Sketch as Sketch Can
Design sketching with imperfect aids and sketchpads of the future

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Résumé français

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Le rôle important de l'esquisse et de l'avant-projet n'a pas eu pour conséquence l'évolution d'instruments de CAO correspondant aux besoins de la création. La CAO telle qu'elle existe à l'heure actuelle favorise la visualisation exacte aux dépens du trait imprécis et intuitif. Ni la technologie de la réalité virtuelle, ni celle du bloc-note électronique ne semblent aller dans la direction voulue pour l'esquisse. Les fonctions et le caractère propre de l'esquisse dans la création assistée par ordinateur sont encore trop peu connus. De même, la phase de l’esquisse se laisse encore difficilement approcher dans la pédagogie de la CAO. Pour pallier à ces manques, l’auteur a choisi deux approches: l'une est d’utiliser les logiciels existants en les détournant de leur fonctionnalité, l'autre est de chercher la synthèse de modèles théoriques de la création architecturale afin de donner à l’esquisse la place qui lui revient dans la CAO. La première approche a été traduite dans des exercices proposés en atelier (à l’aide du module 3D du logiciel Architron), dans lesquels les étudiants ont pu donner libre cours à leur imagination. Il leur a toutefois été demandé de tenir compte d’un certain nombre de contraintes. Pour la seconde approche, les modèles de la conception architecturale selon Lebahar et Chan ont été retenus comme base de départ étant donné leur complémentarité. Dans une prochaine phase de l'évolution de la CAO, il sera nécessaire d'effectuer des recherches de psychologie cognitive et d'ergonomie afin de donner aux concepteurs un nouveau type d'outil: un outil qui saurait se faire discret afin de ne pas fragiliser la création, tout en offrant des moyens qui sublimerait ceux des crayons et des carnets de croquis traditionnels, mais en y ajoutant les apports propres de l'électronique.
Introduction

Sketching plays a manifold role in design and design education now as much as it did in the computerless days. Design sketching is indispensable during the early phases of the architectural design process. But if we ask architects and design educators alike what they are doing with computers, idea sketching is the least mentioned answer if not left out entirely. It is not because they are computer-illiterates, as the computer industry would tend to imply, but because their computers are not offering an adequate environment for design sketching. In education this means that those trying to create computer aided design sketching courses are confronted with the choice of either working with unperfect tools, or waiting for better tools. But by exploring the possibilities in available surrogates we will build the necessary experiences for specifying what is really useful for idea-sketching. Without such exercises, we will never go beyond the electronic metaphor of the sketchbook with pencil or marker.

Productive and reproductive sketching

We should make a difference in education between sketching as a creative or productive activity on the one hand and "re-creative or "re-productive" activity on the other hand (with insistence on the etymological sense of those terms). While a growing number of computer programs is filling the marketplace for those who seek reproductive tools, a quite different situation is encountered in the field of creative design sketchtools. No unconstrained computer medium has been developed for graphic ideation which could be compared to the quick freehand sketch technique or the 3D equivalent of the clay or styrofoam mock-up.

In the pre-computer days, the rough, "quick and dirty" sketch was the right way to communicate an existing concept rapidly. As computer-aided reproductive sketching can be produced in a short time and has also the growing advantage of additional possibilities not provided by hand sketching alone (like easy scaling ` selecting and correcting or replacing, and in case of 3D programs, reproduction of an unlimited amount Of perspective views, floor plans, sections and elevations) there is in fact no need for the traditional rendering sketch except for the individual need to obtain and maintain one's own spontaneous sketching style.

Productive design sketchtools are, on the other hand, either non existent or underdeveloped and concealed in reproductive sketch and drawing tools. But for the time being we must be content with such surrogates and explore the possibilities available, even if they are not fast, supple and easy enough for real ideasketching. Sketch tablets with wireless pencils represent a good starting point for effordless sketching but to make the link between the space in the machine and the space in the head of the designer, the space in the machine should be equally supple and and pliable as the space manipulated by the designer in his head. Virtual reality is at this moment too constraining. New technology should offer sketching power. The notebook technology offers a new ergonomy for text based activities, with icons and gestures instead of menus or written commands. But even notebook technology does not go far enough for our sketching demands. We need sketchpads instead of notebooks, "sketch strokes- instead of -gestures-. New technology in itself is not a solution, it should fit within an existing professional and educational culture.

The role of sketches in design processes

To develop the new tools as sketching tools, we must first know what sketching is and what it is used for. The goals to be sought can be distinguished as:
- preparatory sketches (for instance a simple description of the site),
- doodling sketches (to generate alternatives in the sub consciousness),
- schematic sketches (to depict relationships),
- refining sketches (for detailing found solutions),
- verification sketches (to introduce materiality, measurements and scale),
- presentation sketches (to anticipate the built design),
- explicative sketches (for argumentation purposes).

In order to study the role of sketching in architectural design, various theoretical models can be used as a basis for the observation and description of the sketching process as it is embedded in related activities. Sketch and think aloud protocols (by video, eye movement and computer screen and sound recording) will eventually clarify assumptions included in the models in order to adapt them better to practice. The results can be used to identify and specify adequate sketching features and to translate the obtained knowledge in an appropriate sketching course for (architectural) designers.

Trying to sketch with a non-design modelling tool

In order to grasp the unique possibilities for design sketching hidden in available reproduction programs and as a result to identify adequate surrogates, we have developed small exercises for an architectural course on design morphology. In order to avoid a mere re-creation of the hand sketching technique by using paint programs, we decided to explore the idea sketching possibilities of a 3D volume modelling program on the Macintosh.

To break the usual habit of modelling with blocks (in this case induced by the 3D program Architron) and to get fast results for the students, we decided to start with two “subtraction” exercises.

Students were instructed to create a large block in a few seconds and then to split that block “at random” and as fast as possible in many pieces (figure 1). Afterwards they were asked (a) to remove blocks and simultaneously looking for possible themes and meanings in what is left over and (b) to adapt the resulting set to fit it better to the identified themes and meanings and soon. To strengthen the identified interpretation, the students at the end of the process were allowed to apply some other options available like stretching, slanting and rotating blocks. As in brainstorming sessions, the students were stimulated to postpone criticism, to follow their ideas and interpretations spontaneously and to produce as much as possible in the given time of approximately one hour. The rest of the time of one afternoon they were allowed to refine their ideas, to explain them in written words and to make them graphically understandable for others.

A second exercise (figure 2) was focused on the association of syncopated music and boxes, varying in size, height or pitch, sharpness of edges and horizontal and vertical spacings or positions. Again the first production of spacings was to be done rapidly and rhythmically, with individual refinements afterwards in sizing, pitching and sharpening of the individual blocks. Special emphasis was given to the spatial effects of the produced compositions.

Expressive modelling

The next three exercises are based on the teaching ideas of Ulrich Flemming (1990) about compositional languages like “wall”, “panel” and “structure/infill” architectures. To simulate the ambiguities of idea
sketching and to get the possibilities of “emergent shape”, the students were asked to define and apply a penetrating rule between shapes. The effects can be studied adequately in the wire frame mode of the 3D modeller, although Boolean operations must be imitated manually. In the first of the three exercises the students were asked to apply the rules intuitively, the second exercise introduced some grids and a topology of a building plan as constrains to be met (eventually by changing one or more rules) and the third exercise offered a deformed site as an additional constraint for adapting the plan and to introduce “rules of obedience” (Boric, Micheloni, Pinon, 1984).

To demonstrate the links possible between syntax and semantics, a last training was introduced, dealing with form and its expression. The training is formulated as an elaboration of the foregoing exercises and uses archetypical design elements as defined by Thiis-Evensen (1987/89). And again, to get variations the students were encouraged to brainstorm visually before setting on a solution.

The didactics of sketching with a 3D modeller

Such exercises have to be evaluated within the didactical context of an architectural course. A few of the questions to be asked are:

- is computer sketching didactically correct? The ultimate goal is to learn designing rather than producing the nice or pleasing pictures resulting from free sketching;
- is it useful? The answer is positive if it gives additional possibilities for the idea production in designing or if it shortens the learning time of design sketching (especially in the Dutch situation of a shortened curriculum for design sketching);
- is it sufficient? Can hand sketching he replaced by computer sketching entirely? How adequate can be sketched to record, analyse, generate, develop and to represent architectural objects?
- is it harmful? Are such exercises detrimental to traditional sketching experience? There could be unexpected side effects and a trying out in simulated educational setting will reveal them, if compared with the established (but decreasing) hand sketching courses or existing design studio practices.

To compare exercises, we must first be sure that the courses are appropriate themselves as teaching instruments for architectural design. In fact those courses were developed on the basis of the Beaux-Arts tradition, where there is a belief that all arts have a common basis. Learning to sketch is learning the “perspective d’observation”, drawing still life and nudes. Students are learning an artistic craft just as students in art colleges, with an emphasis on drawing and rendering buildings. In those circumstances, sketching means recording, analysing and representing existing objects or known designs, not shaping and detailing an architectural task to he accomplished. This kind of generation and development of design ideas was the aim of the Bauhaus Grundlehre and its followers in the basic design courses or first year design studio's all over the world afterwards. As the word Grundlehre indicates, this course was just as well meant as a foundation course for all arts students. An essential difference with the Beaux-Arts traditions, however, was that Grundlehre sketching was focused towards designing objects, not reproduction. In the sixties and seventies, some pioneering courses in visual thinking like those by Robert H. McKim (1972) were started, but they did not penetrate mainstream teaching in more than marginal ways.

To evaluate the possibilities of the sketching techniques used to initiate and elaborate design ideas, questions about “cognitive styles in design-education” are important (Cross, 1985). How far will the sketching exercise stimulate:
- divergent thinking? For fluency and flexibility (required if more solutions than one are valid and desirable);
- impulsive, spontaneous behaviour? (to focus the imagination, make it as concrete as possible, by generating solutions early, one can explore the constraints and possibilities of the problem);
- a field independent perception? (to restructure the given problem (necessary to discern other than conventional shapes emergent forms) in patterns of rough (ambiguous) sketches);
- a holistic approach? (to assimilate information and to synthesize a solution, divergent exploration is important: changing the search direction, backtracking and jumping).

We can hypothesize that unambiguous, aesthetically pleasing sketches, made with precision and scaled accurately, are detrimental for idea sketching.

**Understanding design sketching**

Such an evaluation would be of more value if we were supplied with a better understanding of the architectural design process. There are few models of sketching process, but empirical research is still very scarce. Educational experiments could provide a fruitful interaction with research and with an architectural practice still looking for the right tools and for the right way of integrating them. Design sketches are for the exploration of the possibilities and limitations of the design task at hand. Coarseness is then desirable to create multi-interpretability, to associate new knowledge sources suggesting new ways of development. Only after we have studied the role and function of the idea sketch within the design process it is possible to apply such knowledge in effective exercises.

Modelling is an appropriate means to show us more or less hypothetically how things work in general. There are in any case two models offering better possibilities for specifying sketching tools and effective courses in design sketching. Both models are dealing more or less with the role of idea sketching in architectural design. The older model (figure 3) by Jean Charles Lebahar (1983) describes sketch designing as a graphical simulation process aimed at diminishing the uncertainty of the architect. The second model (figure 4 and 5) of the architectural design process is by Chiu-Shui Chan (1990) and is more in accordance with results of recent cognitive research. Both models are compatible with each other and can be combined in one over a scheme (figure 6). Such a united model will give us a hypothetical basis for the observation and description of the sketching process as it is embedded in related design activities.

**The Lebahar model**

In the Lebahar model (figure 3), there is a synchronic dimension which contains a model of problem solving. The architect is using sketches as a process of simulation in which he is at the same time (in information theory terms) the producer, sender and receiver of the simulation, which refers to a not-yet existent simulated object. In figure 3, the abbreviations used have the following meanings:

PA = architect as information system
S = simulation model (sketch, bubble diagram etc)
0 = state of the architectural problem, obtained after transformation by A with the help of S and a number of interactions I, resulting in a partial equilibrium E.
Thus there is at the same time a perceptual and a cognitive aspect to the production and reception of the simulation. What is right and false is tested by the architect/sketcher by comparing the produced sketch and the imagined object. The sketch is thus an instrument of diagnosis, which helps focusing the problem by testing architectural hypotheses. At the same time, the sketch triggers new ideas.

In the diachronic dimension, there is a cycle of transformation of the simulation, with the goal of diminishing uncertainty as to the final form of the object. Each test is at the same time the integration of the experience gained in the previous sketches and a projection into the future. In the diachronical dimension, the quantity of information augments in $0$ (grey zone). At the same time $PA$ contains less unknowns (decrement of grey zone in $PA$). The proportion of certainty/uncertainty in $A$ changes. At the end of the process, $PA$ has been absorbed by $A$, as the state of $0$ shows. The evolution in time is represented by $To$ to $Tn$. $0$ of $To$ is the state of knowledge of the architect at time $To$ (for example knowledge about a type of architectural object).

Lebahar's model is of course much more elaborate when completed by his explanations, but the subtleties of the model cannot be delved into within the short description given here. But Lebahar is still quite vague when it comes to a description of the cognitive model of the architect. Whereas Chan gives a more precise model (figure 4 and 5) of what the Architect is in Lebahar's model, but is not explicit in the diachronic dimension. Thus the two models can be seen as complementary.

The Chan model

Chan summarizes his model as follows: "A design task can be broken down into a sequence of goals. The generation of goals derives either from a goal plan that is stored in memory or from a perceptual test. The means of selecting a goal to work on is referred to as the control strategy. The goal plan contains a sequence of goals that the designer must know in order to process the design task, and must achieve in order to get the design problem into the final goal state. In accomplishing a goal, the designer manipulates a set of design units. A package of knowledge about the design unit called a schema, which contains associated design constraints and rules for application, is stored in a knowledge base as a part of the designer's long-term memory. By taking a set of design units and retrieving its associated schemata, design solutions for a particular goal are generated and tested. This process can be illustrated within a simplified diagram in Figure 1 (figure 4 in this paper). By repeating the process (taking a goal, activating a design unit, retrieving a set of associated schemata, applying a rule to search for a solution and then testing the solution), the design problem gradually moves toward the final goal."

Chan elaborates his simplified model after an empirical study of a designer, that did "confirm the existence of a goal stack, the design schemata, the perceptual test and the search methods used by the subject. Based on the findings, an invariant structure of cognitive processes is mapped into the proposed model and shown in Figure 4 (figure 5 in this paper). When a goal is developed, a design unit and the associated schema are retrieved from long-term memory. The retrieved schemata specify the current goal. This is the problem structuring stage. Then the system searches for rules embedded at the schema for solution generation. This is the problem solving stage. The perceptual-test will control the system whenever the failure in memory retrieval or in search occurs. This cognitive model has a goal-driven but perceptual-test oriented nature." (Chan, 1990)
The design sketch simulation process

With reference to the Chan and Lebahar models, a combined and re-interpreted model can be derived (figure 6). The states are divided according the types of design sketches involved (the big circles, right in figure 6):

- observational sketches (first state, light grey, unambiguous, analytical recording);
- doodling sketches (first intermediate state, medium grey, most ambiguous, schematic, to generate ideas);
- verificational sketches (second intermediate state, dark grey, less ambiguous, to elaborate, refine, detail, dimension, scale);
- explicative sketches (end state, black, unambiguous, to illustrate, to communicate and to represent).

Instead of hand sketches, we have presented here the first results of experiments with computer sketches as possible surrogates.

On the left side boxes denote the architectural problem given by the client and other sources as external information (brief, site, costs, etc.) and how it is incrementally solved (symbolized by the infill of the boxes from black on top to light grey below). Translated in our design morphology exercises: the (drawn and written) tasks given to the student.

The same type of blocks on the right stands for the developed model of the object (internal information), defined by its geometry and (eventually) other properties. Light grey on top denotes all the missing data of the object model and increasing blackness below the growth in knowledge about the object model. From the known data, consequences can be derived about costs, construction implications, building physics, environmental impact, and so on. As an Apple Center of Excellence and a partner of a European COMETT project, we are in the process of applying such evaluation modules in the sketch design phases of a few selected projects.

The biggest block in the scheme stands for the architect as producer, sender and receiver of design information (including his own architectural objectives, ideas, pre- and subsolutions and self imposed constraints). From top (light grey) to bottom (black) in decreasing states of uncertainty about his proposal (object model).

The schemata within the blocks represents a cognitive model of the sketch design process. This model based on Chan's concepts is elaborated in figure 7.

The current goal is what is actualized in short-term memory to work on. Goals are derived either from the goal plan or the perceptual -test. The goal plan is stored in long term memory and steers the design process. Additional perceived problems are transformable in subgoals and can be activitated accordingly. The perceptual -test checks whether the current goal is achieved, whether the found solution satisfies the constraints, whether design units are lacking or the problem context is changed. Goals developed from a perceptual-test are called "stimuli-driven", generated from a goal plan -goal-driven-.

A control strategy (located in the overall box) determines the selection of a goal and the structuring of the solution path. The control strategy is more or less embedded in the applied scales of building drawings and sketches. What can he studied and manipulated on a 1: 1000 scale is quite different from a 1: 1 scale (other
goals, design units and schemata will be perceived and worked on).

Architectural design units are physical or spatial elements of a building like walls or rooms that are considered or manipulated during the course of the design process.

Schemata are knowledge containers organised around design units, their interrelationships, properties and constraints (declarative knowledge) combined with (procedural) knowledge of how to apply them within a design task. Schemata can be embedded within a hierarchical scheme of design units: a knowledge base.

The solution search will guide the designer in the vast combinatorial space of design units. By a global search method he is organizing the task as a whole, subtasks are handled by local search techniques. Methods and techniques can be formalized in instructions and "if-then rules". The wiring of relationships between the different boxes in the scheme will be influenced by the chosen search methods and techniques. Solution tests are goal and schemata driven, perceptual tests stimuli or sketch driven.

A general explanation by example of all the concepts used in the model is written in figure 8. To demonstrate their application in an actual worked out example figure 9 is formulated, based on the explanations given by a post-graduate student (Hugo de Haan) as comments by the produced pictures (figure 10) of his assignment. The remaining pictures of the figure 11 and following gives an impression of the work of other students so far (during the Design morphology course 1991).

Sketchpad of the future

What we need is a clear idea of what we can do for design sketching with the available technology. The discussed design sketch models of Lebahar and Chiu-Shui Chan could be tentatively translated into hardware and software and built in a sketchbook design environment. Much of the required hardware and software is either available or will be offered on the market soon. A lot will remain to be done in order to adapt them to sketching, as research necessary for the specifications is just beginning to bear fruit.

In the Lebahar model "architectural problem- issues can be stored for consultation in the sketchbook memory system, while the -information processing system- can be supported by design aids like our own programs for interactive graphic information processing and for the time being a more usual 3D CA(AD)1) package for both sketching in the "simulation model" mode and modelling/drawing in the -object model" mode. After we have gained some experience with such a system, more intelligence and even fuzzy logic can be built in to assist the sketchbook designer.

In the Chan model the "goalplan" and "knowledge base" could be stored in the memory of the sketchbook system for accessing and presentation on the screen to support respectively the " activatedgoal" state in the short term working memory of the designer and his or her activity of "finding design elements with matching schemata". Again, to support "design generating and testing" activities with sketches a 3D CA(AD)D package can be introduced, while to support "perceptual test activities the designer can be helped by devices like the prototype CAD program "ecart" by Milton Tan (1990) or a program by van der Helm and Leeuwenberg (1988) to calculate both the most specific and the more or less competing interpretations or patterns possible (and corresponding with the interpretations made by people spontaneously). Both programs promise to help the designer to detect -emergent forms- (to enable the abstraction of subshapes, to support the completion of implied "phantom" shapes and to allow multiple interpretations or recognition of ambiguous shapes).

The implication for education is that budding designers could make use of the accumulated experience of
professionals while concentrating on the spontaneity and freshness of sketching in a similar manner to the traditional paper sketchpad or rough 3D maquette. One of the attractions of the old sketchpad was its transportability. Mobility is one of the most important requirements for the free flow of sketching and it can now be obtained while information is stored locally or accessed via telecommunication.

For the time being we are going to simulate this whole sketchbook system idea in our normal computing environment, in order to get experience with the concept, to develop missing or not yet filled in elements and to test the sketch models for their effectiveness. As a background we hope to use the results of our basic research projects about working design styles of architects and schematic design techniques.

At the moment, training students for sketching is mostly training them to reproduce external reality rather than translating their imagined reality into a design concept. The new technologies and the new empirical results of research on sketching should have an impact on training, otherwise we run the risk of applying nineteenth century methods to the electronic sketchpad. Perhaps it will at last he possible to turn the pioneering "visual thinking- concepts from mental training into operational reality.

Acknowledgements

The examples from the course were conceived with the teaching assistance by Philip van Boxtel, Hugo de Haan and Stan van Kol. I also wish to thank my wife, Myriam Daru, for her many suggestions and criticisms.
References


Figure 1
The computer as a sketching machine, with sets of modification rules applied first at random, and afterwards by enhancing the interpretation.

Figure 2
Transformation of random volumes with a rythmical principle (first illustration) and of a selection within a given library, according to the resulting interpretation. The goal was to achieve complexity, variety, rythm in movement and depth effects.
Schéma général de la recherche de l'objet par simulation graphique

Figure 3
The design process as a graphical simulation, according to Jean-Charles Lebahar.
Figure 4
The design process as a goal-driven activity, with perceptual controls, as schematized by Chiu Shui Chan.

Figure 5
Detailed model of the design process according to Chiu Shui Chan.
Figure 6
A general model of the design process, combining elements from the Lebahr and Chan models.
Figure 7
A model of the internal cognitive representation by the architect (as a detail of figure 6).
General translation of the sketching model as a part of the design morphology course.
Goal plan: 1. task understanding: to create and architectural composition with a structure, b. complexity, polymorphic appearance, variety, c. spatial quality, d. (own goal) choose the theme ‘railway strike’ (to integrate the a. to c. demands and direct the own strategic behavior); 2. import or construct design unit(s), 3. cut at random; 4. extend some blocks at random; 5. remove some blocks at random; 6. make some representations, 7. interpret the results aesthetically (consistently structured; varied; rhythm, order in complexity, spatial quality); 8. interpret the results semantically (associated meaning, multi-interpretablility), 9. modify the results accordingly (to intensify the impressions); 10. express the impressions in final representations: a description of the assignment, a short outline on the strategy followed, a written description and pictures of the composition.

Activate a design unit: 1. a short 3D bar/wooden sleeper, 2. a long 3D bar/railway track, 3. a 3D plane/building element, 4. a plane/signboard, 5. a 3D mass/building

Retrieve schemata: 1. identifier: the railway track, 2. variable (design unit): the wooden sleeper, 3. set of rules: duplication, translation, elevation and rotation, 4. value of variable: use no more than 1500 blocks.

Alternative description of schema format of the first exercise, 1. Name: the prototype missing study, 2. (f)unctional a. function: railway track, b. style: block, plane and bar architecture, 3. Description [Dp] a kind of: railway track through a city, 4. (V)ocabulary of parts: bar sleepers and tracks, building masses and planes; 5. Interpretive knowledge (Ks) if identical bars are placed in a row across each other, than it may be a railway sleepers arrangement; if much bigger perpendicular blocks are ordered along the sleepers arrangement, than it may be buildings of a city; 6. Syntactic knowledge (Ks) if modification set X is given, than blocks can be defined and produced, duplicated, translated, elevated and rotated.

Heuristics and other solution search rules: if you want variety, make many different design units; if you want structure, make a hierarchy of block arrangements; if you want structured variety, make a global arrangement first with a few big blocks and detail them later by splitting them in smaller blocks and/or addition of other smaller blocks; if you get an endless perspective, break it by lifting and curving the perspective elements and block them by other elements, if you want to symbolize a railway strike, disassemble and hustle the railway tracks.

Test solution against global and autonomous constraints: global constraints given to the student: 1. number of blocks, 2. quality of presentation (readability, orderly but lively lay-out, clear focus of attention, concise but complete set of pictures and explanations), 3. quality of composition (variety and complexity of elements and rules applied, polymorphic appearance and multi-interpretablility, rhythmic orchestration, depth gradient and massing effects of the applied elements. Autonomous constraints, evoked by execution of the tasks, self-imposed and as a choice argued by the student: the railway strike he endured and wanted to express as a theme.

Design related sketch type applied: 2. the doodle, schematic, relational or generic idea sketch (ambiguous, rough, loose, open-ended, evocative, abstract).

Perceptual test: 1. the current goal (theme, associated meaning, variety, complexity, etc.) is achieved by the blocks and arrangements applied. But a change in the problem space is necessary because the endless perspective is boring and no visual endpoint is reached. 2. buildings as particular design units are missing and the railway tracks are in the wrong position (placed properly on the wooden sleepers) to 3. evoke the intended schema/thematic association/meaning of a railway strike, in the and the global constraints are more or less satisfied (number of blocks, quality of presentation and composition).

Figure 9
The interpretation by a student of the concepts of figure 8 as applied in an exercise.
Figure 10

Graphical results of the sketching exercise as mentioned in figure 9, using the concepts from figure 8.
Figure 11

Introduction of shape grammar concepts into an educational context. Students develop and apply rules intuitively when using them in sketching exercises. Deformation is an added concept, leading to the adaptation of forms to sites.
Figure 12
Attribution of (functional) meaning to abstract forms, leading to the introduction of new rules.
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