Design and Engineering Understood as Processes of Learning

Bo Terje Kalsaas[1] and Anita Moum[2]

[1]The University of Agder and NTNU, Norway
[2]SINTEF Building and Infrastructure, Norway
Email: bo.t.kalsaas@uia.no

Abstract

The purpose of this paper is to develop an analytical model for further verification of design and engineering as processes of learning. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies. We assume that the linear waterfall style of project management for design and engineering is not adequate for coping with the nature of design and engineering. Following the verifications, the next step in this research is to develop a model for improved design management.

The paper addresses the nature of design and engineering and learning theory, and contributes to an improved understanding of the phenomena in question.

Keywords: design, learning, analytical model

1. Introduction

Project planning and engineering are activities that aim to create a foundation for some kind of artefact, e.g. a building with functionality defined by the customer, a bridge or a ship. Kalay (2004) refers to design as a cyclical relationship between two paradigms; design as problem solving, where the designer attempts to produce solutions to ill-defined problems, and design as puzzle making, where design is seen as a process of discovery, where given parts are synthesized into a new and unique whole. The design process, particularly in its early stages, can be characterized by a progressively clearer understanding of the scope, reciprocal interdependencies (Thompson 1967, Kalsaas and Sacks 2011) between different disciplines and subjects, and iterative processes and loops. Iterations can be positive or negative (Ballard 2000).

Several authors characterize Last Planner System (LPS) as a system of learning (e.g. Ballard, 2000; Rooke, 2005; Koskela et al., 2010), which is tied in particular to the high level of focus on involvement, and the mechanisms that are related to the evaluation of completed work plans, and root-cause analysis (continuous improvement). However, it seems like there has been a lack

of contributions to uncover, in depth, why this is the case. Some exceptions are Kalsaas (2012) and Skinnarland and Yndesdal (2012). Kalsaas analyses LPS through a learning perspective, which is based, in particular, on Kolb`s (1984) experiential learning theory and Illeris` (2009) model of workplace learning. Skinnarland and Yndesdal (2012) focus on LPS as a system of knowledge development. The authors ties their theories to collective learning processes, inter alia, Nonaka and Takeuchi`s (1995) well known SECI model.

In the context of this paper, the authors are trying to understand the design process as a learning activity. The relevance is tied to the ability to gain a greater theoretical notion of design as a learning phenomenon, which will create an understanding that can be used to improve design management. For instance by providing a framework that utilizes the learning process in the most effective manner. The paper is structured as follows: at first we investigate the architectural design process, then we look at a selection of learning concepts. Finally, we discuss an analytical model for future research.

2. The architectural design process

Throughout the evolution of design practice, there have been countless attempts to tackle the challenge of understanding, mastering and explaining the processes behind our built environment. The first generation of design methodologists' focus on the design process as something sequential and linear in the 1960s, has long been challenged (Lundequist, 1992). The understanding of the architectural design process as a complex universe of predictable and unpredictable interactions, interrelations and interdependencies between actors and their actions, relates to observations of the practice of architectural design made by researchers such as Cuff (1991), Kalay (2004), Lawson (2006) and Schön (1991).

According to Cuff (1991), the design process is a social construction, where buildings are collectively conceived. Kalay (2004) refers, as previously described, to design as a cyclical relationship between problem solving and puzzle making. Lawson (2006) describes the design process as "a negotiation between the problem and solution through the three activities of analysis, synthesis and evaluation," and challenges the comprehension of the design process as a sequence of activities. He sees the design process to be a simultaneous learning about the nature of the problem and the range of the possible solutions. In the beginning of the design process, the architect, the engineer or the client do not know exactly how the building will look like, what are the problems to come or even what are the requirements to be fulfilled. Schön (1991) characterizes design practice as a reflective dialogue between the designer and the design situation and he emphasizes the crucial role of tacit knowledge. This kind of "feeling of" can be expressed, for instance, by experience-based, intuitive and unconscious habits and actions. This knowledge embodied by the practitioners involved in architectural design is crucial, but hard to grasp and unlock.

The features of the architectural design process described above are closely related to cognitive processes and design thinking. Some features are, however, also given by regulating external factors. Examples of these are (highly simplified):

- The delivery of design information and project material to the stakeholders (client, the building authorities and contractors) are regulated in phases. Each phase presents a higher level of detail and information depth, and each has to be approved by the stakeholders before moving on to the next phase.
- The time and performance related definitions of these phases are mostly specified in the project contracts. These might again be regulated by guidelines or regulatory demands on national level.
- The architectural design process is situated between the statement of the brief (more or less defined) and the start of the building production on the construction site. In practice, limited time resources, tough project budgets and the contractual models might often call for an overlap of the phases (e.g. starting up the work on the construction site before the design phase is completed).

Bearing the two above-mentioned groups of features in mind, the practitioners involved in the architectural design process must deal with an interplay between highly iterative, unpredictable and non-linear activities on the one hand, and regulated and linear activities on the other. Moum (2009) uses the metaphors of "baking bread" and "playing jazz" to highlight and simplify the different character of these features of the architectural design process. Baking bread could be seen as a linear, predictable, explicit and measurable process - based on for instance repetition and routine. This can be related to the activities described above, which are central in order to drive the processes forward due to the agreed time and cost. Playing jazz is on the contrary a rather improvised, intuitive and tacit process leading to a unique performance, based on "the feeling of", on talent, practice and experiences. This process might be compared with the hard-to-grasp elements of the architectural design practice described in the beginning of this section. This "something" going on in the head of the designers, is also a magical "something" resulting in the unique and great architectural solutions and buildings. The "baking bread" and "playing jazz" metaphors are representing co-existent processes in the architectural design practice. The interplay and balance between these are crucial for what actually gets built.

3. Concepts of learning

3.1 Experience-based learning theory

Kolb (1984) emphasises that learning is a process rather than a result. He furthermore claims that knowledge is a transformation process continuously created and re-created, it is not an independent entity that can be acquired or transmitted. Knowledge creation occurs at all levels, from the most advanced forms of scientific research to the child's discovery that being stung by a wasp is a painful experience that is best avoided in the future. "Knowledge" is the outcome of a transaction between social knowledge and personal knowledge. Social knowledge (Dewey, 1938) is the civilised objective accumulation of previous human cultural experiences, whereas personal knowledge is the accumulation of the individual person's subjective life experiences. Knowledge results, then, from the transaction between these objective and subjective experiences in a process called learning. Hence, according to Kolb, to understand knowledge, we must understand the psychology of the learning process; and to understand learning, we

must understand the epistemology – the origins, nature, methods, and limits – of knowledge. Kolb draws heavily on Piaget (1970a) when he emphasises the need for epistemological understanding.

Furthermore, Kolb builds above all on Lewin (1951), Dewey (1910, 1934, 1938, 1958) and Piaget (151, 1968, 1970a, 1970b, 1971, 1978) when developing this well-known model for experiential learning. In this model, the process and structure of learning are depicted as a four-stage cycle involving four adaptive learning modes. These evolve from 1) concrete experience; 2) reflective observation; 3) abstract conceptualisation; and 4) active experimentation. This learning cycle can be understood as a continuous spiral where the different cycles of adaptive learning are repeated in order to allow for further learning. An onion can be used as a metaphor for this process, each layer representing a level of knowledge. Combining the four learning modes, Kolb divides them into two dimensions, where they represent pairs of dialectically opposed adaptive orientations, namely; 1) concrete experience versus abstract conceptualisation; and 2) active experimentation versus reflective observation. The abstract - concrete dialectic is one of "prehension". Prehension is a concept invented by Kolb to describe the representation of two different and opposed processes of grasping or taking hold of experience in the world. This either by relying on conceptual interpretation and symbolic representation, a process described by Kolb as "comprehension" – or by relying on the tangible, felt qualities of immediate experience, which he describes as "apprehension". The active-reflective dialectic is seen as one of transmission, representing two opposed ways of transforming what has been grasped through the prehension of experience. Either through internal reflection, a process Kolb describes as "intention" – or through active external manipulation of the external world, described as "extension". There is thus a clear "division of labour" between these two dimensions of learning; namely that of capturing or grasping experience, and of ensuring that what is grasped, is transported to the level where it is translated into internal understanding and/or external action.

3.2 Workplace learning

Whereas Kolb's model is primarily a model for individual learning processes, Illeris' (2009) model, expanding on the works of Jørgensen and Warring (2002) and Botterup (2000), helps integrate an understanding of individual learning into an understanding of learning in working life. For workplace learning, Jørgensen and Warring (2002) have developed a model based on the concepts of learning environment and learning progress, where learning is seen as taking place in the intersection between the learning environment of the workplace and the learning progress of the employees. A distinction is made between the technical-organisational learning environment and the social learning environment. The technical-organisational aspect is constituted by the material conditions tied to technology and to the way the work is organised, which may, for example, facilitate or limit work variation, and thus impact on the possibilities for learning. The work community and social interaction constitute the social learning environment. Learning progress is linked to each employee's background and stage of life, as well as to his or her capacity to be open to and benefit from learning. Learning takes place in a dynamic interaction between the learning environment and the individual's learning progress.

Illeris (2009) divides the technical-organisational learning environment into six categories: 1) division of tasks/work; 2) work content; 3) scope for decision-making; 4) scope for using one's qualifications; 5) scope for social interaction; and, 6) work strain. A rigid division of work can undermine the individual's perception of the work as meaningful (Taylorism). Work content is linked to the work's social significance and to its significance for the individual (learning progress). The scope for deciding over one's own work is connected to the style of leadership (dialogue versus orders from above) and to the organisational structure (flat structure and decentralised decisions versus hierarchical, bureaucratic structure). Illeris points out that the opposing ideas and interests, which emerge in the encounter between different trades or professions, can create fertile learning environments. They can, however, also help consolidate mutual myths and images that place the other party in the role of being an opponent. Technological conditions are very important for the scope for social interaction and for the social learning environment. Work performance pressures (speed and intensity) can hamper learning because they interfere with the time or physiological/mental energy needed in order for learning, development, experimentation and trying out of new ideas to take place.

Based on Botterup (2000), this part of the model can be expanded to include "work practice". Work practice is connected to society in the interface between the technical-organisational environment and the social learning environment – which is now expanded and described as "the social and cultural learning environment". The practice concept contains what actually takes place "in practice", but it also includes practice as a constituting expression of human consciousness and learning.

In the general learning model, which is individually oriented, Illeris (2009) distinguishes between three dimensions: the cognitive dimension; the psychodynamic dimension; and the surroundings/society. The acquisition process of learning takes place between the cognitive and the psychodynamic dimensions, which in their turn interact with society; whereas work identity is found in the tension between the cognitive and emotional dimensions. The cognitive dimension includes aspects of content and reason. It is linked to what Habermas (1984, 1987) describes as "the system". The psychodynamic dimension covers motivational and emotional aspects, and is linked to Habermas's "lifeworld". It is society that provides the conditions for learning. The lifeworld is tied to communicative rationality, and the system to instrumental rationality, and the two are strongly intertwined. Lundvall (1992) relates "instrumental" rationality to the expected outcome of interaction (cause-effect); and "communicative" rationality to intuition, worldviews and other factors related to communication. Habermas's theoretical contribution is often used in the innovation literature; see e.g. Moodysson (2007) and Kalsaas (2011).

Illeris distinguishes between different forms of learning in the cognitive dimension. He describes "assimilative" learning as a general form of learning: it is used in everyday life in the encounter with new impressions and impulses. This is also the most common form of learning in schools, as the students' knowledge is gradually built up over time. "Accommodative" learning is a more demanding form of learning, as it transcends boundaries. In this kind of learning, we cannot immediately understand or relate to what is happening. It requires that

existing understandings are overcome or broken down, which in turn requires creative efforts to restructure what is already known, through reflection. This is denoted "relearning" in Kolb's work. So-called "aha experiences" and a perception that "the pieces have fallen into place" occur in relation to this form of learning. Accommodative learning is crucial in any attempt at introducing improved work practises. "Transformative" learning is the most demanding form of learning examined by Illeris. We may encounter this type of learning if we lose our job and have to retrain in order to get a new one, which often means that we have to develop a new worldview or a new basic outlook. This can be perceived as a life crisis on the personal level.

The psychodynamic dimension of learning, with its emotional, intentional and motivational patterns, is influenced by the cognitive dimension in the shape of our knowledge and skills. For example, so-called "bad chemistry" between individuals can drastically hamper our ability to learn. However, if we gain better insight into the work of those we do not initially feel sympathetic towards, such emotions may change. The reasons for defensiveness and resistance to learning are found in the emotional dimension. Illeris sees the factor of "defending identity" – which is one of several mental defence mechanisms – as crucial in this context. In our working lives we often establish an identity tied to something we master well, and which others also consider us as proficient at. For example, someone may be good at using an advanced control system, PLC controlling, programming, and so on. Strong work identities can easily lead to active resistance to any change, which might threaten these identities – such as change that involves an accommodative learning process. According to Illeris, the general tendency for adults is that the more demanding and complicated the learning requirements, the greater the psychodynamic barriers in the shape of defensiveness or resistance. Levin and Klev (2001) point out that learning is often prevented because we wish to avoid situations in which individuals might lose face. This is also a central concern in Argyris's (1990) works. This phenomenon can be linked to the psychodynamic dimension.

The best conditions for workplace learning are found in the area where work practice and work identity overlap. It is possible to imagine that if there is no such overlap, individuals might try to modify their work practices in such a way that they become aligned with their work identity, or they might resign and look for work with a different employer.

3.3 Learning loops and learning cycles

Ashby (1960) and Argyris and Schön (1996) distinguish between single-loop and double-loop learning. Single-loop learning can be conceptualised as "Doing Better", and double-loop learning as "Doing Differently". It is part of the nature of this difference between double and single loop learning that beginning to do things in a different way is more demanding than pursuing the already established strategy, but with a few adjustments, in terms of the learning involved (in other words, assimilative versus accommodative learning). Expanding on Ashby (1960), Argyris and Schön (1996) argue that for a company, "doing differently" might require external resources to be brought in to help with the improvement work. Thus, greater competence on grasping via comprehension can be built through action research approaches

where academics and researchers cooperate with the company. This relates to the traits considered by March (1999; see below) as limiting the value of experiential learning.

Rooke (2005) relates Kolb's (1984) experiential learning cycle to Deming's Quality Cycle (Deming, 1986), also widely known as "Plan-Do-Check-Act". "Plan" relates to abstract conceptualisation; "Do" to active experimentation; "Check" to concrete experience; and "Act" to reflective observations. Deming's quality circle, which draws on his joint work with Shewhart from 1939, is, in all its simplicity, widely applied in lean implementations and popular among consultants in the field. However, unlike Kolb's work (1984), the quality circle does not offer any conceptualisation of learning as such. Rather, it is assumed that learning is likely to take place along the course of the Plan-Do-Check-Act cycle.

3.4 The limitations of experiential learning

According to March (1999), learning from experience does not produce perfect results by itself. It has its limitations. Firstly, experiential learning tends to exaggerate the importance of actual events relative to the events that might have occurred, and "thus to be quite sensitive to the rate of experience relative to the change in the world" (p. 332). Secondly, experiential learning tends to close the door on experimentation, according to March. It is fairly easy for a fast learner to fall into a pattern of repeating rewarding behaviour, and to stop reaching for the best possible performance. This can mainly be attributed to the ways in which strategies, competence and aspirations adapt simultaneously. Thirdly, experiential learning is not a good way to learn theories of behaviour. The starting point for March's line of argument is that if behaviour conforming to one theory produces rewards, the other theories will tend to be neglected.Because of these problems, simple experiential learning in organisations is a flawed process. However, research and consultation can supplement this learning; not by attempting to substitute it but by helping to mitigate the limitations of ordinary and experiential knowledge.

Fujimoto (1999) avoids the problem of the limitations associated with experiential learning by distinguishing between "routinised manufacturing capability" and "routinised learning capability" on the one hand, and "evolutionary learning capability" on the other in his study of learning in the Toyota Company. Evolutionary learning capability, he argues, is a "nonroutine ability that affects creation of the above routine capabilities themselves through irregular processes of multi-path system emergence" (p. 17).

4. Towards an analytical model – design and learning

A qualitative model can be created by establishing causes and effects between internal variables, expectations, and contexts (Barth 1966). This model might appear to be similar to a quantitative model, but the variables are assigned with qualitative values, not numbers. The model is subject to empirical testing, and with the same values on the variables, the same result can be expected. Thus, different values on the same variables can provide other results. This concerns an analytical generalization where the transfer value might be larger than the case itself.

Creativity, problem solving, decision-making, and attitude change, are according to Kolb (1984) other words for experiential learning. Previously in this paper, problem solving was presented as one of two paradigms in design. The other mentioned paradigm is puzzle making, which can be connected to creativity. This part of design work, was related with «playing jazz» earlier in this paper. Decision-making is an obvious part of design, where decisions on some parts must be made in order to advance processes, even if it might be necessary to make changes later. In addition, attitude change can be connected to accommodative learning (Illeris 2009) and re-learning (Kolb 1984). During the design process it is imaginable that attitude changes are connected to the way designers and engineers work together, e.g. when transitioning the collaboration to Big Room organizing. Innovation can also be connected to design, especially when the design in question has something unique about it, e.g. signature buildings. In the innovation literature, learning is considered as a fundamental process for innovation, and knowledge as the most strategic resource.

Another possibility is to relate design to the value shop model for value configuration (Stabell & Fjeldstad 1998). This model, which is an alternative to Porter's value chain concept for intensive technology (Thompson 1967), is represented as a circle of five generic activities: problem finding and acquisition, problem solving, choice, execution and control/evaluation. When the participants have reached the control/evaluation phase, the circle can be repeated if it is desirable. The relevance for design in the value shop model becomes obvious when we think in terms of puzzle making and problem solving, where problem finding and solving, and choice can be related to reflection and abstract conceptualization in Kolb's learning theory. Furthermore, execution is the equivalent to active experimentation, and control/evaluation can be considered as concrete experience.

Experiences indicate that the design of complex construction projects gradually matures. The designers learn gradually during projects, thus getting a better understanding of the scope, and the issues are solved gradually towards a "good enough" design. In the context of design theory earlier in this paper, it is mentioned that design tasks includes «the joy of discovery, and the frustration of fruitless explorations». In other words, there is much trial and error in the early stages of design, and trial and error is, in this context, an apparent part of the learning process with active experimentation, concrete experience, and reflective observation/evaluation. Concrete experience is, however, virtual as the drawings represents a model of the real world. Furthermore, abstract conceptualization will be included in some cases, e.g. during structural analysis.

4.1 A minor case study illustrating project planning and learning

In order to advance the understanding of the design process and the respective learning processes, we provide an example from a rehabilitation project of a villa (Table 1). The villa was originally constructed in 1953 during Norway's post-war period. The building was in a poor condition, compared to modern requirements for indoor climate, insulation, bathroom, etc.

Table 1. The design process and the respective learning processes in a villa project.

Building authorities	The client	The architect
	The client has a vision of upgrading the building to modern standards. He wants to elevate the ceiling to make room for a loft with an ocean view. In addition, he wants to upgrade the building in accordance to the latest energy standards.	*The architect pays a visit, and discusses the vision with the client. The architect inspects the building in question, and then he sits down and starts sketching the new improved version in his notebook. Based on the knowledge he has acquired through experience, he is able to quickly understand how to implement the upgrades efficiently, e.g. create a new entrance, which gives access to both floors including stairways and storerooms.*
	The client discusses the upgrades with the architect in several iterations. One of the first changes in regards to the architect`s suggestion is the idea of building a conservatory. The client provides the architect with an idea from a magazine. He encourages the architect to come up with additions and enhancements to the conservatory. The alternative that the architect provides is chosen after discussions of functionality and esthetics.	
Preliminary meeting with the local building authorities.	*The idea of partitioning the lot is put on hold after the meeting, as it requires rezoning.*	
Approval that the submitted drawings can be treated as an exemption from the zoning plan's height requirements.	*Application for building permit. None of the neighbors complain.*	
Requirements that the drawings set absolute requirements for legal height, and that the apartment downstairs will require a new application.	*The client makes an effort to adapt the drawings to the requirements from the local authorities. The apartment downstairs is removed from the drawings in order to prevent a delayed startup.*	*The architect adjusts the drawings in accordance to the requirements of the local authorities.*
The local building authorities approve the drawings.		

After the first visit from the architect, the drawings were revised several times throughout the following months. However, the major concept and facade of the building was mainly decided during the two hour long visit by the architect. When the client had started the design process, changes was generated through internal discussions in the client's family, discussions together with friends, and by studies of other construction projects, etc. Clearly, when the client is participating in a construction process, the buildings in the environment are observed in a new way. Ideas and inspiration are absorbed when observing and analysing other solutions. The final project change gradually, and in the context of this simple example the learning is especially happening for the client.

5. Conclusions

The paper verifies that learning is a central phenomenon in project planning, however, this version is unable to provide a complete analytical model of the phenomenon.

Future research will focus on developing an analytical model of learning in engineering. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies.

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