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Sabine Ammon studied architecture and philosophy at the Technische Universität Berlin. Study and research visits led her to the University of London, Harvard University and ETH Zürich. Furthermore, she practised building design as a free-lance architect. Her dissertation "Wissen verstehen. Perspektiven einer prozessualen Theorie der Erkenntnis", Weilerswist 2009, develops a theory of knowledge, based on the philosophy of symbols.
In her current research project she explores the epistemic dimension of architectural design processes.

TRANSFORMING TACIT KNOWLEDGE
The example of architectural drawings

There is a commonly held, but limited view of architectural drawings. Drawings are usually seen as a means of representing buildings: they depict what is to be constructed. Through the elaborate modes of projection and refined notational systems used in architectural drawings, they relate to buildings, whether planned or existing.[1] We undoubtedly find in this view an important function of architectural drawings. They convey information that is essential to the construction process and that identifies the specific features of a building. However, when concentrating on how a drawing refers to a potential or actual built structure, many other important functions of drawings remain concealed. By using the example of transforming tacit knowledge, this article aims to expand this narrow view. Drawings do not only depict and represent; they also serve as an important tool to develop the building. They are used as a means to create, to think, and to imagine. To a great extent, drawings perform this broader function by making tacit knowledge explicit. In so doing, drawings trigger important transformations that occur throughout the design process.[2]

1 An influential account of a theory of notation can be found in Goodman, Nelson: *Languages of art. An approach to a theory of symbols*, Indianapolis: Bobbs-Merrill 1968. In the following, the expression "notational system" will be used in a broad sense relating to any established notation.
2 I concentrate in the following on drawings as a case study. Nevertheless, there are other elements in the design process such as models and descriptions that have a comparable function. Additionally, novel techniques of building information modeling (BIM) are leading to an increas-

In order to identify and understand these additional roles of drawings, we have to shift our focus of investigation in several directions. First, we have to extend the investigation from the products of the design process to the design process itself. It is important to note here that the notion of "design process" is used in the following in its broader sense. Often, "designing" is used to describe a very early stage in which the architect decides on the overarching idea and how to develop it into a spatial concept. However, when the notion of "design" is used here it characterizes a more comprehensive process, including the whole evolution of a project from its commencement to its conclusion, usually starting with sketchy ideas and demands and leading to the planning and revision of details, which usually lasts all the way through the actual construction process.

Second, as a consequence of this broad understanding of the design process, we also have to extend our notion of "architectural drawings." When we look at design as a comprehensive process we find many different forms of drawings: not just the detailed final technical plans used on the building site or the elaborate illustrations showing potential investors the future appearance of a building. When we ask what plays an active role in the design process, suddenly anything that is scribbled or written down starts to matter: sketches, early technical drawings, and the range of detailed technical drawings that make the design and construction process possible. Many different forms of notation are used in these, with elements ranging from the very rudimentary to the highly differentiated and abstract, from graphical and symbolic to verbal and numerical.

Third—and this is crucial for the present investigation of the transformation of tacit knowledge—to understand the additional roles that drawings play, we have to introduce a novel perspective on the design process. Design is usually equated with the creation of artifacts. As a consequence, drawings are only perceived in their relation to future or existing artifacts. However, design is, at the same time, an epistemic process. In the design process, creating and knowing go hand in hand.[3] Out of this interplay the new emerges, which can be investigated from two perspectives: the design process gives rise, on the one hand, to artifacts, and on the other, to knowledge. This novel perspective on design, contained under

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ing dissolution of these categories. The investigation of these interrelations will be left for further research. For a taxonomy of design tools, see Gänshirt, Christian: *Werkzeuge für Ideen. Einführung ins architektonische Entwerfen*, Basel u. a.: Birkhäuser 2007.

3 For an early account of this view see Goodman, Nelson: *Ways of worldmaking*, Indianapolis: Hackett 1978, p. 22; recently: Banse, Gerhard et al. (Ed.): *Erkennen und Gestalten. Eine Theorie der Technikwissenschaften*, Berlin: Edition Sigma 2006.

Fig. 1. Watergy building in Berlin Dahlem.

the umbrella of the theory of knowledge, clearly show that existing knowledge is used, modified, recombined, and structured through design to generate new knowledge.

If we want to explore these processes of transformation in more detail, important but as yet overlooked aspects of drawings come into focus. A determining feature of design is its procedural character, which remains largely ephemeral. Most of the knowledge involved is therefore tacit knowledge.[4] Looking at the design process, we have to distinguish two major fields of tacit knowledge. On the one hand, there is practical construction knowledge. In order to design a new building, the designer needs to know how it is to be constructed. He or she needs a great deal of knowledge about materials, construction techniques, and the construction process. On the other hand, knowledge about the design process is needed. Designing means evaluating and weighing alternatives. It is a decision-making process. Therefore, the architect needs to know how to apply the relevant knowledge and when to call on experts from other fields for assistance. Additionally, knowledge about how to evaluate and weigh alternatives is important. Both fields of tacit knowledge are crucial for the design process. Moreover, both fields of tacit knowledge are made—at least to certain extent—explicit. This is crucial for the design process: when knowledge is rendered explicit, it becomes easier to handle, which in turn makes it possible to check the evolving design. Architectural drawings are an important means of transforming tacit knowledge into more explicit forms of knowledge. In this way, they become a crucial means for generating new ideas and objects in the design process.

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4 For a common notion of tacit knowledge see Delaney, C. F.: “Knowledge, tacit”. In: E. Craig (Ed.): *Routledge Encyclopedia of Philosophy*, London: Routledge 1998. Retrieved October 30, 2009, from http://www.rep.routledge.com/article/P048. In the following, the notions of tacit and implicit knowledge will be used synonymously to describe the realm of practice, embracing experience, skills, and expertise. This has to be seen in contrast to the notion of explicit knowledge, which is set down in any form of notations—be it graphic, numerical, symbolic or verbal.

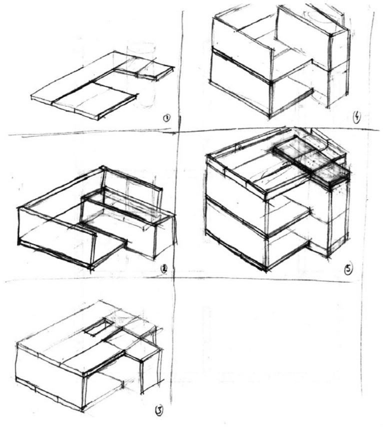


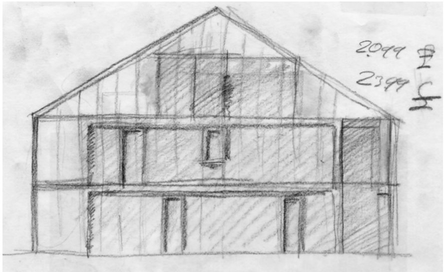
Fig. 2. Planning of the construction sequence. Opposite page: Fig. 3 and 4: show the changes during the design process from a conventional greenhouse-inspired architecture to a novel combination of heating system, greenhouse, and living environment.

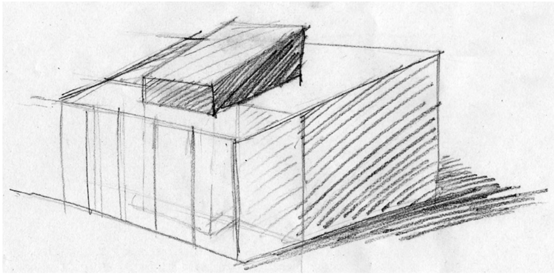
To explain this rather general claim, I propose six theses. They explore the complex relation between knowledge and architectural drawings in more detail, making the transformational potential of architectural drawings visible. The examples chosen to illustrate the argumentation originate in the design process for a research building in the Berlin district of Dahlem. This prototype is part of the research project Watergy[5] in the Department of Architecture at the Berlin University of Technology that deals with solar heating and cooling systems as well as with closed water cycles (fig. 1). The seasonal solar heating system is based on energy transport via steam. For this reason, the greenhouse, with its humidifying function, plays an important role in the design. The planning process started in the year of 2003, and construction of the building was completed in 2006. In the following years, the prototype was operated successfully as a zero-energy building.

*Thesis 1: Architectural drawings are an external tool for thinking that makes it possible to develop complex construction projects. A*rchitectural drawings constitute a tool for developing spatial constellations. Complex three-dimensional forms cannot be developed exclusively in the architect's head. Of course, there are significant differences here between the beginner and the professional. With more training and experience, the architect can imagine a wider variety of constellations. In this case, the drawing becomes more a means of conveying information. However, it is only possible to design complex buildings with the help of tools for visualization. To understand them as mental representations would be a major mistake, since visualizations do not merely depict future buildings. Only by using and modifying these techniques—say, by sketching, drawing, and calculating—does the design evolve.[6] The sketches in figure 2 develop the construction sequence for a building. In addition to the use of two-dimensional

5 For detailed information see www.watergy.de.

6 See Ferguson, Eugene S.: *Engineering and the mind's eye*, Cambridge, Mass.: MIT Press 1992, p. 96, who distinguishes among thinking sketches, prescriptive sketches, and talking sketches.

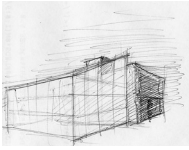
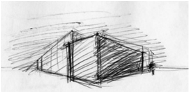
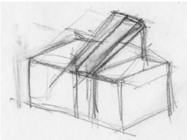
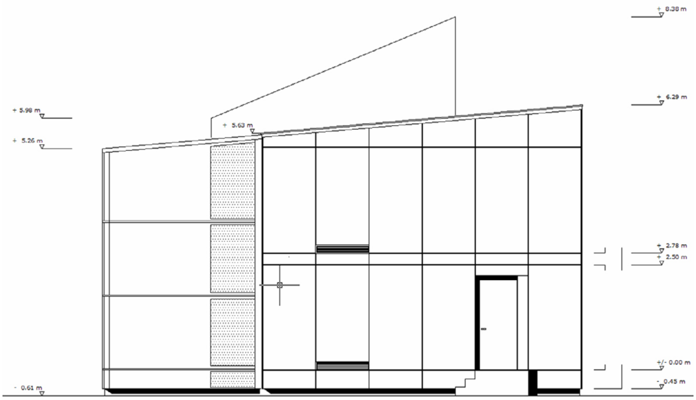




drawings, other techniques are often used that open up further dimensions for exploration. There are complementary three-dimensional techniques like models, mock-ups, and prototypes, and even four-dimensional techniques if we consider simulations, which give information on the construction sequence, studies on illumination, and virtual on-site inspections.

Thesis 2: Architectural drawings explore the tension field between novel creations and established knowledge practices. Design is a creative activity performed by individuals. On the one hand, the design has to adhere to rules, laws, and principles. It is bound to established practices and established knowledge. On the other hand, design is about creating something new that goes beyond anything that existed before, and this requires a framework that provides latitude to violate existing rules and challenge established knowledge. As a consequence, architectural drawings need to serve two functions: they must express existing rules, practices, and knowledge, but they must also provide the latitude for creating something new (see fig. 3 and 4). Notational systems provide the framework for developing a new design. They set the limitations on what can be depicted and described explicitly. In so doing, they restrict the design. This does not mean that it is impossible to design something that cannot be depicted with the existing notational systems, but it is very difficult. At the same time, the characteristics of the drawing tools and drawing practices influence the emerging design. To give just one example: the stencil plate or, more recently, the algorithm for calculating the curve influence the shape of the building.

Thesis 3: The typological sequence of architectural drawings enables the evolution from fuzzy constellations to an unambiguous product in the design process. If we look at the design process, we see an initially blurred imagination that gradually comes into focus. Often, the effect is described by a vicious lack of definition. Yet describing it in this way overlooks a crucial aspect: that the blurriness is important for this stage of the design. Design must be understood as a process that starts with a rough outline of something that will only much later come into being. It is not blurry just with respect to the shape of the building, but

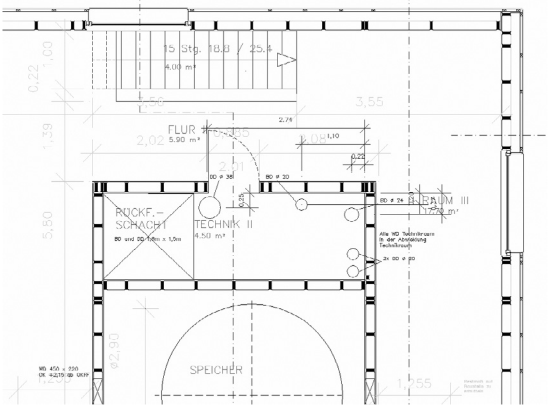





also with respect to its general structure, conditions, constraints, and objectives. Gradually, all these components come into focus. This is a complex process of evaluating and weighing in which numerous features are systematically specified and clarified. Parameters are defined and approximate values are determined. At the end of the planning process, a thoroughly detailed building emerges. Traditional modes of drawing support this process. The architect usually starts with rough pencil sketches. Here, the geometry and outer surfaces are sketched out with a few lines. Through the design process, these sketches evolve into the precise technical implementation plans that will be used to construct the building. The numerous decisions and parameters that emerge along the way are conveyed in the final plans (see fig. 5–8). Interestingly, the use of computer-aided design (CAD) has a significant effect on this process. CAD is being used at ever earlier stages in the design process. Through the use of this tool, the important vagueness of the initial drawings is lost in several respects from the outset. A discrepancy emerges between the detailed drawing methods used and the still-hazy parameters of the design. This in turn leads to problems in flexibility and variability, which are crucial for testing a design.

Thesis 4: Architectural drawings transform implicit knowledge of building practices and make it available for the design process. Architectural drawings convert certain aspects of practical construction knowledge into notational systems. By representing and exemplifying these aspects, this knowledge can be employed throughout the design process. The transformation that takes place can be regarded as a form of translation. In order to manage this difficult task, the practical knowledge needs to be structured, ordered, and parameterized. The notational system highlights certain aspects while ignoring others. If we look at an architectural drawing of a wall, for example, we obtain information about its width and height, but none on how to lay the bricks.

When we look at the notational system used in technical drawings, the system seems to be comprised of different elements (see fig. 9). First, there are graphic elements: for example, geometric lines, circular elements, curves, and hachures.

Opposite page, left: Fig. 5, 6, 7: show early rough sketches exploring the relation between building and greenhouse in contrast to Fig. 8 (right) representing the final configuration in a detailed technical drawing.
Right: Fig. 9 shows a part of the design plan containing graphic, verbal, numerical, and symbolic elements.



Even the line drawing itself contains information in the thickness, color, and style of the lines. Second, we find symbolic elements like pictographs; third, we find numerical elements; and forth, we find verbal elements. For all four types of elements, their position and order contains information. It is important where they are placed and in relation to what other symbols. Only if they are read together is the relevant practical information transmitted.

Another aspect is worth noting. To make these notations, to work with them, and to read them, a great deal of practical knowledge is needed. Without this background knowledge, it is impossible to use the information appropriately and successfully. We therefore have to recognize the very close connection that exists between modes of drawing, knowledge of drawing, and practical knowledge.

Thesis 5: Architectural drawings convey information and instructions for the design and construction process. Architectural drawings serve as a means of recording and documenting the design process; they duplicate and distribute information. As a storage medium, they structure and process information. Again, we find a process of transformation—but here, the other way around. The knowledge embedded in the notational system is turned back into practical knowledge. The construction company and the craftsmen receive instructions on how to build by reading the technical drawings (see fig. 10 and 11). The drawings also play an important role in conveying information throughout the design process. They are important for the design team and others involved in the project, serving as a means to share information on the design process and on the planned structure. Their function for the client, the administrative body, and consultants is similar.

When we look at these processes more closely, we discover a further interesting aspect. This process requires a range of different notational systems working together in addition to profound background knowledge of construction. First, as already mentioned, we need several elements in the technical drawings; second, we need several types of drawings, including section, ground plan, and elevation; and third, we need a detailed written building description. Usually, notational systems are not sufficient. We also need oral systems of communication; where

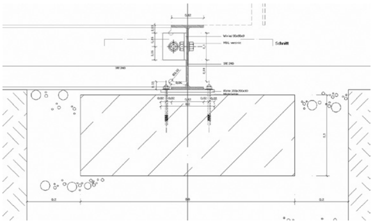


Fig. 10 (top) and 11 (bottom): show a detail drawing of the foundations with instructions for the construction and its later realization.

words are not enough, gestures come into play. The fact that architectural drawings do not stand alone tells us a lot about how tacit knowledge is transformed into notational systems.

Thesis 6: Architectural drawings visualize a multi-criteria and multidisciplinary decision-making process and enable its verification. During the design process, many criteria must be incorporated, structured, and assessed. This does not only apply to questions about the shape of the building; it also goes for the needs of the client and future users of the building. Numerous demands have to be satisfied: requirements of urban planning, structural analysis, building physics, fire protection, legal regulations, and aspects of sustainability among others (see fig. 12). In order to bring all these aspects together, the most important factors need to be singled out. Multidisciplinary decisions have to be made. In order to achieve a result, a balance must be found. The process involves extended negotiations as well as intensive testing and optimizing. During the process of reaching a decision, comprehensive knowledge sources have to be searched and adapted to the case at hand. The knowledge can again be implicit or explicit; it can be the possession of experts or made available in textbooks, journals, catalogs, or electronic resources. The architectural drawings help to find a solution through testing. By sketching several options, advantages and disadvantages can be explored and defined. By incorporating the information into the drawing, a vast amount of information is managed. Solutions can be visualized and, in the course of visualization, verified.

Further research needs to be done to show whether the six theses I have proposed here hold. If they do, then drawings are not just representations; they do not just put on paper what architects already have in their heads. Rather, what we observe taking place in the design process are substantial processes of transformation that embody implicit construction knowledge and implicit design knowledge, giving this knowledge explicit form. If proven, these findings will lead to a much stronger claim: the thesis that certain explicit forms of knowledge are crucial preconditions for the design process. We can even put this conclusion into more straightforward terms: design is only possible through certain means of

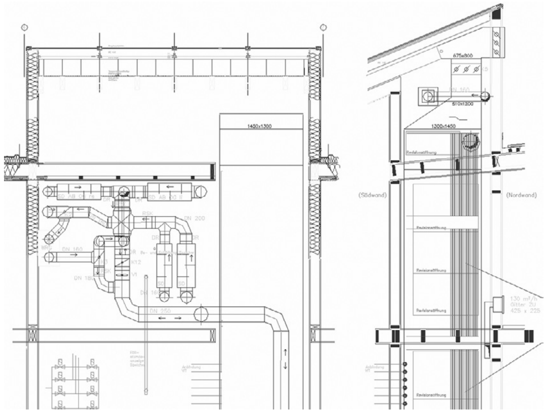


Fig. 12: shows a section of the installations room and shaft integrating demands of building construction, building services, solar technology, energy, and the heating system.

rendering knowledge explicit. But one needs to be careful here: it would be a mistake to conclude that more explicit forms of knowledge are always better for the design process. It is important to differentiate carefully according to the phase of the evolving design. Interestingly enough, the process of turning implicit forms of knowledge into explicit ones is more important at some stages than at others. We have seen that the impact of information conveyed in the drawings increases with the development from rather unspecific plans to very detailed ones. Whereas too much explicitness hampers the evolving design in the beginning, at the end of the process one needs as much explicitness as possible.

Besides its systematic implications, the assertion that certain means of rendering knowledge explicit are required during the design process gives also rise to an interesting historical dimension of the problem. For centuries, architectural knowledge was handed down mainly as practical and implicit knowledge. In the nineteenth and twentieth century, this knowledge became more and more mediated by notational systems—on the one hand, as civil and structural engineering became increasingly scientific, and on the other, as industrialization demanded new means of transmitting information. The need for more explicit forms of architectural knowledge must be seen in relation to the increasing complexity of building projects, the acceleration of planning and construction processes, and the specialization, internationalization, and automation of working procedures. At the same time, the notational system of architecture has also evolved significantly to convey more reliable information. Unlike our alphabetical system, which has gone through centuries of modification and improvement, the notational system of architecture is relatively new and still under development. Looking at these changes—including the shift to computer-based design processes with the turn of the twenty-first century—, the historical perspective also promises to reveal insights into the function of implicit and explicit forms of knowledge in architectural drawings and their transformational potential.

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