the verbal descriptions, which only give broad indications of categories" (pp. 157–158). The technicians are not able to distinguish in these documents the important and relatively exactly specified design aspects from unimportant details and elements that are placeholders for broad categories (e.g., the type of neckline or the chest pattern). As they "have no way of judging what to believe, [they] usually take what is standard as more likely to be reliable" (p. 174). This leads to the products, that is, the garments, often being more traditional than intended by their designers. The technicians repeatedly produce garments "that violate the designers' intentions." They also often state that "what the designers want can't be done" (p. 174).

Notice that this conclusion—technicians refer to standards for understanding the specifications they receive—is not restricted to these specific technicians and these particular technical sketches. It may hold for anybody who is to interpret any semiotic expression produced by other people. Both designers and other participants in the development process of an artifact, interpret the language as well as the graphical expressions by their colleagues, in terms of the standards they are familiar with—and of their own past experience of artifacts more or less similar to the current object of the design project.

Still another communicative situation—but one that is not necessarily present in every design project—is that between designers and users. With respect to interactive-software design, Carroll (2006) notices that there is a big and crucial "gap" between the worldviews held by designers of software and its potential users. Participatory design is one way to bridge this gap. Research in this domain has produced many proposals for possible design representations enabling the two parties to communicate:

"Many of these approaches essentially implement a user interface design at the earliest stage of system development: Designers can show concretely what they have in mind, rather than specifying it mathematically, and other stakeholders can react and critique what they can actually see and manipulate. . . . A slightly more abstract approach is scenario-based design in which system functionality and the experience of using that functionality are described in narrative episodes of user interaction." (Carroll, 2006)

Argumentation—a "hot item" in studies on cooperative activities—has only been touched on in this book (cf. Rittel, 1972/1984's argumentative model). Authors attribute a more or less broad sense to the notion. We conceive argumentation as an attempt to modify the representations held by one's interlocutors. Many activities in co-design are thus argumentative.

*Boundary representations.* As advanced by Star (1988), in collaborative design, one needs "boundary objects" to serve as an interface between people from different "communities of practice." These objects may take many artifactual forms, for example, representational. We have proposed to qualify as "boundary representations" (no connection to the b-rep model for representing a cube) the representational version of boundary objects (Visser, 2009). The fact that they work does not mean that partners from different communities view or use them in the same way. Different partners may interpret them differently, but they work if they contain sufficient details understandable by these parties. No party needs to understand the full context of use adopted by their interaction partners. It is the acknowledgment and discussion of the differences that enable people to use them successfully together.

An example of a representation meant as a boundary representation is the technical sketch used by the knitwear designers examined by Eckert (see Stacey & Eckert, 2003, p. 163, see also our presentation above). They do not work as boundary objects, because they do not contain sufficient detail to be understandable by the different parties involved. Successful communication depends not only on "the sender's use of appropriate representations for information," but also on "the recipients' ability to construct meaning from those representations" (Stacey & Eckert, 2003, p. 158).

According to Stacey and Eckert (2003), two factors play herein a particularly important role:

"The extent to which the participants share context and share expertise; and the tightness of the feedback loops. . . . In face-to-face communication, failures of comprehension can be identified and conveyed very quickly, and speech, gestures and sketches are used to explain and disambiguate each other. . . . In less tightly coupled exchanges, the need to prevent rather than correct misunderstanding is correspondingly greater." (p. 162)

With respect to these factors, Eckert observed that in nearly all companies that she had visited, designers do their conceptual design without any input from the technicians that are to implement their designs. This absence of communication may explain, at least in part, that the technical sketches used as specification documents by the knitwear designers are ambiguous—that is, in the form that the two parties use them: Without any other interaction allowing them to be acknowledged and discussed. "The less the participants discuss, and the less knowledge and contextual information they share, the more sketches, diagrams and other communications need to carry with them the means of their own interpretation" (Stacey & Eckert, 2003, p. 163).

### CONSTRUCTION OF INTERDESIGNER COMPATIBLE REPRESENTATIONS

In a paper on "bringing different points of view together," Fischer (2000) writes:

"Because complex problems require more knowledge than any single person possesses, communication and collaboration among all the involved stakeholders are necessary; for example, domain experts understand the practice, and system designers know the technology. Communication breakdowns are often experienced because stakeholders belonging to different cultures (Snow, 1993) use different norms, symbols, and representations. Rather than viewing this *symmetry of ignorance* (Rittel, 1984) (or 'asymmetry of knowledge') as an obstacle during design, we view it as an opportunity for creativity. The different perspectives help in discovering alternatives and can help uncover tacit aspects of problems." (Fischer, 2000, p. 3)

Construction of interdesigner compatible representations when co-designing proceeds through activities qualified as "grounding" (Clark & Brennan, 1991) and "cognitive synchronization" (D'Astous et al., 2004; Falzon, 1994), through a negotiation process resulting in "social constructions" (Bucciarelli, 1988) or through argumentation resulting in the settling, "dodging," or substitution of "issues" (Kunz & Rittel, 1979). A great amount of time is spent on these activities (Herbsleb et al., 1995; Karsenty, 1991; Olson, Olson, Carter, & Storrosten, 1992; Olson et al., 1996; Stempfle & Badke-Schaub, 2002). Recent studies have observed that synchronization can also take a gestural form (cf. research in Tversky's STAR team, <http://www-psych.stanford.edu/~bt/gesture/>, retrieved August 16, 2005).

In our study on software-review meetings (D'Astous et al., 2004), we showed that the construction of interdesigner compatible representations of the to-be-reviewed design solution was a prerequisite for the occurrence of evaluation activities, which were the prescribed task. We also observed that cognitive synchronization concerned not only the problem solutions but also the criteria and the evaluation procedures.

Given that designers have their personal representations, collaboration between designers calls for confrontation, articulation, and integration of these different representations, in order for the designers to be able to reach a solution that is adopted for the common activity. The confrontation of personal representations also leads to conflicts between designers, which they are to resolve (see a remarkable early study in the domain of architectural design by Klein & Lu, 1989).

An interesting reading of (Simon, 1969/1996) thinking about representations is provided by Carroll (2006). Carroll notices that in the second edition of *Sciences of the Artificial*, Simon's view seems changed. In "Social Planning," a new chapter in this edition, Simon "suggested that *organizations* could be considered design representations (pp. 141–143), using the example of the Economic Cooperation Administration (ECA), the entity that implemented the Marshall Plan in 1948" (p. 12). At the outset, people involved in ECA did not agree on this agency. Carroll quotes Simon who "observes (p. 143), 'What was needed was not so much a 'correct' conceptualization as one that would facilitate action rather than paralyze it. The organization of ECA, as it evolved, provided a common problem representation within which all could work'" (p. 12). As the ECA proceeded, one of the six original conceptions prevailed. Carroll comments, "many uses of prototypes in participatory design are compatible with this suggestion; prototypes provide an evolving framework for exploring design options and gradually focusing on a final solution" (Carroll, 2006).

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