Title: An Ontological Account of Donald Schön's Reflection in Designing

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Abstract: This paper proposes an ontological model of Donald Schön's notion of reflection in the domain of designing. We address two views of this notion. First, we present a functional view that describes reflection in terms of the designer's interactions with the design object and their intended and unintended consequences that then drive further interactions. Second, we present a constructional view that models reflection as a mechanism with a set of properties that distinguish it from other processes in designing. We describe both views using the function-behaviour-structure (FBS) ontology. This elaborates existing accounts of reflection and locates it within a uniform framework of designing, which lays the foundations for a multi-disciplinary approach to studying reflection.

Keywords: design model(s), design ontology, design process(es), design science, reflective practice

1 Introduction

Donald Schön's notion of "reflection-in-action" (Schön 1983; Schön 1987) describes how most professional practice is based on the interconnection of thinking and action. Quoting Schön (1987, p. xi), reflection-in-action of practitioners is "the thinking [about] what they are doing while they are doing it". Reflection allows practitioners to change the way they go about solving problems; or as Schön puts it:

"In an *action-present* – a period of time, variable with the context, during which we can still make a difference to the situation at hand – our thinking serves to reshape what we are doing while we are doing it. I shall say, in cases like this, that we reflect-in-action." (Schön 1987, p. 26)

Designing is one of the fields to which Schön applies his notion of reflection-in-action (often shortened to just "reflection"). He describes designing as a "reflective conversation with the materials of a design situation" (Schön 1992, p. 3), in which designers interact with their intermediate design representations. Specifically, designers change their view of the current design as a result of them generating and interpreting representations of the design. Schön and Wiggins (1992) illustrate this concept using the following excerpt from the design protocol of a school design task, performed by a first-year architecture student called Petra:

"I had six of these classroom units but they were too small to do much with. So I changed them to this more significant layout (the L-shapes). It relates grade one to two, three to four, and five to six grades, which is more what I wanted to do educationally anyway. What I have here is a space which is more of a home base. I'll have an outside/inside which can be used and an outside/outside which can be used – then that opens into your resource library/language thing." (Schön and Wiggins 1992, p. 136)

The example shows that "reflective" designing can be schematised as "seeing-moving-seeing" (Schön 1992, p. 5): The first "seeing" allows Petra to observe and evaluate her current design, resulting in the recognition that the classroom units were "too small to do much with". The upper part of Figure 1, taken from Schön and Wiggins (1992), shows Petra's initial drawing. Her "moving", i.e. her act of drawing a modified design representation (lower part of Figure 1), aims to solve this problem. Petra's repeated "seeing" of the results of this drawing finally includes a second judgment, that the initial problem has now been solved. It also includes the recognition of a set of unintended, desirable consequences of her "move", namely the spatial grouping of proximate grades, and the creation of two kinds of spaces ("outside/inside" and "outside/outside").

[Fig. 1 here]

According to Schön's model, design concepts are the consequences, intended or unintended, of the designer moving through the state space of possible designs. Every step of the designer through that space is seen as a "move experiment", which is then taken as the basis for both evaluating previous design concepts and generating new design concepts. Reflection is a cognitive process that is the driver of this "interaction of making and seeing" (Schön and Wiggins 1992, p. 135).

Schön's choice of the term "reflection-in-action" fits well with where we see the focus of his work: on the role that reflection plays "in action", i.e. its effect on subsequent decisions during the design process. We call this a functional view of reflection, concentrating on the observable phenomena, i.e. the designer's interactions, caused by reflective activity by the designer.
On the other hand, we define a constructional view of reflection, regarding reflection as a process with a well-defined set of distinct properties. Little work has been done in identifying these properties and studying reflection as an underpinning mechanism rather than a descriptor for the interactive nature of designing.
In this paper, we will present an ontological model of reflection that accounts for both the functional and the constructional view. We use the term "ontology" in the sense it has been used in computer science rather than in philosophy (Gruber 1995; Øhrstrøm 2005), providing a systematic framework for describing the concepts of a domain and their relationships. We will use the function-behaviour-structure (FBS) ontology of designing (Gero and Kannengiesser 2004). Most representations of this ontology as used in previous work can be considered lightweight (i.e., not formal), since its predominant purpose has been to identify, explain and sometimes predict designerly behaviour rather than to engineer systems that perform automated reasoning. The ontological account of Schön's reflection in this paper will follow the same approach.
Section 2 adopts the functional view of reflection. Here we derive an ontological model of reflective designing based on the situated FBS framework (Gero and Kannengiesser 2004), which we apply to an expanded version of the design example introduced above. Section 3 provides an ontological description of reflection from the constructional point of view. We show how this description allows delineating reflection from other processes in designing. Section 4 concludes this paper with a summary of the benefits and limitations of our approach.

2 A Functional View of Reflection

2.1 A Framework of Reflective Conversation in Situated Designing

Situatedness is a paradigm that provides a framework for understanding how a designer's interactions affect both what is designed and the designer's experience (Gero 1999), drawing on models of situated cognition (Dewey 1896; Bartlett 1932; Clancey 1997; Ziemke 1999). It can account for the central role of Schön's reflection-in-action and related phenomena reported in empirical studies of designers (Suwa et al. 1999). Gero and Kannengiesser (2004) have modelled situated designing as the recursive interaction between three different worlds: the external world, the interpreted world and the expected world, Figure 2(a).

[Fig. 2 here]

The *external* world is the world that is composed of representations outside the designer. This world is the designer's medium for communication, either with other designers or with the designer themselves. The latter kind of communication corresponds to Schön's concept of "reflective conversation with the materials of a design situation". The "materials" are represented in the external world and typically include iconic and symbolic representations of the design object, such as the drawings shown in Figure 1.
The *interpreted* world is the world that is built up inside the designer in terms of sensory experiences, percepts and concepts. It is the internal representation of that part of the external world that the designer interacts with. The interpreted world corresponds to what Schön (1992, p. 9) denotes as the "design world", in which the objects and relationships of a design are constructed and reconstructed by the designer. This has the implication that all aspects of the design depend on the unique experience of the individual designer. For example, Schön (1992) points out that Petra's judgments of her designs as being "too small to do much with" or "more significant" are fundamentally subjective; and other designers might not necessarily agree with her.
The *expected* world is the world the imagined actions of the designer are expected to produce. It is the environment in which the effects of actions are predicted according to current goals and interpretations of the current state of the world. The expected world corresponds to the designer's current design state space, i.e. the state space of all potential design solutions currently considered by the designer. This world is located within the interpreted world, as all goals and expectations can be viewed as interpreted

representations of potential future designs. In Schön's design example, Petra's L-shapes are the effects, represented in the external world, of her projections of a larger layout, in the expected world.
The three worlds are linked together by three classes of connections: interpretation, focussing and action. *Interpretation* transforms variables which are sensed in the external world into the interpretations of sensory experiences, percepts and concepts that compose the interpreted world. This process includes Schön's notions of "seeing" and "worldmaking" (Schön quoting Goodman (1978)).
Focussing takes some aspects of the interpreted world, and uses them as goals for the expected world that then become the basis for the suggestion of actions. These actions are expected to produce states in the external world that reach the goals.This process uses the results of qualitative judgments or "appreciations" (Schön quoting Vickers (1965)) of the design. If the interpretation is judged to be useful or required for the current design task, focussing integrates that interpretation into the design state space.
Action is an effect which brings about a change in the external world according to the goals in the expected world. This process corresponds to what Schön calls "moving", including, for instance, the act of drawing.
Figure 2(b) presents a specialised form of this view with the designer (as the internal world) located within the external world and placing general classes of design representations into the resultant nested model. The set of expected design representations (Xe^i) corresponds to the notion of a design state space. This state space can be modified during the process of designing by transferring new interpreted design representations (X^i) into the expected world and/or transferring some of the expected design representations (Xe^i) out of the expected world. This leads to changes in external design representations (X^e), which may then be used as a basis for re-interpretation, changing the interpreted world.
Novel interpreted design representations (X^i) may also be the result of *constructive memory*, which can be viewed as a process of interaction among design representations within the interpreted world rather than across the interpreted and the external world. Constructive memory is best exemplified by a paraphrase of Dewey by Clancey (1997): "Sequences of acts are composed such that subsequent experiences categorize and hence give meaning to what was experienced before". The implication of this is that memory is not laid down and fixed at the time of the original sensate experience but is a function of what comes later as well. Memories can be viewed as being constructed in response to a specific demand, based on the original experience as well as the situation pertaining at the time of the demand for this memory. Therefore, everything that has happened since the original experience determines the result of memory construction. Each memory, after it has been constructed, is added to the existing knowledge (and has the potential to become part of a new situation) and is now available to be used later, when new demands require the construction of further memories. These new memories can be viewed as new interpretations of the augmented knowledge.
In Figure 2(b), both interpretation and constructive memory are represented as "push-pull" processes. This emphasises the role of the designer's individual experience that constructs or "pulls" new design concepts to match first-person knowledge rather than just replicates or "pushes" what can be seen as third-person knowledge (Gero and Fujii 2000).
Design representations can be viewed as describing any of three aspects of an artefact: function (F), behaviour (B) and structure (S). These aspects are the basic constituents of the function-behaviour-structure (FBS) ontology that has been applied to various artefacts, including physical objects (Gero 1990; Gero and Kannengiesser 2004), software (Kruchten 2005) and processes (Gero and Kannengiesser 2007a). We briefly present the fundamental notions of this ontology:

- *Function* (F) of an artefact is defined as its teleology ("what the artefact is for"). For example, some of the functions of a window include "to provide view", "to provide daylight" and "to provide rain protection".
- *Behaviour* (B) of an artefact is defined as the attributes that can be derived from its structure (S) ("what the artefact does"). In the window example, behaviours include "thermal conduction" and "light transmission".
- *Structure* (S) of an artefact is defined as its components and their relationships ("what the artefact consists of"). Components of a window structure typically include a pane of glass, a frame and a set of hinges, each of which is often specified by a set of variables describing geometrical or topological details, and materials. The notion of structure can be applied at any level of granularity, and in any domain of designing. For example, depending on the class of artefact and the perspective we choose to take, we may talk about mechanical structures, spatial

structures, molecule structures, data structures or organisational structures. Processes can also be described as structures, by viewing them as compositions of inputs, transformations and outputs. Humans construct relationships between function, behaviour and structure through experience and through the development of causal models based on interactions with the artefact. Function is ascribed to behaviour by establishing a teleological connection between the human's goals and measurable effects of the artefact. There is no direct relationship between function and structure (De Kleer and Brown 1984). Behaviour is derived from structure using physical laws or heuristics. This often requires knowledge about external effects and their interaction with the artefact's structure. In the window example, deriving the behaviour "light transmission" requires considering external light sources. An example for processes is accuracy, which is a behaviour derived from the process output and an external benchmark.
Function, behaviour and structure can be used to specialise the model of interacting worlds, by replacing the variable denoted as X in Figure 2(b) with F, B and S. This results in the situated FBS framework (Gero and Kannengiesser 2004), Figure 3. It includes external requirements given to the designer, namely requirements on function (FR^e), on behaviour (BR^e), and on structure (SR^e). It also introduces the process of comparison between interpreted behavior (B^i) and expected behavior (Be^i), and a number of processes that transform interpreted structure (S^i) into interpreted behavior (B^i), interpreted behavior (B^i) into interpreted function (F^i), expected function (Fe^i) into expected behavior (Be^i), and expected behavior (Be^i) into expected structure (Se^i). Figure 3 uses the numerals 1 to 20 to label the resulting set of processes; however, it should be noted that they do not represent any order of execution. We have highlighted those processes in the situated FBS framework that are consistent with Schön's descriptions and examples of reflection. These are the processes labelled 6, 9, 12, 13 and 14; they will be illustrated in the following Section.

[Fig. 3 here]

2.2 An Ontological Account of Schön's Example

We return to Schön's report of Petra's design session introduced in Section 1. Table 1 shows that what Petra describes as a simple change in her design (from the six classroom units to the three L-shapes, Figure 1) can be modelled as a set of five activities in our ontological framework:

[Table 1 here]

1. Constructive memory (process 6 in Figure 3): Petra, after finding her initial school layout as too small, uses her design knowledge to generate a new design candidate based on three L-shapes.
2. Focussing (process 9): Petra decides to take the new design candidate as a basis for her future design moves, which includes this candidate in the current design state space.
3. Action (process 12): Petra's act of drawing, resulting in the three L-shapes, gives an externally visible account of her new design decision.
4. Interpretation (process 13): Petra "visually apprehends" (Schön 1992) what she has produced. This activity is subsumed in Schön's notion of "seeing". In particular, Petra "sees" the following features:
    a. six spaces (classrooms) within three L-shapes
    b. relations between the spaces within an L-shape
    c. outer spaces, partially enclosed by the L-shapes
5. Derivation of behaviour from structure (process 14): Petra derives a number of qualitative statements based on her interpretations, relating to:
    a. area of classrooms: the new layout of the classrooms is now "much more significant" than the previous layout
    b. proximity of grades: the six spaces are related in three pairs ("grades one to two, three to four, and five to six")
    c. area and enclosedness of outer spaces: the outer spaces have a sufficient area and enclosedness to serve as a "home base", in the sense of a "partially protected space" (Schön 1983, p. 154)

Petra's interpretation of the six spaces (bullet point 4a) and derivation of their area (5a) confirms her expectations regarding "much more significant" classroom sizes. They can be viewed as the intended

consequences of the new structure she produced. In contrast, the interpreted relations between the spaces (4b) and the derived behaviour of pair wise proximity (5b) have not been anticipated (or intended). Petra recognises the usefulness of this behaviour with respect to her pre-existing intentions of relating proximate grades "educationally anyway". Similarly, the interpretation of outer spaces (4c) and the associated behaviours of area and enclosedness (5c) are emergent (and thus unintended) consequences of Petra's reflective conversation.
Further excerpts from Schön's design protocol show how the results of this conversation provide the basis for addressing other design issues. For example, the overall partitioning into three instead of six components is refined into the third dimension, resulting in three levels imposed onto the sloped contour of the proposed building site, Figure 4. This can be viewed as part of a subsequent reflective conversation. Quist, Petra's studio master, sketches out the consequences:

"We get a total differential potential here from one end of the classroom to [the] far end of the other. There is 15 feet max, right? – so we could have as much as 5-foot intervals, which for a kid is maximum height, right? The section through here could be one of nooks in here and the differentiation between this unit and this would be at two levels." (Schön 1983, pp. 85-88)

[Fig. 4 here]

Represented in the situated FBS framework, this reflective conversation can be viewed to comprise the following activities:

1. Constructive memory (process 6): Quist, who intends to explore the effects of using Petra's new design concept on the given building site, arranges the three L-shapes laterally on three different levels, as a result of applying his individual design knowledge.
2. Focussing (process 9): Quist includes this candidate in the current design state space.
3. Action (process 12): Quist draws the sketch represented in Figure 4, which corresponds to the lateral arrangement he wants to explore.
4. Interpretation (process 13): Quist interprets what he has produced, which includes additional spaces at "5-foot intervals" emerging from the level differences.
5. Derivation of behaviour from structure (process 14): Quist derives the behaviours of (lateral) area and enclosedness from the additional spaces, which he refers to as "nooks".

The design protocol shows how Quist uses the emerging "nooks" as a basis for further design moves:

"Now you would give preference to that as a precinct which opens out into here and into here and then, of course, we'd have a wall – on the inside there could be a wall or steps to relate in downward. Well, that either happens here or here, and you'll have to investigate which way it should or can go. If it happens this way, the gallery is northwards – but I think the gallery might be a kind of garden – a sort of soft back area to these." (Schön 1983, p. 89)

The sketch in Figure 5 represents some of the issues raised in this part of Schön's protocol. The reflective conversation used to produce and explore this sketch can again be described in terms of the five activities in our framework.

[Fig. 5 here]

3 A Constructional View of Reflection

The ontological framework we have presented so far assumes a functional view of reflection. It provides a level of description that captures the designer's interaction with the design situation but is too coarse-grained to represent reflection as an underlying process. This Section switches from the functional to a constructional stance, which aims to provide a more detailed ontological representation of reflection as a precursor for the designer's reflective conversation.
Schön's descriptions of reflection, from a constructional perspective, imply the use of memory: "We think critically about the thinking that got us into this fix or this opportunity; and we may, in the process, restructure strategies of action, understandings of phenomena, or ways of framing problems" (Schön 1987, p. 28). "Restructuring" can be viewed as an activity of homogenous change, as the objects of

"thinking" are modified in the light of the current situation but remain essentially the same objects. This fits well with two of the definitions provided by the *Merriam-Webster* dictionary, summarising the physical meaning of reflection: "the production of an image by or as if by a mirror" (which maps onto homogeneity) and "the action of bending or folding back" (which maps onto change).

Constructive memory, representing a homogenous transformation of previous experiences, can be seen as subsuming the notion of reflection. The primary kinds of experiences reflected on in Schön's descriptions are experiences with design objects, or, more exactly, with the structure of design objects. Therefore, we can represent Schön's reflection as being captured by process 6 shown in Figure 3.

This representation can be further elaborated, using an approach to reflection that is more process-centred. Specifically, we apply the FBS ontology directly to the process of reflection. To better distinguish the FBS view of reflection from the FBS view of the design object being reflected on, we will use the terms "design function", "design behaviour" and "design structure" when referring to the latter, and the simpler terms "function", "behaviour" and "structure" for the former. We conjecture the following FBS view of reflection:

- Function (F): to modify the design structure state space
- Behaviour (B): (1) the accuracy with which the result of the reflection solves a given design issue (e.g. the ability of Petra's L-shapes to solve her "too small to do much with" problem), and (2) the interestingness of the result that is a non-linear function of the degree of novelty relative to the experiences of the designer (Saunders and Gero 2004)
- Structure (S): consists of the following components: an interpreted design structure (the input component), a "push-pull" mechanism (the transformation component), and an (altered) interpreted design structure (the output component)

This view provides three levels at which reflection can be analysed and compared with other processes in designing.

At the function level, reflection can be characterised as crucial for non-routine designing as it modifies the design structure state space, without which only routine design outcomes could be produced. However, the function of reflection is not unique, since it can also be ascribed to the process of re-interpreting external design structure (subsumed by processes 3 and 13 in Figure 3). As an example of this process can be seen the emergence of outer spaces from Petra's drawing, described earlier.

At the behaviour level, instances of reflection can be characterised in quantitative terms. We can generally assume that most instances of reflection reach relatively high values of interestingness. This implies that the experiences they produce are neither too similar nor too different than previously encountered experiences (Saunders and Gero 2004). We further assume that most instances of reflection exhibit accuracy only in a limited sense: The external benchmark needed to compute accuracy is likely to comprise very few salient features the designer deems important, aiming to produce good (enough) results. This assumption is derived from the principle of "ecological rationality" in cognitive science (Todd and Gigerenzer 2003).

At the structure level, reflection can be characterised as the most unique among all other processes in designing, based on its input and output being of the same type (we referred to this as homogeneity). For example, all processes of design synthesis are heterogeneous, as they take design behaviours as input, and produce design structures as output. All design analysis processes are also heterogeneous. They transform design structure (and, eventually, given external effects), as input, into design behaviour, as output, irrespective of their instantiation as, for instance, thermal stress analysis, kinetic analysis or cost analysis. The homogeneity of reflection holds for all instances of reflection, no matter what specific design structure is used as input and output. This allows applying the notion of reflection to a broad range of artefacts being reflected on.

A designer's actions can be viewed as forming a particular class of artefacts. Reflection on such an artefact corresponds to Schön's notion of "reflection-on-action", which he describes as "thinking back on what we have done in order to discover how our knowing in action may have contributed to an unexpected outcome. We may do so after the fact, in tranquillity or we may pause in the midst of action (stop and think)." (Schön 1987, p. 26) An action as the input and output of reflection can itself be viewed as a process with its own function, behaviour and structure. (We will refer to the function, behaviour and structure of an action as "action function", "action behaviour" and "action structure", respectively.) An instance of reflection-on-action can be interpreted from Schön's (1983) protocol of Petra's design session:

"At the beginning of the review, Petra is stuck:

[Petra:] I've tried to butt the shape of the building into the contours of the land there – but the shape doesn't fit into the slope.

Quist criticizes her framing of the problem, pointing out that she has tried to fit the shapes of the buildings into the contours of a "screwy" slope that offers no basis for coherence. Instead, he resets her problem:

[Quist:] You should begin with a discipline, even if it is arbitrary... you can always break it open later." (Schön 1983, p. 93)

Schön (1983, p. 85) explains that what Quist means by "discipline" is a building geometry that is imposed upon the "screwy" site to provide coherence. This geometry may be "broken open" later, i.e. partially dissolved and replaced against another one.
We can interpret Quist's re-"framing of the problem" as a reflection on Petra's initially intended action (or design strategy). The desired action function remains unchanged – to generate a coherent composition of the building shape and the site. What is primarily changed by Quist's reflection process is action structure, Figure 6. The initial action structure is composed of the given site (as input), the adaptation of the building shape to that site (as transformation), and a coherent building–site compound (as output). Quist's reflection-on-action uses this action structure as input and transforms it into an altered action structure as output. The altered action structure consists of a building geometry (as input), the configuration of the site using that building geometry (as transformation), and a coherent building–site compound (as output).

[Fig. 6 here]

4 Conclusion

Our paper has presented a model of Schön's reflection that differs from previous work, including Schön's own work, in two ways. First, it elaborates the existing verbal descriptions of reflection and its effects on the process of designing, by specifying reflective conversation as a set of distinct activities. We have referred to this as a functional view of reflection. Second, the model is embedded in an ontological framework that allows identifying the unique properties of reflection with respect to other processes in designing. We have presented a detailed model of these properties, distinguishing function, behaviour and structure properties, forming what we have called a constructional view of reflection.
The overall benefit of this ontological account is that it provides a framework for research in reflection, irrespective of the discipline of designing and the specific object being reflected on. This enhances understanding of reflection, as the various forms in which it appears in different disciplinary accounts of designing can now be represented uniformly. For example, we have shown in our earlier work (Gero and Kannengiesser 2007b) that instances of reflective conversation in software engineering can be described in terms of the same five activities as presented in this paper. This work can be extended to other disciplines that have observed activities consistent with the notion of reflection. One candidate is strategy design in the management sciences, where the term "strategizing" has been used to denote the interactive construction of strategies through reflective conversation (Cummings and Wilson 2003). Using our ontological model of reflection allows comparing and integrating insights from the various disciplines, and thus facilitates cross-domain transfer of methods for stimulating reflection.
There are also limitations in this model of reflection. A number of observations have been made in designing that are consistent with the idea of reflection but would be more appropriately described as reflection on design function or design behaviour rather than on design structure. For example, Schön (1983) has described how various functions of Scotch Tape, such as to wrap packages and to curl hair, emerged through a reflective conversation between designers and users. The situated FBS framework can accommodate possible extensions of our model of reflection, as it provides a set of processes similar to the ones already in our model, but at the ontological levels of design function and design behaviour. Possible implementations of our ontological account in terms of cognitive or computational models are beyond the scope of this paper. However, they are clearly needed for developing a thorough

understanding of reflection, and for building tools that more effectively assist designers in reflecting on the design than the technologies currently available. Current research themes associated with this issue include work on constructive memory and situatedness.

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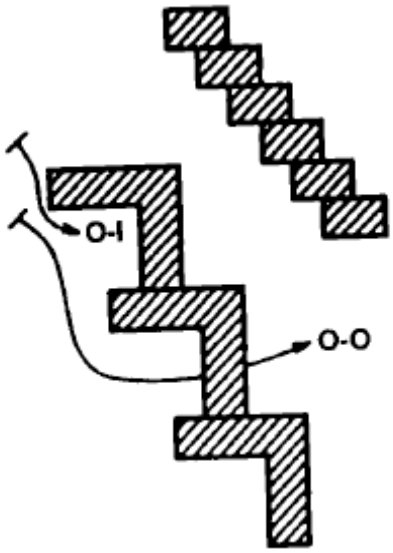
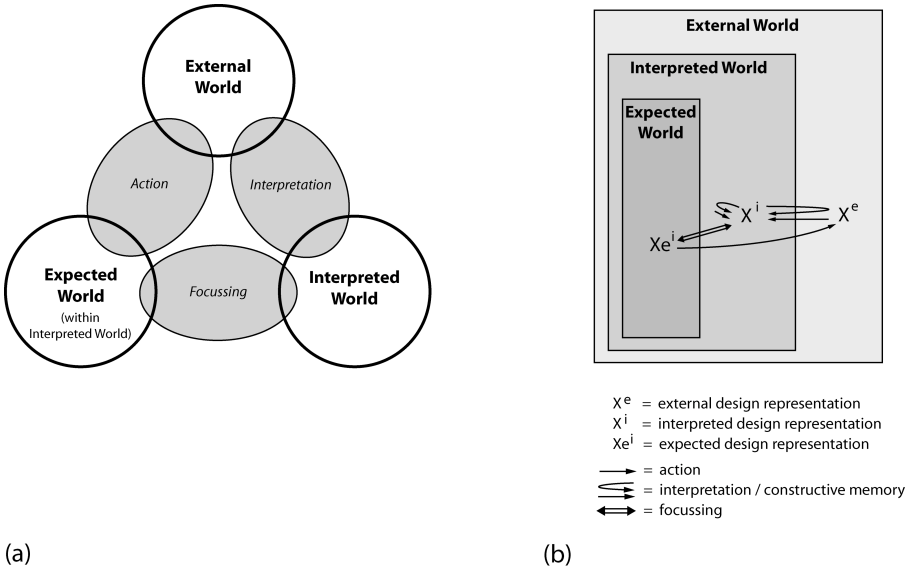


Figure 1 Petra's drawings of the layout of a classroom (image from Schön and Wiggins (1992))



(a) (b)

Figure 2 Situated designing as the interaction of three worlds: (a) general model, (b) specialised model for design representations (Gero and Kannengiesser 2004)

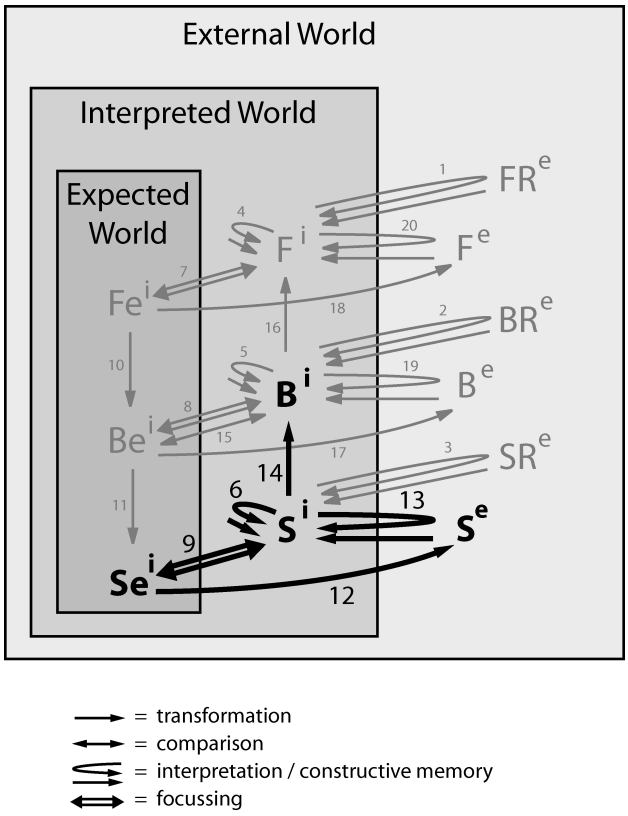


Figure 3 The processes of reflective conversation (highlighted) in the situated FBS framework

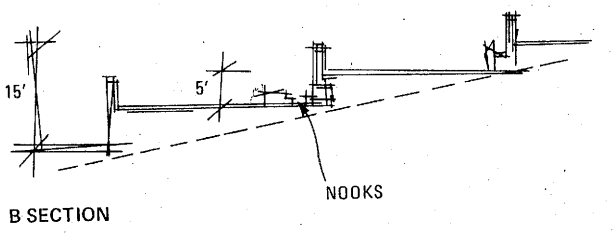


Figure 4 Sketch of classrooms and contour of the site (image from Schön (1983))

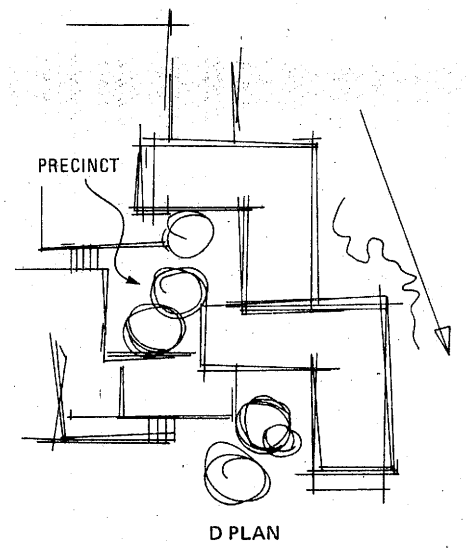


Figure 5 Sketch of classroom layout and surroundings (image from Schön (1983))

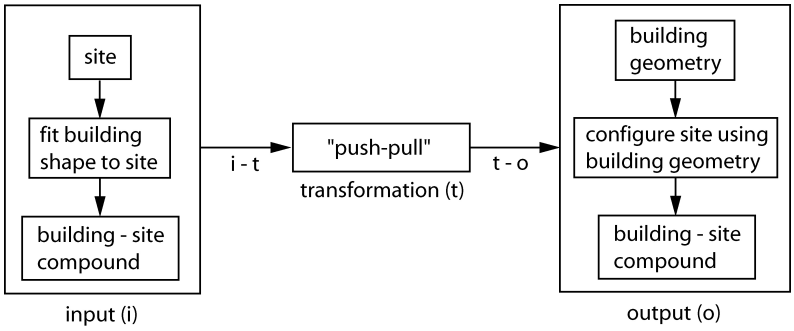


Figure 6 The structure of reflection on action structure, interpreted from Schön's (1983) example

TABLE 1 Schön and Wiggins' (1992) example of reflective designing, mapped onto the processes labelled in Figure 3

Example from Schön and Wiggins (1992)	Processes labelled in Figure 3
I had six of these classroom units but they were too small to do much with. So I changed them to this more significant layout (the L-shapes).	Constructive memory: 6 Focussing: 9 Action: 12 Interpretation: 13
It relates grade one to two, three to four, and five to six grades, which is more what I wanted to do educationally anyway. What I have here is a space which is more of a home base. I'll have an outside/inside which can be used and an outside/outside which can be used – then that opens into your resource library/language thing.	Transformation: 14

This is a copy of the paper: Gero, JS and Kannengiesser, U(2009) An ontological account of Donald Schon's reflection in designing, *Design Sciences and Technology* (to appear).