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Fredrik Nilsson

Knowledge in the Making

On Production and Communication of Knowledge in the Material Practices of Architecture

Abstract

This article discusses some conceptual frameworks and notions used in, or with the potential to further develop, theories and understandings regarding the specific processes and forms of knowledge in creative practices of architecture, design and art. More articulate conceptual frameworks are not only of importance for strengthening disciplines and practices, but can also make valid contributions in wider societal contexts in relation to contemporary challenges in built environments. With the point of departure in the notions “material practice” by Stan Allen and “making disciplines” by Halina Dunin-Woyseth, theoretical frameworks and approaches by, for example, Andrew Pickering, Nigel Cross, Alben Yaneva, and Gilles Deleuze & Felix Guattari are discussed. The contemporary world has brought challenging societal developments and complex transformations of built environments, but new tools have also enabled other forms of design experiments, including non-verbal languages and various model worlds. The article argues that we must constantly study the contemporary situation, but also reflect upon our means of designing and production, as well as our forms of working and collaboration. New relationships between theory and practice, between research and practical designing, between academia, architectural practice and different actors in society, must be articulated and established through conscious strategies.

Keywords: making disciplines, architectural knowledge, design knowledge

Introduction

The aspect of “making”, of physical action, of actively doing, of modelling, as well as altering things, is central to architecture and architectural design, both in relation to the actual designing and to the ways in which knowledge and theories are used and generated within architecture as a discipline and profession. Physical models in different materials, as well as immaterial models using different media and tools, are important aspects of design processes. This is not least because they enable the exploration and integration of different perspectives and facets in graspable entireties, with the potential to reveal and communicate insights to different actors. The learning of skills to produce material and visual artefacts, and to use them to communicate, is therefore important in the education of architects and designers. These different abilities, means and ways of representation are then used in various combinations to explore and refine projects in the architectural practices, leaving many material traces along the way to final designs and built architecture. For example, the physical traces and “waste” of design processes was the point of departure in the exhibition “Beauty and Waste” by Herzog & de Meuron (fig. 1). “Making” is part of a specific way of thinking, as well as of producing and implementing knowledge.

Designing and making are also ways of connecting the object of design to external factors, and of coping with the constantly changing conditions and challenges in the surrounding world. This is not least the case for architectural design, being almost always part, and dependent, of material and cultural, as well as political and economic, contexts. Contemporary challenges need new approaches and ways to manage the complexities of current urban situations and built environments. We need new, sustainable technical solutions and social spaces; new materials and modes of production bring new opportunities, but also

the requirement for other kinds of processes, making use of tools for variety, expression and precision in detailing. We have more complex buildings and construction processes intervening in existing built environments, and also rapidly changing cityscapes and urban transformations in formal and informal structures. Design thinking and “making” are ways to approach complex situations and make important contributions to the management of complexities, while integrating, and connecting, the different aspects and elements into something manageable.

In architectural and design thinking, artefacts play a central and important role, both as bearers of knowledge and as results of making processes, and the material and immaterial artefacts are used in several ways, during and after the actual design processes. The theme of these processes as explorative practices, involving material-making and its tools, is often discussed in architectural installations and exhibitions (fig. 2 & 3). Making is a way to work with, and integrate, all the different perspectives that are characteristic of architecture; merging contradictory elements and aspects into a whole is part of design ability. The making of objects and artefacts also generates and embodies specific forms of knowledge.



Figure 1 (Left): The exhibition “Beauty and Waste” by Herzog & de Meuron showed the physical traces of design and thought processes that every project leaves behind in the form of models, sketches and material samples. Herzog & de Meuron, NAI Rotterdam, 2005. Photo: Fredrik Nilsson

Figure 2 and 3: Architectural design as explorative material practices related to making processes has been a recurring theme in installations at the Architecture Biennale in Venice. Middle: Gehry Partners, “Ungapatchket”, Venice, 2008. Right: Studio Mumbai, “Work-Place”, Venice, 2010. Photos: Fredrik Nilsson

This article is based on a keynote lecture given at the conference “Making, Materiality and Knowledge,” and is an attempt to discuss some conceptual frameworks and notions that have been used in, or have the potential to further develop, theories and understandings regarding the specific processes and forms of knowledge used in creative practices of architecture, design and art. This forms parts of the framework for the strong research environment ‘Architecture in the Making. Architecture as a Making Discipline and Material Practice’, funded by the Swedish research council, Formas, which, in a national collaboration between the four schools of architecture in Sweden, aims to develop theories and methods from the perspective of architectural practice to strengthen architectural research. Articulate conceptual frameworks of this knowledge and these abilities are not only of importance for strengthening the disciplines and practices, but can also make important contributions in wider societal contexts in relation to contemporary challenges in built environments.

Embodied and materialised knowledge; “making” knowledge

Built environments consist of many types of materialised knowledge. It is possible to read patterns of socio-cultural contexts and processes, as well as material and technical patterns, mechanisms and solutions, in the built world around us. The material world is sometimes consciously designed to embody solutions to, and knowledge of, specific problems and situations; built environments are often more the emergent result of cultural and societal patterns and forces. Existing buildings, objects and environments are also used by architects in design processes as means to learn and communicate knowledge. In attempting to gain a more in depth understanding of these objects and processes, architectural research borrowed theories and methods from other disciplines; sometimes without reflecting on the specific character of architecture as a discipline. This eventually led to a strong critique from both the profession and from academia, and a growing need to develop more articulate conceptual and theoretical frameworks relevant to the specific field of architectural practice and research; for architecture as a profession and as a discipline (See e.g. Leatherbarrow, 2001, pp. 83–85; Lundequist, 1999, p. 7; Zaera-Polo, 2005, p. 4).

Architecture has been described as a “material practice” and a “making discipline” in attempts to develop a more field-specific scholarship. Central here is the aspect of a transformation of reality that is based on contemporary conditions, but directed towards the future. It is concerned not only with representations and interpretations of the world, but also with the creation of performances and transformations.

Stan Allen described architecture as a material practice, and he defined material practices as activities that transform reality by producing new objects and organisations of matter, such as, for instance, engineering, urbanism and landscape architecture. He also makes a distinction between what he calls hermeneutic and material practices. Hermeneutic practices are activities that interpret and analyse representations, and which primarily focus on the past and with issues of interpretation and meaning. In contrast, material practices analyse contemporary situations to create transformations that look towards the future. They work with concrete matter, not primarily with images, meaning or even with objects, but with performance, and produce concepts and theories from material and practical procedures (Allen, 1999, pp. 52–53, 2000, pp. xvii–xviii). These theories and concepts are constructs that are useful in the specific transformations of concrete situations and contexts of application.

The hermeneutic and material practices discussed by Allen can be related to the distinction between representational and performative idioms for considering science, as discussed by Andrew Pickering. In the representational idiom, science is viewed as attempting to represent nature and to produce knowledge about how the world is, while, in the performative idiom, science is activities that deal with the world as it is constantly doing things; it is full of material agency and actions, rather than facts (Pickering, 1995). Material practices can be seen as relating to the performative idiom, where the transformational agency and constantly changing world are points of departure.

According to Allen, architects have a unique basis of methods, tools and techniques, as well as a trained imagination and a capacity for constructing alternative worlds. Architecture has always had an intimate connection with society and the construction of social reality, which is full of changing conditions and different perspectives, and this often leads to a situation where architectural research finds it difficult to meet the demands of traditional scientific research. Architecture as a material practice deals with concrete materials and the formation of external reality, it works in contexts of application, it is constantly on the move and in close contact with specific material and social situations.

The active forming and making of artefacts as central in certain professions, also when considering how knowledge is generated and used (see fig. 4 & 5), as well as how they

develop as academic disciplines, has led to discussions around “making professions” and “making disciplines”. In this context, Halina Dunin-Woyseth, professor and founder of the doctoral programme at the Oslo School of Architecture and Design, has played an important role in developing strategies to enable stronger relationships between scholarly and creative design practices, through her pioneering work on the conceptual frameworks for “making professions and disciplines” (see e.g. Dunin-Woyseth, 2002; Dunin-Woyseth & Michl, 2001). According to Dunin-Woyseth, the “making professions” include the fields of art production, object design, industrial design, architecture, landscape architecture, urban design and spatial planning, and they represent a great variety and volume of artefacts and man-made environments. The making professions use a specific “making knowledge”, which relates to the established distinction between knowledge-that and knowledge-how (Ryle, 1971), where making knowledge primarily belongs to the broader category of knowledge-how. Dunin-Woyseth argued that to develop a making discipline, the making knowledge must achieve disciplinary viability and comply with the demands of two worlds; it must adhere to the world of the profession and simultaneously follow the rules of the academic world. A making discipline must be of relevance to the practice of the making professions and must be capable of fulfilling the criteria of science, which constitute disciplinary knowledge (Dunin-Woyseth & Michl, 2001, p. 2).

The difficulties in fitting established academic criteria have long been discussed in the design fields. As far back as 1969, Herbert Simon pioneered design theory by opposing the natural sciences with the design sciences in his seminal book *The Sciences of the Artificial*, in which he delineated clarifying distinctions between the different approaches. Natural sciences deal primarily with nature and how to understand the existing world, while design sciences focus on artificial things, “how to make artefacts that have desired properties and how to design”. To design is to imagine and devise “courses of action aimed at changing existing situations into preferred ones” (Simon, 1981, p. 129). Simon stressed ideas of modelling and simulation as important to the design of artefacts. Central to design is the construction and use of models as a way of making. The generation of different alternatives, often in large numbers, to be tested against a system of criteria, is in itself frequently something that must be constructed for the specific case; it is a way to navigate, and manage, the uncertainties of the situation. Simon defined design as the way to imagine and create alternatives, and to change the existing situation into one that is preferred. It is not primarily about how things are, but how things could be, how they could be made. It is not concerned with the essential, but the possible. In relation to academic norms of formalisation and well-defined disciplines, design and the science of the artificial seem loose, intuitive, informal and recipe-like.

Simon’s programme on design was further developed by Donald Schön, especially with regard to the ways in which knowledge in the design field is created, formed and used in a model world. His highly influential book *The Reflective Practitioner. How Professionals Think in Action*, which is today still referred to surprisingly often, is very much concerned with thinking in the making. Here, design is described as a reflective conversation with the situation, with its materials and with one’s own sketches, models and design moves. Schön argued that when the designer reflects at the same time as s/he acts in a situation, and when s/he uses reflection-in-action, the designer becomes a researcher in the practice context. The practitioner “is not dependent on the categories of established theory and technique, but constructs a new theory of the unique case”, he or she “does not separate thinking from doing” and because experimenting is a kind of action, implementation and application is built into the inquiry (Schön, 1983, p. 68). In the process of design, a repertoire of artefacts and patterns of possible solutions are used, and Schön emphasised this as important for design knowledge (Schön, 1983, p. 138). These repertoires consist both of patterns of matter, material artefacts, and patterns of processes, design methods. The training of designers to a

high level relies on the transfer of sets of solutions and approaches that can be used to confront new design problems.

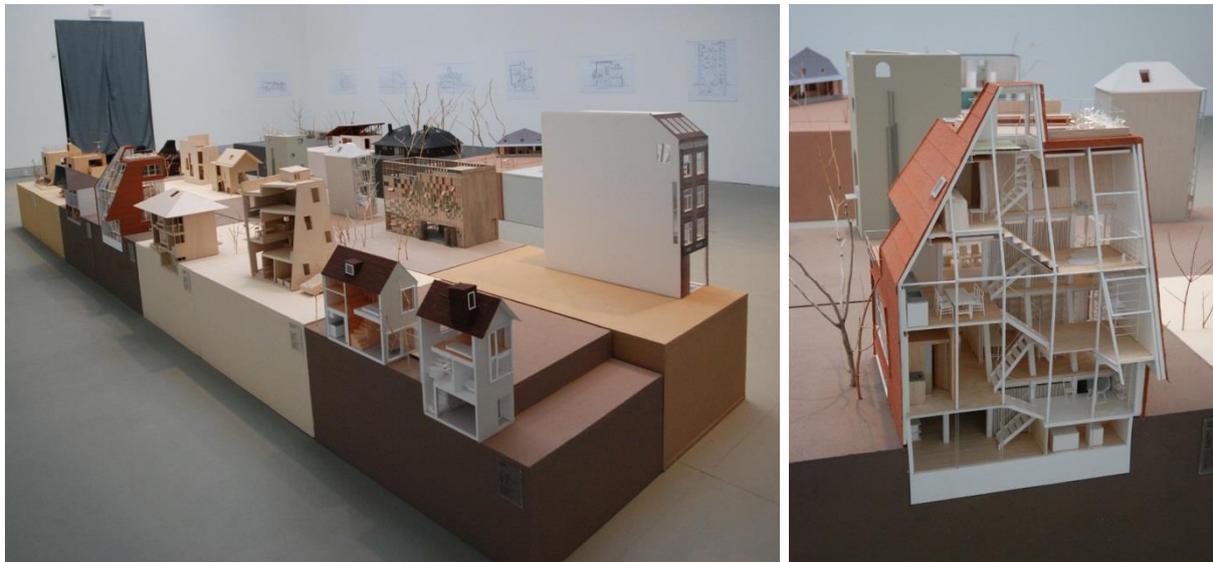


Figure 4 and 5: Architectural knowledge communicated through the object language and repertoire of Atelier Bow-Wow, as a result of dialogues between clients' lifestyles and site conditions. Atelier Bow-Wow, "House Behaviorology", 2010. Photos: Fredrik Nilsson

Critical dialogues and transgressions of borders

The two criteria for reaching disciplinary viability of making knowledge, professional relevance and scientific status, require a base, and Dunin-Woyseth proposed the triadic concept of History, Theory and Criticism as something that may provide this foundation, and as a cornerstone of the knowledge of designers (Dunin-Woyseth & Michl, 2001, p. 6). The importance of history is obvious, not least in relation to the repertoires highlighted by Schön. The importance of theory is paramount in all scientific disciplines, and criticism can be stressed as a central element in bridging practice and academic discourse. The challenge for the making professions of building a knowledge base that is on a par with academic disciplines can, according to Dunin-Woyseth, only be met by establishing a tradition of relevant discourse through the process of repeated critical discussions and debates that develop standards of quality. She also stated that it is not about claiming the superiority of disciplinary knowledge over other kinds of knowledge; but that the making disciplines can form a platform for fruitful dialogues with established fields of disciplinary knowledge. Organised scepticism and criticism within inter-subjective discourses will provide more informed and knowledgeable practices, as well as give rise to exchanges between fields where design can provide valuable contributions to academic development.

The dialogues between a making discipline and a specific academic discipline will vary according to the character of the making object of study and the academic discourse in question, and the role that the making discipline can play in providing a platform, or frame, for those dialogues in ways other than would traditional academic disciplines. "The role of making disciplines is that of a quality supportive framework for making discourses, rather than of a traditional academic discipline where methodology is the theoretical basis for the choice and application of methods" (Dunin-Woyseth & Nielsen, 2003, p. 28). In recent years, developments in artistic research and discussions with regard to "research by design" have shown that the making disciplines are on their way to achieving status as academic

disciplines. There have been difficulties in integrating knowledge production in creative practice and contexts of applications within the framework of traditional research and scholarship, but developments during recent decades, as well as interest from the scientific world, have made it possible to start conceptualising the field of knowledge in design and architecture in new ways (Dunin-Woyseth & Nilsson, 2008), and to find strategies for developing the required research cultures (Dunin-Woyseth & Nilsson, 2011a, 2011b). In addition, of course, that which is considered scientific status is not something static and given, once and for all.

The discussions on the concept of transdisciplinarity have opened up some new vistas on arenas where knowledge is generated, and the concept has been the focus of several scientific areas for some years, not least in relation to architectural research and issues of research by design. It has been fruitful in developments of research in close relation to fields of practice, but it is also obvious that the established academia has shown interest in design thinking as a way to broaden the scope of research and acknowledge types of knowledge and problems that are difficult to manage within traditional borders. The main feature of the emerging form of knowledge production, as identified in the seminal book *The New Production of Knowledge*, in which it is called Mode 2, is that it operates within a context of application where problems are not set within a disciplinary framework (Gibbons et al., 1994, pp. 3–5). Through the close involvement with practice, this mode involves the interaction of many actors and sets of practitioners within broader social and economic contexts, and therefore becomes more reflexive, accounting for several perspectives.

The strong feature of experimental attitudes and innovation is emphasised, including an interest in specific, concrete and ordered structures and processes, rather than general, unifying first principles. The search for knowledge through design is central, and the new tools enabled by computers and information technology have played important roles (Gibbons et al., 1994, pp. 43–44). Computers have become powerful tools of science, generating new languages and images capable of connecting and linking fields in novel ways. Examples can be drawn from images of fractals, visual modelling of data and the development of GIS, image analyses in medicine, all of which show, in different ways, how images and communications cut across disciplines.

The transdisciplinary Mode 2 of knowledge production implies a shift from a search for fundamental principles to enquiry that is oriented towards contextualised results, reached through experimental practice (Gibbons et al., 1994, p. 19). The focus is on following the problem and its concrete materials and actors through an experimental process guided by design principles.

Recent years have witnessed extensive discussions on the concept of transdisciplinarity and its relevance in the fields of urbanism, architecture and design. Several books, articles and journal issues have been dedicated to the theme of transdisciplinarity, with a range of uses and interpretations of the concept and its potential (See e.g. Doucet & Janssens, 2011; Linder, 2005; Stanek & Kaminer, 2007). A growing number of interesting approaches has also been emerging, whereby design abilities are used to grasp current conditions and complexities in urban situations and built environments, and where images, models and artefacts are used to explore, visualise and communicate complex relationships (See e.g. Burdett, 2006). These approaches are recognising other ways of producing and communicating knowledge (fig. 6 & 7). The verbal has often been regarded as the most appropriate and legitimate way of producing and communicating scientific knowledge, while design knowledge is often “tacit” or articulated in other languages that are more implicit and contextual, through material and visual means. However, design involves particular kinds of thinking and intellectual abilities that use specific means of expression, articulation and communication.



Figure 6 and 7: Physical models visualising and exploring the density and spatial character, as well as complex relationships, of several global cities. The 10th Architectural Biennale “Cities. Architecture and Society”, Venice, 2006. Photos: Fredrik Nilsson

Communicating and formalising knowledge in design

The particular design abilities have been described by Nigel Cross as multifaceted cognitive skills that are possessed by everyone, to some degree. These design abilities fundamentally rely on non-verbal media of thought and communication. Maybe this is one of the reasons why designers appear to be so reluctant, or unable, to verbalise their skills and knowledge. In the specific “designerly ways of knowing” employed by designers, knowledge is embodied both in the *processes* of designing and in the *products* of designing, according to Cross. Knowledge is accumulated in, and transferred through, methods and approaches, as well as various models and design artefacts. Designers have trained abilities for non-verbal thinking and communication, where certain “codes” are used to translate abstract requirements, formulated in the brief, in the visions of the client or in the wishes of the users, into concrete objects. These “codes”, or non-verbal thoughts, both “read” and “write” in “object languages” (Cross, 2007, pp. 26–29).

The ways in which to use these “object languages” in more inter-subjective critical discussions and discourses is a crucial question for the development of the making disciplines, as well as research within, or close to, architectural and design practice. How do we formalise these languages so they can be used to communicate knowledge to broader scientific communities, without losing their specific generative capacities?

Of course, issues of how knowledge and research approaches should be formalised are constantly on the agenda within scientific and scholarly discussions. In this regard, one can refer to the two contrasting scientific models discussed by Deleuze and Guattari: one model being uniting, comparing and formal; the other dispersing, transient, generative and informal (Deleuze & Guattari, 1987, pp. 369–370). The first model is royal science, searching for laws through constants and relationships between variables, finding forms and first principles; and the second is nomad science, concerned with the relationship between material-force, rather than matter-form, unconcerned with finding constants, but with producing change and transformation, the making of new worlds. Royal science attempts to control the world by

counting and measuring at a distance, and it works with a homogeneous, striated and formalised space. In contrast, nomad science explores the world by travelling through it, with the material, it envisages a heterogeneous, smooth space of contact; close to the material, tactile and manual, rather than the visual.

Deleuze and Guattari also contrasted two types of science, or scientific procedures: to reproduce or to follow. One is concerned with reproduction, iteration and re-iteration, while the other can rather be seen as itineration, journey, guide or map. Reproduction is central to royal science and a more distanced perspective on the world, and reproducing “implies the permanence of a fixed point of *view* that is external to what is produced: watching the flow from the bank” (Deleuze & Guattari, 1987, p. 372). To follow is not necessarily aiming to reproduce, and one has to follow when “singularities” in the material and not general forms or first principles are sought; you are forced to follow when you are concerned with the world’s continuous variation, instead of finding constants.

The ways of formalising knowledge differ between the two scientific procedures. A static perspective is dominant in royal science and reduces heuristic, ambulating and transforming characteristics, but there are also important plays, tensions and interchanges between the different procedures. Both sides are interdependent, putting pressure on one another; they both work within each other, constantly inspiring and bringing to order, challenging and displacing. It is not a dualism or polarity, but rather a matter of established and ruling procedures that are constantly being influenced and transformed from their margins while, at the same time, providing the required formalisation of experimental explorations. They provide different perspectives, using different attitudes and modes of thought, placing more abstract ideas and norms in relation to material thinking, processes, actors and objects.

Here, we can return, and relate this, to the two idioms for thinking about science that were delineated by Andrew Pickering: the representational versus the performative. The representational idiom views science as an activity that seeks to represent nature and to produce knowledge that maps, mirrors or corresponds to how the world actually is. In contrast, one can instead start from the idea that the world is not primarily filled with facts and observations, but with *agency*, that the world is constantly *doing things* that have a bearing on us, not as observations of disembodied intellects, but as forces applied to material beings. In the performative idiom, science is regarded as a field of powers, capacities and performances, situated in machinic captures of material agency. In many ways, everyday life is concerned with coping with material agency coming at us from outside of the human realm, and Pickering suggested that we should both see science as a continuation and extension of these ways of coping with material agency, and view machines as central to how scientists do this (Pickering, 1995, pp. 6–7).

In addition, it is here a matter of interplay and interdependence between the two idioms, and Pickering stressed that focusing on material performativity does not imply forgetting the representational, and conceptual, aspects of science. The move to the performative implies a certain strategy for considering scientific knowledge, where the performative idiom can include the concerns of the representational idiom, and can, according to Pickering, be viewed as a rebalancing of our understanding of science away from a pure obsession with knowledge, and towards recognition of the material powers of science. Here, the machine is conceived as a balancing point between the human and the non-human, and between the worlds of science, technology and society. Pickering viewed science as performative, where performances, the doings, of human and material agency, are reciprocally intertwined. The contours of human and material agencies emerge in the temporality of practice, where they both define and sustain each other (Pickering, 1995, p. 21). This could also be viewed as entailing more temporal and situation-dependent intertwining of different practices and ways of thinking.

Mapping architectural thinking and making

Following the approaches of Science and Technology Studies and Actor-Network-Theory, Albena Yaneva developed what she called an “ethnography of design”, with a certain pragmatic approach that is not concerned with symbolic or critical interpretations of architecture and its practices, but based on pragmatic, radical empiricism. Yaneva set out to understand the “architectural specificity” of concrete architectural objects, networks, moves and habits in architectural offices. Here, design invention comes from sets of everyday trajectories of models and persons moving through the office space, allowing themselves to be transformed and leave traces of various kinds. The nature of design invention was not viewed as an abstract concept of creation. Rather, Yaneva saw it as something that resolves into concrete actions and practices: “in collective rituals, techniques, habits and skills ingrained by training and daily repetition, in reuse of materials and recycling of historical knowledge and foam chunks. ... That is, a view of design as constituted from the inside; it stems from the experience of making” (Yaneva, 2009a, pp. 14–15).

Yaneva followed architects in their “architectural laboratories”, similar to the way in which STS has followed scientists in theirs, to understand architectural thinking and its results from practices, such as experiments with materials and shapes, presentations for clients and users, reactions to mock-ups, public protests to design proposals. This is about studying different “associations”, and Yaneva identified, and pointed to, the immense capacities of design objects to connect heterogeneous actors. Associations are traced architecturally, and new associations are shaped by drawing and circulating plans, cutting and scaling models, presentations and discussions with the public. In this context, a building is not defined by what it is or means, only by what it does on different levels in an existing context. “This particular capacity of a building to *associate* both human and non-human actors, and in different periods of time, makes it an important social actor” (Yaneva, 2009b, p. 198). Yaneva’s view can be seen as performative, focused on agency, but it is not about forgetting the past. She stated that design relies on a cognitive and experimental move of going back, to carefully rethink and recollect, to re-invent, re-interpret, and re-do things in new combinations of conservation and innovation.

Architectural thinking and making are about associating various elements, connecting different components (both non-human and human, material and immaterial) by activities of modelling, testing and transforming artefacts, often in a specific material thinking; thinking through the material and the artefacts, including their making.

Different ways of thinking are constantly in use in various practices and our daily lives, and Deleuze and Guattari have described how these different modes of thought use a variety of components that are put together differently. According to these authors, the three main modes of thought are science, art and philosophy. Science is a mode of thinking that works with functions that are put together on planes of references, establishing relationships like cause and effect. Art uses percepts, combined sensations of perceptions and affections, put together in planes of composition. Philosophy works with, and creates, concepts in consistent planes or systems; what they refer to as planes of immanence. The objective of these distinctions is not to establish clearly separated disciplines, but, in my view, the opposite: to show that different modes of thinking are simultaneously at work in all disciplines.

The most important difference between science and philosophy that Deleuze and Guattari pointed to is the varying attitudes towards chaos. Here, chaos is not just disorder, but the infinite speed with which every form takes shape and vanishes, “chaos is an infinite speed of birth and disappearance” (Deleuze & Guattari, 1994, p. 118). According to these authors,

philosophy attempts to maintain the infinite speed, but to simultaneously have consistency in thought, and I suggest that this is also true of art. In contrast, science surrenders the infinite speed and movement; it is a freezing, a fantastic slowing down. Perhaps the establishment of the making disciplines could be viewed as a slowing down, but one that also attempts to maintain some transformational speed and movement, as well as a strong relationship with the core of the material practice; a discipline at the intersections between royal and nomad science.

Strategies are required to make an often chaotic world manageable, understandable and meaningful, when dealing with its many facets. With this in mind, the established modes and approaches of science, art, philosophy etc., have been developed, and they all, in different ways, aim to help us cope with the world. Science, art, design and other approaches have different tools and ways of preferred expression and forms of elaboration and communication of thoughts, such as texts, drawings, models and images.

Martin Kemp has studied the creative and fruitful interplays between art and science, and he has discussed the central role of visualisations and different modes of representation in science. The history of science is full of thinking by means of visual insights, construction of visual models and visual communication, where the creative interaction between verbal and non-verbal modes of communication has also been crucial. According to Kemp, there is no clear distinction between the creative arts and creativity in science, engineering and technology. This can also be related to the continuum from creative practice to scientific research that has been introduced in discussions of practice-based research in recent decades (Dunin-Woyseth & Nilsson, 2008; Frayling et al., 1997). Throughout history, there are numerous examples of when artistic and designerly thinking has supported scientific developments. Leonardo da Vinci's explorations and investigations were often based on drawings and models as tools; Johannes Kepler built models to understand and investigate planets and the solar system; Descartes used sketching as part of his reflections on how to envisage and represent the ways in which nature works through both "seeable" and unseen mechanisms; Galileo Galilei used ink drawings of the moon to study it long before telescopic photography was used for similar investigations (Kemp, 2000, pp. 20–21, 36–41). The development of photography made possible studies of phenomena relating to motion and speed, and allowed science to see things that were before unseen. Visual techniques have also been used to envisage phenomena and relationships that are not only passive observations. In quantum mechanics, Richard Feynman's explorations used abstract models and diagrams as crucial means for thinking and communication, and, in biology, the artist Irving Geis collaborated with scientists to create models of graspable molecules (See Kemp, 2000, 2006; Nilsson, 2009).

Concluding remarks

In architectural practice, experiments and explorations with models and artefacts are central, connecting physical construction and scientific understanding with aesthetics and material spatiality, as well as with historical contexts and material cultures. The contemporary world of flows has brought challenging societal developments and complex transformations of built environments, but the digital age has also provided tools that enable new forms of design experiments, including other non-verbal languages and various model worlds. In this context, we must constantly reflect upon and study the contemporary situation and development, which have introduced new means of designing and production, as well as new societies and communities, where other forms of working and collaborating are required. New relationships between theory and practice, between research and practical designing, between academia, architectural practice and different actors in society, must be articulated and established through conscious strategies. Here, we should consider "reflective practices", rather than the

“reflective practitioner”, accounting for the emergence of architectural practices consisting of complex sets of “collaborative constellations”, which produce and share knowledge and methods through cooperation between many disciplines, as ways to handle the complex issues of the contemporary world. Issues of communication and inter-subjectivity are of great importance in these contexts and crucial for further development.

There is also a need to reflect on and discuss how collaborations and work within, and between, academia and practice are set up, and how these “making” and “material” aspects of architectural thinking can be utilised and further elaborated in architectural research and in production of knowledge about our societies, as well as in the production of the material world and its multitude of cultures. When dealing with the challenges faced by contemporary and future sustainable societies, knowledge and solutions materialised in the built environment could be used in more conscious and critical ways. The specific capacity of design thinking to manage complexities may provide important contributions to exploring and gaining knowledge for contemporary situations. The constant interplays and “tensions” between the formal and the informal, between different modes of knowledge production, between the existing material cultures and the making processes of architecture and design are crucial for further development of the making disciplines. It is about the knowledge produced, communicated and used in the making of things and the world, and this design knowledge is also knowledge constantly in the making.

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