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DESIGN: ONE, BUT IN DIFFERENT FORMS

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Abstract. This paper defends an augmented cognitively oriented "generic-design hypothesis": There are both significant similarities between the design activities implemented in situations and crucial differences between these and other cognitive activities; yet, characteristics of a design situation (i.e., related to the design process, the designers, and the artefact) introduce specificities in the corresponding design activities, cognitive structures that are used, and resulting design. We thus combine the generic-design hypothesis with that of different forms of designing. In this paper, we propose a series of candidates underlying such forms of design, outlining a number of directions that need further elaboration.

Keywords. Generic design; Cognitive design research; Design cognition; Design practice; Design theory.

Based on their empirical studies of "activities as diverse as software design, architectural design, naming and letter-writing," one of Thomas and Carroll (1979/1984)'s conclusions is that these activities

"appear to have much in common" (p. 234). On the basis of a theoretical analysis, Simon (1969/1996) considers that engineers and composers are engaged in a "common creative activity" in their "creative, professional design process" (p. 137).

The notion "generic design," proposed by Goel and Pirolli (1992) combines this idea of common features between the design activities in different domains, with still another assumption. On the one hand, design is a "natural category of activity" (Goel & Pirolli, 1992, pp. 398-399); on the other hand, the activity is distinct from nondesign activities. Goel and Pirolli formulate their "intuitions about generic design" as a "hypothesis about the *design problem space*." "Problem spaces exhibit major invariants across design problem-solving situations and major variants across design and nondesign problem-solving situations." (p. 399)

According to Goel and Pirolli (1994), the generic-design principle "was one of the corner stone premises of the design methodology movement" (p. 53). Whereas this movement was not based on an analysis of the cognitive activities underlying design, Goel and Pirolli aim to "motivate the notion of generic design within information-processing theory," that is, within the framework that Newell and Simon (1972) developed in order to analyse problem solving from a cognitive viewpoint.

A notion close to that of "generic design" is what Zimring and Craig (2001) qualify as "domain-independence" of design. One may interpret this notion, however, as only referring to design being invariant across domains, not necessarily to design differing significantly from other cognitive activities. In this sense, the idea of a domain-independent theory of design is defended by many design researchers and practitioners, among whom certain authors indeed argue their position on the basis of similarities between two or more domains of design (Gero & McNeill, 1998).

During the "Design Dialogues: one" meeting, entitled "Universal Theory of Design: is a domain independent theory of design possible?,"¹ the participants explored "the reasons for the apparent lack of progress in design research over [the decade 1985-1995] and in particular whether the search for an atemporal, acultural, domain independent theory of design is a reasonable or realistic goal." During this meeting, Nigel Cross stated that "A primary goal of the Design Research Society since its founding in

¹ "Design Dialogues: one" was "the first in an occasional series of discussion meetings on design theory sponsored by the Design Research Society," held at University College London, May 17, 1995, organised by Janet McDonnell and Brian Logan (McDonnell, 1995).

the 1960s has been a domain independent theory of design within the context of a science of design²" (McDonnell, 1995). "On the question of whether theories, of whatever kind, can be domain independent, there was a... diversity of views.... some participants believing that some form of universal theory is possible ranged against those who argued for the incommensurability of different views of design or that the elimination of context necessary for a universal theory would result in an activity unrecognisable as design" (McDonnell, 1995).

"Domain" in this context is generally equated with "discipline" ("discipline of practice"), such as engineering, architecture, computer science, or industrial design, but it may be used in a wider acceptance. Discussing domain-general versus domain-specificity in cognition, Frensch and Buchner (1999, p. 142, quoted in Zimring & Craig, 2001, p. 126) define a domain as "anything that a given constraint can potentially be generalized to and from."

The idea, however, that design significantly differs from nondesign activities is stated explicitly less often. Cross (2001a; 2002b) advances—as the underlying axiom of the design discipline he defends (see below)—that there are "forms of knowledge special to the competencies and abilities of a designer." Yet, specifying these forms of knowledge is not evident. Zimring and Craig (2001) consider that "common descriptions of design—that designing involves abductive reasoning, construction, ill-defined problem solving skills—...are not always sharp enough to both distinguish design from other types of problem solving and unite design across different design-related disciplines" (p. 125). The authors propose that the analysis and description of design in terms of "mid-level constructs" "may be more profitable in scaling research across disciplines" (p. 126). Zimring and Craig (2001) propose, as examples, "mid-level" processes or types of reasoning, such as mental simulation, decision making, and analogical reasoning.

Using Google with the keyword "generic design" mainly leads to references in the domains of AI and knowledge-acquisition (e.g., KADS and successor work), based, for example, on Chandrasekaran (1983)'s "generic tasks," on the notion of "generic design methods," and other "generic design agents" (see, e.g., Warfield, 1994). These are all normatively based approaches to design, whereas we are concerned with a cognitively oriented descriptive analysis of design and nondesign activities.

² Notice that a "science of design" is not necessarily a "design science." Cross (2001a; 2002b) clearly distinguishes the two (see below).

In this framework, the present paper is a first step in an endeavour to examine an *augmented cognitively oriented generic-design hypothesis* (which concluded our book, *The Cognitive Artifacts of Designing*, Visser, 2006b): *Analysed from a cognitive viewpoint, design has specific characteristics that distinguish it from other cognitive activities, but also takes different forms depending on the main dimensions of the design situation* (i.e., the design process, the designers, and the artefact). If this is the case, it would have consequences for design environments, support systems, and design education, notably for the representations and activities preferentially used when designing, and the constraints and criteria selected for consideration.

In this paper, we will focus on these different forms of design. Before examining them in section 3, we will briefly discuss the two constituents of Goel and Pirolli's generic-design hypothesis, i.e. commonalities between designing in different situations (section 1) and differences between designing and non-designing (section 2). In section 4, the Conclusion, we will discuss our augmented cognitively oriented generic-design hypothesis.

1. Design is one: commonalities between designing in different situations

From the early 1980s on, following Simon (1969/1996) and his analysis of design in *The Sciences of the Artificial*, researchers in cognitive design research have characterised design as an activity that is a rather different from that presented in prescriptive design models. They have also amended, however, more or less, Simon's position (see iii to vi).

- (i) Design is a problem solving activity (one of Simon's central stances with respect to design, based on the framework developed in Newell & Simon, 1972);
- (ii) Design problems are ill-defined problems (Simon, 1973/1984 qualifies them as "ill-structured")
- (iii) Design problems are complex problems that are not decomposable into independent sub-problems;
- (iv) Rather than one solution, "the" "correct solution, design problems have several, acceptable solutions, which are more or less satisficing;
- (v) Design problems and solutions lack pre-existing, objective evaluation criteria;
- (vi) Problem analysis and solution elaboration progress in parallel (rather than in consecutive stages);
- (vii) Designers cannot resort to a pre-existing plan for their activity: the organisation of their activity is opportunistic, in that, dependent on the design situation, they combine different strategies;
- (viii) Reuse of knowledge (coming from particular previous design projects) combined with use of generic knowledge (especially, from design methodology, the application domain, ergonomics).

These qualifications were based on studies in different application domains and contributed to the position, which often remained implicit, that design is a generic activity (claim formalised by Goel & Pirolli, 1992).

In recent years, we have continued to amend Simon's position. We have developed the idea that designing is more appropriately qualified as the construction of representations than as problem solving (Visser, 2006b, 2006c). From a formal viewpoint, design is indeed a "problem solving" activity—based on the design specifications, designers are rarely able to evoke from memory a pre-existing problem-solving procedure. However, qualifying design "just" as problem solving is not very informative. In this paper, we cannot detail these ideas.

In this section, we present some empirical studies revealing more or less similar features between designing in different situations.

Except for Goel and Pirolli's work (1994; 1989), the generic-design hypothesis has received few substantiation through comparative cognitive analyses. There is, however, a series early, empirical cognitive design studies conducted by Carroll and various colleagues in different design disciplines (see the review of this work in Thomas & Carroll, 1979/1984). In their discussion, Thomas and Carroll conclude that software design, architectural design, naming, and letter writing have many commonalities.

In his paper *How is a piece of software like a building? Toward general design theory and methods*, Gross (2003) advances that these two types of artefacts are alike on several dimensions (their size, level of complexity, lifetime, and degree to which their components are subject to change, the proportion of reusable components in their structure, the sanitary risks and safety concerns that particular uses or states of these artefacts may introduce, the type of their use or user, and the differences between their client and user. We will develop most of these dimensions below.

Reymen et al. (2006) have performed empirical case studies in three design disciplines—architectural, software and mechanical design—in order to develop domain-independent design knowledge. The authors conclude that the supposed "important differences" between these design disciplines "concern mainly differences in terminology" (p. 151). One may notice, however, that the authors did not observe designers at work. They conducted interviews concerning particular design projects (four in each discipline) and analysed the documentation of the corresponding projects.

Many authors have advanced that reuse is both an essential and a typical design strategy. Juxtaposing observations gathered on industrial designers (in the Delft study, Visser, 1995b) and observations on software designers (Visser, 1987), we have established that designers from both disciplines indeed proceeded to reuse. In spite of their assertions about the importance of reuse in design, many authors did not present any empirical support (see our critical analysis in Visser, 1995a; Visser & Trousse, 1993)—even less concerning design in general. Most examples concern software design (Détienne, 2002).

Notice that in all studies presented in this section that have established "commonalities between designing in different situations," these different situations have always been different domains of discipline.

2. Design is different from non-design

In the domain of cognitive design research, the tendency is to aim models that generalize across design tasks in different situations—even if often authors do not say so explicitly. In addition, despite this more or less implicit adherence to the generic-design hypothesis, and the frequent quotation of Goel and Pirolli's work, there has been little empirical research to corroborate the hypothesis.

Advocating that, from a cognitive viewpoint, design is definitely different from other activities, Goel and Pirolli (1994; 1989) quote the examples of chess and medical diagnosis. The supporting elements for the generic-design hypothesis come from a comparison that the authors make of protocols they collected in three design disciplines (architecture, mechanical engineering, and instructional design) with protocols from two nondesign tasks. These were, however, nondesign play problems: cryptarithmic and the Moore-Anderson logic task³. In their conclusion, the authors notice that, now that results have been obtained with such extreme well-structured tasks, other activities need to be examined.

In *The Sciences of the Artificial*, Simon (1969/1996) considers the cognitive activities implemented in economics and in design as different. Analyzing economic theories, he is very sensitive to the way in which economists idealize human rationality and neglect its limits⁴. With respect to design, however, in

³ The nondesign protocols came from the literature in problem-solving research, i.e. from Newell and Simon (1972)'s *Human problem solving*.

⁴ This, for his time, completely new approach of economics in terms of "bounded rationality" bestowed Simon with the 1978 Nobel Prize in economics.

our opinion, he seems to underestimate human cognitive limitations—something we illustrated in great detail in *The Cognitive Artifacts of Designing* (Visser, 2006b).

There has been much discussion in the design-research community around the relations between design and science (Cross, 2001a; 2002b; Sargent, 1994), some authors considering that a design science is to be developed (Hubka & Eder, 1987), others, such as Cross (2001a; 2002b), judging that the two are to be clearly distinguished. Cross "develops the view of 'design as a discipline', based upon a 'science of design', not a 'design science'" (cf. Note 3, cf. also Simon, 1969/1996's *Sciences of the Artificial*, which are the science of design). For Hubka and Eder (1987), the design science addresses the problem of determining and categorizing all regular phenomena of the systems to be designed, and of the design process." (p. 124)

According to Archer (1979) "there exists a designerly way of thinking and communicating that is both different from scientific and scholarly ways of thinking and communicating, and as powerful as scientific and scholarly methods of enquiry when applied to its own kinds of problems" (p. 18). This idea of "designerly ways of knowing" is further developed by Cross (1982) (see also Cross, 2006)

Lawson (1979/1984) compared students from a design discipline and a nondesign discipline: architecture and science⁵. He observed that the students from science analyzed their problems in order to discover their structure, whereas the students from architecture "proceeded by generating a sequence of high scoring solutions until one proved acceptable" (p. 218). This conclusion has constituted one of the bases for distinguishing architects from scientists, qualifying architects as "solution-focused" and scientists as "problem-focused."

In his analysis of the structure of design processes, Dasgupta (1989) considers design problem solving a special instance of scientific discovery. Cagan, Kotovsky and Simon (2001) point out the cognitive and computational similarities between the "seemingly disparate activities" of scientific discovery and inventive engineering design (Cagan et al., 2001, p. 442). Moreover, "[highly creative] design activities are often labeled invention." The "major conclusion" of the authors' comparison is that, "at a deep level, the cognitive and computational processes that accomplish [design and discovery] are virtually identical" (Cagan et al., 2001, p. 463). These "underlying cognitive activities [are] based

⁵ Lawson's (1979/1984) comparison concerned performances by students (fifth-year architectural and fifth-year science), on artificial tasks supposed to represent architectural-design activities: selecting and arranging coloured blocks of different shapes so as to try to maximize the amount of one certain colour showing around the outside faces, with an undisclosed rule requiring certain blocks to be present.

on problem solving, pattern recognition, analogical reasoning, and other cognitive knowledge retrieval mechanisms" (Cagan et al., 2001, pp. 452-453). With respect to these problems, the authors indeed defend what we have qualified elsewhere (Visser, 2006b; 2006c) as Simon's "nothing special position"⁶.

There is, however, a "fundamental difference" between the two: "the *goal* of the process: Scientific explanation versus creation of a new artifact. . . . Design starts with a desired function and tries to synthesize a device that produces that function. Science starts with an existing function and tries to synthesize a mechanism that can plausibly accomplish or account for that function" (Cagan et al., 2001, p. 455). However, "their cognitive models of search, once the problems are defined, are the same" (Cagan et al., 2001, p. 455).

In *The Sciences of the Artificial*, Simon (1969/1996) establishes a correspondence between social design (social planning) and scientific discovery: they also share a type of search, that is, a "search guided by only the most general heuristics of 'interestingness' or novelty" Simon (1969/1996, p. 162).

3. Design is one, but takes different forms

The idea that there may be different forms of design has been hinted at in informal discussions, generally without empirical or theoretical evidence (Löwgren, 1995; Ullman, Dieterich, & Staufer, 1988). Without any such underpinning, for example, the engineering-design methodologists Hubka and Eder (1987) assert that "the object of a design activity, what is being designed . . . substantially influences the design process." It is indeed generally the artefact product, characterising the design discipline (architecture, mechanical or software design) that has—more or less implicitly—been considered as the variable underlying the differences in question.

In "Variants in design cognition," Akin (2001) states that "in different fields of design, cognitive processes have both similarities and differences" (p. 105). The author focuses on architectural design, generally contrasting it with engineering design. Besides, he claims that "the profession of architecture rewards the heart while engineering rewards the brain." (p. 105) Analysing various studies on design, Akin concludes that architects differ from other designers. Concentrating on three "principal categories

⁶ This position presented, for scientific thinking, in Klahr and Simon (2001, p. 76) is often adopted by Simon. He applies it to design, for example, when he states that "no qualitatively new components" need to be introduced in the classic general problem-solving mechanisms in order to be able to handle design problems (Simon, 1973/1984, p. 197). For Simon (1969/1996, p. 115), no "special logic" is necessary—even if he "admits" that standard logic is to be adapted to the search for alternative solution elements (1969/1996, p. 124).

of design cognition... representation, strategic behavior and innovation," he identifies "four, more specific cognitive behaviors that [he regards] as principal variants of the field of architecture," that is, "cognitive skills that characterize architecture but not other fields" (p. 106). The characteristics identified by Akin that he considers as typical for architects can be recapitulated as follows: compared to other designers, architects are more inclined to use (1) rich representations, (2) creative, inventive strategies, (3) non-standard problem composition schemata, and (4) complexity management strategies. Akin also advances that, compared to, especially, engineering design, architects continue their search for alternative solutions even if they have already formulated a satisfactory concept. Architects would thus not commit themselves prematurely to an early selected kernel idea, something that is often considered a general characteristic of designers. In a discussion of premature commitment, we have claimed however that the analyses in the cognitive design research literature on which this conclusion is based, require inspection (Visser, 2006b). Moreover, with respect to these creative, flexible characteristics that, according to Akin, are distinctive for architects, in other studies they have also been implemented by other designers (see Visser, 2006b).

Purcell and Gero (1996) have observed a difference between mechanical and industrial designers as regards their susceptibility to use features of example designs. In certain situations, mechanical designers showed "[design] fixation in the traditional sense of reproducing the characteristics of [an example] design, including incorrect features" (p. 381). They did so when "the example shown embodied principles that were typical of the knowledge base of the discipline" (p. 381). However, when innovative design examples were presented, they seemed to "identify [the core innovative principle involved in the example] and then explore how this could be used in the particular design situation" (p. 381), leaving out of the designs they produced many of the specific aspects of the example design. The fixation effect was completely absent with the industrial designers. However, these designers did not use either the innovative example to produce innovative designs. "In a sense these [industrial designers] may have become 'fixated' on being different" (p. 381): "it is possible that what occurs in fact is a search for difference rather than innovation" (p. 380). The authors suggest two sources for the observed differences between the designers from the two disciplines. They may result from differences in their education: industrial design may emphasize creativity and trying many different ideas. Second, "the areas of knowledge that make up industrial design are more diverse than those studied in mechanical engineering" (p. 374) and many of them "are associated with less well articulated bodies of knowledge than those that make up the knowledge base of mechanical

engineering. For example, aesthetics plays a prominent role in industrial design education..., while it plays little formal role in mechanical engineering" (pp. 374-375).

Having studied designers from different domains (software and various types of mechanical design) in their daily work situation, we have identified differences between professionals working on industrial projects and design students or other design-knowledgeable participants solving design problems in laboratory experiments (Visser, 1995b, 2006b, 2006c). Some notable differences concern (1) designers' opportunistic organising their activity—whereas in simpler and in more restricted situations, designers are often able to follow systematic decompositional approaches (as generally prescribed by normative methods, e.g. top-down, breadth-first). (2) Reuse of elements from previous projects is also a typical, professional design approach—even if reuse may have been observed also in experimental studies (Détienne, 2002). (3) Finally, in our study of a professional software designer (Visser, 1987), we noticed that user considerations were among his guiding principles, something which led him, for example, to adopt certain variable-naming strategies—an observation that has not been mentioned by researchers studying design in artificially restricted situations.

These various observations, which do not seem specific to a particular domain of design, point to the influence of (1) design education, (2) the complexity of a design project, and (3) the design setting.

Researchers studying software design or HCI have also contrasted their domain of research with other domains. In the cognitive design research literature, one frequently encounters allusions to, or implicit testimonies of the specific character of software design compared to other types of design—design of HCI is much less the object of discussion in this context (see Visser, 2006b; 2006c for a discussion of these attitudes). The responsible variable(s) remain(s), however, unexplored. In their bibliographic cocitation analysis, Atwood et al. (2002) "found [a set of authors representing Software Engineering design methodologies] to be essentially unconnected with the remainder of the author set" (p. 129): "software design has its own design literature" (p. 132). Indeed, general "design journals," such as *Design Studies*, *Design Issues*, or *The Journal of Design Research* rarely publish papers on software or HCI design. The separation between software (and HCI) and other types of design holds for scientific events as well. Conferences in the domain of design research concern software design and/or HCI (i.e., treated either together or singly), or other types of design. Of course, there are specialised conferences in many domains of design, but when they announce as their object "design" without further specification, conferences generally do not expect research on software or HCI (for a list of example references, see Visser, 2006b, Section. 22.1). There are of course exceptions to these general

affirmations. An example in the domain of conferences was the International Conference in honour of Herbert Simon, "The Sciences of Design. The Scientific Challenge for the 21st Century" (Lyon, France, 15–16 March 2002) (Forest, Méhler, & Micaëlli, 2005; Perrin, 2002).

Refining our analysis initiated in Visser (2006b; 2006c) and continued in Visser (2006a), this paper proposes three dimensions that we suppose underlie differences between forms of design: the design process, the designer, and the artefact. Under each of these dimensions, we propose several variables.

3.1 PROCESS

The design process is under the influence of various variables. We identified its organisation, the tools in use by designers, and the place of the user in the design process as variables that may lead to different design activities and different designs.

3.1.1 The organisation of the design process

The organisation of their task or the process they are involved in is liable to influence people's activity. Be the organisation imposed by one's hierarchy, or devised by oneself, it works as other tools: It not only structures, but also guides people's activity, through immaterial and material means, such as design methods, plans, and other tools, such as representational tools, calculation and simulation aids (cf. the sub-section *Tools in use*).

The time scale of the design process. Design is considered an off-line activity. One might thus naively suppose that designers, contrary to, for example, controllers of dynamic situations, have all their time to think over their projects, to analyse and change views, to discuss and confront their views with colleagues. The reality is different. First, most industrial, or other professional design projects generally take place under temporal constraints—even if their stringency may differ depending on external organisational (workshop, client), art factual, and other factors. Second, planning—both as a component activity of design and as a design activity itself (Visser, 1994)—is obviously subject to temporal variables. Several early empirical design studies have examined the role of temporal constraints in the context of planning, for example, the famous study on route planning by B. Hayes-Roth and Hayes-Roth (1979). We will come back to temporal constraints in our discussion of "designing in space versus designing in time."

Individual versus collective design. Certain artefacts are designed generally by an individual designer, others are usually the work of a team. Complexity and size of artefact (two dimensions mentioned by Gross, 2003) may play a role, but are certainly not the only variables. Industrial design (product design) is often performed by individual designers; many engineering design projects are conducted collectively—but these are only tendencies.

We have defended elsewhere that there is no reason to suppose that cooperation modifies the nature of the basic cognitive activities and operations implemented in design (i.e., generation, transformation, and evaluation of representations) (Visser, 1993a). Because cooperation proceeds through interaction, it introduces, however, specific activities and influences designers' representational structures (both on sociocognitive and emotional levels). Some examples of such activities are coordination, operative synchronisation, construction of interdesigner compatible representations, conflict resolution, and management of representations that differ between design partners through confrontation, articulation, and integration. Activities involving argumentation—that is, in our view, activities aiming to modify the representations held by one's interlocutors—obviously play a particularly important role. The construction of interdesigner compatible representations (Visser, 2006b, 2006c), their existence beside designers' private representations, and their management introduce factors that may add complexity to collective design situations compared to individual design.

3.1.2 Tools in use

Given our view of design as the construction of representations, we privilege representational tools in this discussion, especially external representations and the means to produce them. Designers' internal (mental) representations evidently also play a crucial role in their activity, but these representations are, besides of individual factors, mainly dependent of other components of the situation.

Design methods. By definition, designers proceed differently depending on the method designers follow. In the domain of software design, several authors have compared the use of different design paradigms⁷, have observed differences, both with respect to activities and to resulting designs.

Lee and Pennington (1994), for example, have shown these two types of differences between software design using an object-oriented and using a procedural paradigm. With respect to the activity,

⁷ The term is used here in the sense of a design method.

the differences concerned the domain and solution spaces developed, the duration of problem domain analysis and of solution evaluation. As also observed by other authors (see references in Lee & Pennington, 1994), the resulting designs "[reflected] fundamentally different models of the solution. Procedural design methodologies result in designs in which the modules represent procedures that complete subparts of the task, whereas object-oriented methodologies result in modules that represent objects in the environment." (p. 581; for other differences, see the paper)

Kim and Lerch (1992), in their comparison between object-oriented (OOD) and "traditional functional decomposition" (TFD) methodologies, expect "OOD to radically change the cognitive processes in logical design" (p. 491). Based on the preliminary results obtained in a pilot study, the authors note that "OOD may achieve substantial time savings over TFD in logical design. . . . 1) by simplifying rule induction processes used in functional decomposition; 2) by guiding designers on how to build more effective problem spaces; and 3) by allowing designers to run mental simulation more efficiently and more effectively" (p. 489).

The maturity of a domain may influence the availability—and thus the use—of tools. In 2004, the NSF launched a "Science of Design" program in 2004 aiming to "develop a set of scientific principles to guide the design of software-intensive systems." (*Science of Design*, 2004) An underlying idea was that "in fields more mature than computer science [such as architecture and other engineering disciplines, for example, civil or chemical engineering], design methodology has traditionally relied heavily on constructs such as languages and notational conventions, modularity principles, composition rules, methodical decision procedures and handbooks of codified experience However, the design of software-intensive systems is more often done using rough guidelines, intuition and experiential knowledge."

As noticed above, research in the domain of software design has shown that design methodologies may have an influence on the design activity and on the resulting design. One may suppose that being familiar with the constructs and other tools that have been developed in a domain, may influence, probably facilitate, designers' activity—even if cognitive design research has shown the difficulty of designers' *effectively* working according to design methodology prescriptions (Carroll & Rosson, 1985; Visser, 2003; Visser & Hoc, 1990).

One may notice that related to the idea that underlies the present variable and that is only touched upon here, is the question of well-defined versus ill-defined problems and the implications for the

nature of the activities involving these problems (see Visser, 2006b, 2006c). From a cognitive-activity viewpoint, most or all ill-defined problems might be analysed as design problems (Visser, 1993b). Going one step further, Falzon (2004) proposes to adopt design as a paradigm for analysing all problem-solving activities. Eventually, Falzon posits, each design problem becomes a state-transformation problem (the typical type of problem examined in classical cognitive-psychology laboratory research), because of people's acquisition of expertise and habits, and of technological evolution. Falzon nevertheless also notes the possibility that there will always remain multiple possible perspectives and situations in which people refuse themselves to refer to procedures and routines. As an example, he refers to a study by Lebahar concerning painters who try to establish conditions that rule out the possibility to refer to routines.

External representations. According to Zhang and Norman (1994), external and internal representations differentially activate perceptual and cognitive processes. With Scaife and Rogers (1996), we presume that things are less systematic, and more complex. Nevertheless, we suppose that the use of internal and that of external representations involve processing differences. Therefore, designing may differ between situations depending on the importance of certain types of representations. One may suppose that, for example, design of physical artefacts (e.g., architectural or mechanical design) differs from design of symbolic artefacts (e.g., procedures or organisations).

Indeed, one of the factors underlying the differences that are often emphasised as existing between software and other types of design may be due to the different types of representations primarily used. The possibilities provided by particular types of external representations such as sketches and other figurative drawings compared to those offered by purely alphanumeric representations (especially, with respect to the ease of visualisation and manipulation, and their corollaries) may facilitate, for example, simulation and other forms of evaluation of what are going to become physical artefacts.

This observation surely does not only apply to classical (i.e., nonvisual) forms of software design. It probably also holds for other symbolic artefacts, such as other procedures, plans, and organisational structures.

According to Akin (2001), architects differ from designers in other domains with respect to their relative more frequent use of (1) analogue compared to symbolic representations and (2) varying representations. The author attributes this greater variety of representations to architectural design's situated and user-dependent character. Akin also points to the lack of universally accepted

representational standards in architecture (cf. other elements of Akin's position presented in the introduction of Section 3). We already put into perspective Akin's view of architectural designers as particularly resourceful and flexible. The lack of standards, be they universally accepted or not, is, however, indeed a variable that may have its influence (see also our remark concerning *The maturity of a domain*).

According to Zimring and Craig (2001), disciplines differ with respect to the ease or even the possibility for users to understand the intermediate and final representations of the artefact under design that are currently used. They assert, for example, that architectural drawings of layout or appearance of the building to be designed "are at least theoretically understandable by end-users..., resulting in patterns of collaboration, testing and accountability that differ significantly from those associated with more 'invisible' design processes. An engineer, for example, working on a car engine is not likely to collaborate with end users directly, given the difficulty the average car driver has in understanding the mechanics of engines." (p. 128)

With respect to the role of representation, we wish to state explicitly that the importance of its role undeniably also depends on the designer (see Section 3.2).

Possible means for evaluation. Domains differ in the methods and other tools that may be used in order to evaluate design proposals (Malhotra, Thomas, Carroll, & Miller, 1980, pp. 129-130). In engineering, more or less "objective" measures and other criteria for future artefacts' performance can be used and different proposals can be ranked rather objectively. One can calculate whether a particular design (e.g., a bridge) meets particular functional requirements, such as accommodation and maximum load. The results of qualitative evaluation used in other domains and that are based on subjective criteria such as aesthetics, may be more difficult to translate into a "score," and thus to compare. In between the extremes of completely objective and entirely subjective evaluation are different types of simulation, physical and mental.

3.1.3 The user in the design process

Designers design for other people, the "users" of the artefact product. In each domain of design, users are central—even if not always for the designers and even if the use of artefacts may be—or seem to be—more or less direct (cf. also *The artefact's impact on people's activity and the possibility to anticipate it*). One might think that industrial design products (such as, pens, chairs, household boxes)

are in "direct" use by their users, whereas the relation between the product of a city-planning project and its users is much less direct. This is clearly an illusion.

Domains differ, however, with respect to their common practices, for example, concerning the way in which designers usually take into account the potential, future users and their use of the artefact product.

Integration of user data into the design. In HCI, for example, there is a tradition and, correspondingly, much effort towards the integration of user data into the design. This has varied from such data being introduced into the design by design participants who "know" the users, but are not these users themselves, to approaches such as participatory design in which the users have themselves a voice in the design process (Carroll, 2002).

It seems likely that the number and variety of participants who take part in a design process influence this process, probably more its socio-organisational than its cognitive aspects (see also *Individual versus collective design*). Yet, on a cognitive level, the difficulty of integration may augment with the number of different representations to be integrated—thus with the number of types of participants. In addition, the participation of "nontechnical" design participants may introduce a specific difficulty, both for the users and for their professional design colleagues.

Gross (2003) mentions two specific user-related variables: The difference or equivalence between client and user, and the type of use or user, which may change (more or less), or may remain constant. These two variables get a particular weight in the context of the abovementioned influence that number and variety of participants may have on the design process. Notice that for Gross (2003) these are variables on which a piece of software is like a building.

3.2 DESIGNER: INTERINDIVIDUAL DIFFERENCES

Differences between designers will often affect both their activities and the representations constructed. This influence may occur by way of one or more of the variables proposed hereafter. The use of certain types of representations or other tools may influence design thinking, but a particular designer may be more inclined to adopt a particular type of representation, or feel more at ease with its use.

Design expertise. A classical cognitive-psychology result confirmed in cognitive design research is that experts and novices in a domain differ as to their representations and activities (Chi, Glaser, & Farr,

1988; Cross, 2004; Expertise in Design, 2004; Glaser, 1986; Glaser & Chi, 1988; Lee & Pennington, 1994; Reimann & Chi, 1989).

We have proposed to distinguish, in addition to *levels* of expertise, also different *types* of expertise (Falzon & Visser, 1989; see also Visser & Morais, 1991). We have indeed observed how experts in the same domain exhibit (1) different types of knowledge and (2) different organisations of their knowledge—a result comparable to that regarding levels of expertise.

Reymen et al. (2006) found differences between junior and expert designers with respect to certain aspects being experienced explicitly by the junior designers and implicitly by their expert colleagues, and vice versa for other aspects. "Expert designers focused, for example, on more aspects of the product lifecycle, they gave more attention to controlling the design process, and they gave higher importance to interaction with different stakeholders at the beginning of a design process." (pp. 150-151)

Routine character of a task. The routine character of a task is not an objective characteristic of this task, but depends on the representation that people construct of their task. This task characteristic is thus dependent on interindividual differences.

Most design projects comprise both routine and nonroutine tasks. In a comparative analysis of three of our empirical design studies, we have established a link between the more or less routine character of a design project and the way in which analogies are used (at the action-execution and at the action-management levels) (Visser, 1996). This, in turn, influences, at least in part, the possibilities a designer has for reuse in a design project.

Idiosyncrasies. "The reality of professional design practice seems to be that individual designers have differing design abilities—some designers just seem to be better than others, and some are outstandingly good." (Cross, 2002a, p. 14) In addition to studies comparing experts and novices, there are also clinical studies on experts, which have led researchers to identify specific characteristics of particular experts (Cross, 2001b, 2002a). Cross (2002a), who mentions several studies on exceptional designers, presents three case studies he has performed himself on creative design in engineering and product design. Even if the author considers the corresponding three designers "exceptional", he notices that "there appear to be striking similarities in their design strategies, which suggest that general models might be constructed of design expertise and creative processes in professional design practice" (2002a, p. 14).

There are, however, also exceptional designers with certain particularities not found in most other designers. It is known of Frank Lloyd Wright, for example, that contrary to most architects, he could conceive of and develop a design entirely without using external representations, not sketching or drawing until the very end of the design process (Weisberg, 1993, quoted in Bilda & Gero, 2005).

Different "types of people." An idea often encountered, especial among architects themselves, is that, rather than possessing personal idiosyncratic characteristics, architects are of a "special kind," a different "type of people" than, especially, software designers or engineers. They would have a different "personality": they would be, for example, more creative and more aesthetics-oriented.

Several researchers, architects themselves or not, also consider architects a special kind of designers. Akin (2001), for example, considers that architects attribute another value to creative and unique designs than other designers do (see also Akin's studies presented above).

3.3 ARTEFACT

We have identified three artefact variables: social embeddedness, type of artefact, instantiated by structures versus processes, and artefacts' evolution. The proportion of reusable components in the artefact's structure is one of the factors proposed by Gross (2003) that make "a piece of software like a building." We do not have any further data or hypotheses concerning a related variable.

3.3.1 *Social embeddedness*

Referring to Rittel and Webber (1973/1984), Zimring and Craig (2001) point to the "social embeddedness" of planning and design problems. In their analysis of societal planning problems as "wicked," Rittel and Webber (1973/1984) indeed attribute the major part of this wickedness to planning problems' social embeddedness. We consider that, even if other than societal planning problems may be socially embedded, many planning problems are not especially: for example, planning one's route through a city (Chalmé, Visser, & Denis, 2004; Hayes-Roth & Hayes-Roth, 1979) or planning a meal (Byrne, 1977).

The influence of the social embeddedness of a problem on the design activity will be similar to that of its ill-definedness. Social embedded problems may have various, different solutions. These solutions may be considered more or less appropriate, more or less acceptable, depending on the criteria adopted by the person who judges them.

A related issue in which societal questions play an important role is the way in which the user of an artefact is taken into account in its design (see *The user in the design process*). Winograd (1996) considers that its user-oriented character makes software design comparable to architectural and graphic design, and different from engineering design. He considers, however, that the design of interactive software is completely different from other software design (Winograd, 1997). Among the arguments advanced for these claims, none is based on cognitive analyses of the activities.

In his famous *Sciences of the Artificial*, Simon (1969/1996) implicitly establishes a radical distinction between design activities in engineering and in social design (see our detailed discussion in Visser, 2006b, 2006c). In his discussion of social planning, Simon (1969/1996) states that in this form of design (and, maybe, also in inventive engineering design, see Visser, 2006b, 2006c), "representation problems take on new dimensions" relative to the "relatively well-structured, middle-sized tasks" of engineering and architectural design (p. 141), which he presents—implicitly—as the prototypes of design in *The Sciences of the Artificial*. For "real-world problems of [the] complexity" of social planning, Simon considers that designers may refer to "weaker" criteria than in the case of standard design. Processes such as "search guided by only the most general heuristics of 'interestingness' or novelty" may provide "the most suitable model of the social design process" Simon (1969/1996, p. 162). With respect to the sources of social design problems' greater "complexity," Simon suggests that differences of at least three types may be involved: Problems' degree of structuredness, their size, and the nature of their object (see our detailed discussion of these differences in Visser, 2006b, 2006c).

It seems that only when he discusses social problems (as well as economic, and perhaps scientific discovery problems, see the introduction to Section 2. *Design is different from non-design*) that Simon seriously considers human's bounded rationality and takes into account the role of what he calls "representations without numbers," generative constraints such as "interestingness" or "novelty," and critical constraints such as the "defensibility" of a decision.

The hypothesis that we have formulated in order to explain—at least, in part—this view of design adopted by Simon is that he considers (1) routine engineering and architectural design as standard design, and (2) social planning as a form of design that is radically different from standard design.

In ever more domains, people become convinced of the societal aspects of their action. One may suppose that this evolution has—or will have—its influence on design. "The common thread in the new approach to traffic engineering is a recognition that the way you build a road affects far more than the

movement of vehicles. It determines how drivers behave on it, whether pedestrians feel safe to walk alongside it, what kinds of businesses and housing spring up along it." (McNichol, 2004) (see also tendencies such as ecodesign, ecological design, and sustainable design, see, e.g., Méhier, 2005)⁸ (cf. also our discussion in *Artefacts' evolution* of the influence of users' interaction with artefacts on designers' activities—especially those related to the anticipation of the artefact's behaviour over time)

3.3.2 *Artefacts' evolution*

"Interactive systems are designed to have a certain behavior over time, whereas houses typically are not," according to Löwgren (1995, p. 94). Even if this assertion is questionable with respect to "behaviour" in general, behaviour over time is a variable on which artefacts differ—and the types of behaviour of different artefact products are quite diverse. An artefact's behaviour over time may be related to its impact on people (the "transformative" nature of artefacts, see Carroll, Rosson, Chin, & Koenemann, 1998), through the interaction that people engage in, and to its use by people who are not necessarily transformed by this use. It may also be due to its deterioration, dependently or independently of people. Two variables introduced by Gross (2003) are the degree to which components of the artefact may be subject to change or renewal, and the more or less extended lifetime of the artefact.

All artefacts change over time. Houses may not display "behaviour" over time, but they change. Systems such as organisations or interactive systems are subject to specific types of change. Designers are supposed to anticipate the transformation that their artefact products undergo—be it of deterioration or another evolution type. The possibility of anticipation may vary between situations (domains), not necessarily depending on the degree of impact. It depends, among others things, on the possibility of simulating the artefact, or testing it in other ways. For interactive and (other) socially embedded artefacts, anticipation may be performed through simulation. The future behaviour of certain technical artefacts may be anticipated based on calculations.

The artefact's impact on people's activity and the possibility to anticipate it. Predicting people's future use of an artefact product and further anticipating the impact of the product on human activity, is one of the "characteristic and difficult properties" of designing (Carroll, 2000, p. 39). Indeed, "design has broad impacts on people. Design problems lead to transformations in the world that alter possibilities

⁸ See also the founding of a Japanese "Union of EcoDesigners" and the organisation of various EcoDesign conferences since 1999.

for human activity and experience, often in ways that transcend the boundaries of the original design reasoning" (Carroll, 2000, p. 21). Gross (2003) mentions sanitary risks and safety concerns that particular uses or states of an artefact may introduce.

Even if all design has impact on people, certain domains seem more sensitive than others do. HCI, that is the domain with which Carroll (2000) is especially concerned in his discussion quoted above, is an example of a domain in which design has particularly broad impacts on people. Yet, this holds for all design with societal implications.

Distance between intermediary representations and final product. The design of an artefact is a different activity than its implementation (Visser, 2006b, 2006c). For certain types of artefacts, however, there seems to be a relatively fluid, steady transition between the different forms that may take the design concept and the final artefact product—what may be qualified as a shorter "distance" between the two. An example is symbolic artefacts, such as software. This does not imply, however, that design and implementation are not distinct for such artefacts. It might, however, clarify our observation that software designers find it particularly difficult to separate design from coding (Visser, 1987).

It is with respect to the distance between the design concept and the final artefact product that Löwgren (1995, p. 94) opposes architectural and engineering design to "external" software design ("design of the external behavior and appearance of the product, the services it offers to users and its place in the organization").

Delay of implementation. Design is by definition concerned with artefact products that do not yet exist. A central aspect of designing is thus, once again, anticipation. The bases of this anticipation may vary depending on other variables (designer's knowledge, experience, and activities, such as simulation; users' taking part), but anyhow the conditions of existence, the behaviour, and the use of the artefact products will be more or less different from those anticipated: The world changes without possibility of being completely controlled.

The implementation of certain types of artefacts is much longer in coming than that of others—and not because of laziness or indifference of the workshop or the client, or due to lack of resources. Voss, Greene, Post, and Penner (1983) have noticed that the solving of social-science problems is particularly difficult because of the "delay from the time a solution is proposed and accepted to when it is fully implemented" (p. 169). Such a delay clearly complicates the anticipation of the artefact's evolution and

other matters involved in its evaluation (though simulation or other means). Even if this observation is particularly applicable to social-science problems, it may also hold for other types of design.

3.3.3 *Type of artefact*

"Type of artefact" (or domain of design) is "of course" a variable that explains the existence of different forms of design. As noticed already, however, few elements are available concerning underlying variable(s). An example is software design—often considered as "essentially different" from design in other domains, without examination of the responsible variable(s). One candidate variable could be the difference between structures and processes. Data concerning the influence of this variable may come from results obtained in studies concerning what may be considered particular instances of structures and processes, that is, spatial and temporal entities.

Designing in space versus designing in time. Studies comparing problems governed by temporal and problems governed by spatial constraints have shown that designers deal differently with these constraints (Chalmé et al., 2004; detailed in Visser, 2006b). An example of design that preferentially implements temporal constraints is planning (meal planning, see Byrne, 1977; route planning, see Chalmé et al., 2004; Hayes-Roth & Hayes-Roth, 1979). Research, however, has not yet settled clearly the specificity of the relative ease and difficulty involved in the corresponding types of design—it has even less identified the underlying factors.

Structures (which may correspond to states) are not necessarily spatially constrained, but processes have systematically temporal characteristics. By analogy to the differences between the cognitive treatment of spatial and temporal constraints, one may expect that structures and processes are represented differently (especially mentally, but also externally), thus processed differently, and therefore lead to different design activities (cf. Clancey, 1985's distinction between configuration and planning).

4. Conclusion

In this conclusion, we will first briefly discuss the generic-design hypothesis and then focus on the point of our augmented cognitively oriented generic-design hypothesis that has been central in this text, that is, design *also* takes different forms.

The validity of the generic-design hypothesis. Given the scarcity of empirical evidence, the generic-design hypothesis needs more research. The only systematic study was that by Goel and Pirolli. At least two critical remarks can be formulated against this study. First, the nondesign tasks were small, artificial game tasks (they took between 15 and 40 minutes). Second, as the authors notice themselves, their study "purposefully took two points (ill-structured design tasks and well-structured game tasks) at the extremities of the spectrum of problem types" (Goel, 1994, p. 71). They consider that, "given that [they] have found interesting differences, it would be instructive to... explore the intermittent points in the space" (1994, p. 71).

The validity of the hypothesis that design also takes different forms. If because of rare empirical evidence, the generic-design hypothesis needs more research, this holds *a fortiori* for this our hypothesis. Our proposals of most variables are based on a broad knowledge and analysis of the results of some 25 years cognitive design research. For some of them, we were able to advance precise empirical data, but most would need comparative studies about the hypothesised differences between design situations. In the analysis presented in this paper, we have introduced material that still requires further analysis, and indicated a number of directions—to be followed, modified, completed, and developed, by other researchers or ourselves.

It is conceivable that not all variables advanced have the same degree of influence. Given our view of design as the construction of representations, we suppose that variables related to representational structures and activities are particularly influential. Yet, variables may also depend on other underlying factors and their influence on the activity may exert itself by way of representational structures and activities.

The variables and the characteristics of the different forms of activities and cognitive structures—if their influence were to be confirmed—may have their methodological and other implications for design support. Given the centrality of representation in designing, the development of appropriate support modalities for representational activities and structures already imposes itself. However, according to the role of representation, and the type of representation preferentially used in design tasks in specific design situations, the development of specific support modalities may be worthwhile. Research on these questions may take advantage of the progress already obtained in the domains of software and HCI design. There has been considerable research on visualisation and other visual tools, for example, on diagrammatic reasoning (see the diagrammatic reasoning site, retrieved 24 May 2007, from <http://zeus.cs.hartford.edu/~anderson/>; see also Blackwell, 1997). There is also potentially useful

research into representational formats and their exploitation that is not specific to design (e.g., research on multiple —external— representations, see van Someren, Reimann, Boshuizen, & de Jong, 1988).

A question that might be asked after the presentation of all these—possibly—different forms of design is: If there are so many differences between the implementations of design thinking in different situations, then what about the idea that design is a "generic" activity? In order to answer this question—and counter the underlying opposition to the generic-design hypothesis—, we now come up with the fourth member of our augmented cognitively oriented generic-design hypothesis. In its complete form, this hypothesis is the following:

- (1) Design thinking has distinctive characteristics from other cognitive activities;
- (2) There are commonalities between the implementations of design thinking in different design situations;
- (3) There are also differences between these implementations of design thinking in different situations;
- (4) However, these differences do not reinstate commonalities between designing and other cognitive activities, whereas the commonalities between all the different forms of design thinking are sufficiently distinctive from the characteristics of other cognitive activities, to consider design a specific cognitive activity.

Given the hypothetical character of the third member, which was examined here, we did not mention this fourth member before. If one supports the idea of design as a generic cognitive activity, it is, however, the counterpart of the third member. At the end of this paper, this fourth member remains completely hypothetical and requires new empirical research comparable to Goel and Pirolli (1994; 1989)'s—but preferentially, in our opinion, performed in real, i.e. professional design situations.

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