A SYSTEM DYNAMIC APPROACH FOR SIMULATION OF EXPERIENCE TRANSFER IN THE AEC INDUSTRY

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ABSTRACT

This paper describes possibilities of using a system dynamic model to simulate experience transfer scenarios in a construction and property management organization. This experience transfer simulation model can be used to evaluate potential benefits and establish the processes that improve transferring of knowledge and learning in an Architecture, Engineering and Construction (AEC) organization. The methodology is based on causal loops and trends of the AEC industry in order to illustrate the relationships between selected features of the complexity of experience transfer. The aim is to apply methodologies of system thinking and system dynamics to depict the issues and needs involved in an experience transfer process faced by a fragmented and multifaceted AEC industry, and then decompose the complex process into manageable pieces.

Based on prior surveys, the known experiences and costs at the project stage and at the operative and management stage, features are defined and assumptions made. Then relationships are identified to represent experience transferring needs in dynamic conditions. In addition, causal loop diagrams are employed to depict the processes of experience transfer,

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and theoretical simulations of different scenarios are carried out. The paper also includes a brief description of the applied theories learning system.

The results of the simulations of different scenarios show that this methodology is applicable in order to decompose a complex learning system. The operationalization of intangible parameters such as priority and awareness are difficult however, due to a high degree of individual understanding of the concepts.

Keywords: experience transfer, system thinking, system dynamic, AEC industry

CE Database Subject Headings: Knowledge-based systems, Systems management, Resource management, Methodology.

INTRODUCTION

This paper discusses experience transfer and experiential learning in the AEC industry. Information feedback from the operation and maintenance stage to the early design stage, has significant benefits and increases the life cycle profit in the AEC industry. Knowing that the room for making changes decrease and the cost of changing increase as the project progress, Lê (2006) have especially stressed the unused possibilities in the early stages, i.e. the potential for improving of performance and value added in future projects, is unused. These unused possibilities originate from the conservatism culture in the AEC industry. Knowing (know-how) and understanding (know-why) of what works and what does not work, can improve the decision-making process in the early planning stage, the project performance and the quality of the constructed facility. The economic consequences of cross-project learning breakdowns have been well documented in the AEC industry worldwide (Cain 2003, Egan 2002, Gallaher et al 2004).

Despite significant investments in computer-based management information systems, effective transfer of previously acquired information and experience has not been realized, particularly in improving learning. There are many other factors besides information technologies that significantly influence individual and organizational learning. Effective use of knowledge from prior projects within an AEC organization can potentially lead to greater competitive advantage by improving designs, and a more effective management of constructed facilities (Fruchter and Demian 2002). Even though AEC companies have implemented managerial tools and deployed management techniques that have proven effective in other industries, the overall quality of the products and efficiency of the industry remain far behind that of manufacturing and other industries (Björnsson et al 2003). Ercoskun and Kanoglu (2003) believe that one explanation is the lack of an enterprise-wide customer orientation infrastructure, which could provide feedbacks to the project development process.

The purpose of this paper is to identify the issues involved in achieving transfer learning across a multi-project environment, and to develop an experience transfer simulation model, which can be used to investigate potential benefits and to create initiatives to improve the experience transfer and learning process. The focus is on linking experiences gained at the operation and maintenance stage of one project to the earlier construction stages in subsequent projects. Computer simulation is a powerful tool for investigating the behavior of complex systems, such as organizations. In particular, computer simulation provides the ability to conduct controlled experiments in an environment that captures the most important aspects of the problem under investigation. The effects due to the combination of the various factors that influence, or are thought to influence, organizational learning will be difficult to understand without a formal simulation model. The number of factors, their interactions over time and the consequences of those interactions, both immediate and delayed due to the cultural and structural dimensions of an organization, all conspire to make the organizational learning problem incomprehensible. In this study, the system dynamics modeling approach is employed. System dynamics is a very flexible modeling paradigm that emphasizes process and information flows, two central aspects of the learning process. The objectives of this work are:

- To develop a causal loop diagram that can depict the experience transfer processes between the designer and the operative and maintenance personnel in a collaborative learning environment;
- To suggest a simulation model based on the causal loop diagram;
- To identify relationships for the simulation model based on experience; and

- To conduct simple simulations.

LEARNING

Although the simulation model focuses on the transferring and collaborating learning between individuals, this section briefly describes the learning system.

The learning system

There are many understandings of a learning system. In this paper, the learning system consists of three main components, which are external or inter-organizational learning, organizational learning and individual learning (Sveiby et al 2002). The learning subsystem involves three dimensions (Marquardt 1996). Firstly, levels of learning, i.e. individual, group and organizational, secondly, types of learning, i.e. experiential learning, adaptive learning, anticipatory learning, deuteron learning and active learning, and thirdly, critical organizational learning skills, i.e. systems thinking, mental models, personal mastery, team learning, shared vision, and dialogue. Figure 1 below illustrates the three main components in a learning system and the transferring ability between these components. These are also influenced by time, culture and awareness parameters in a positive way. The learning barriers decrease the learning and transferring ability in a learning system.

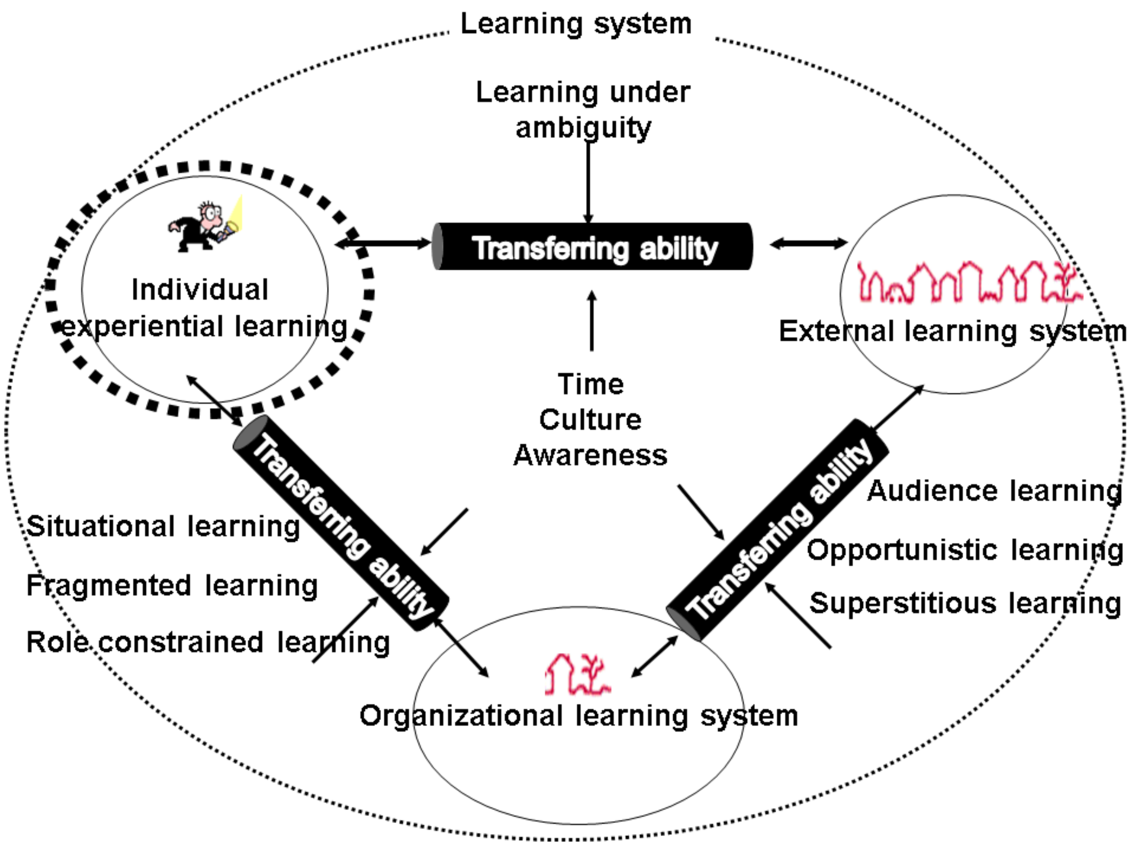


Figure 1 Participants in a learning system

There are many factors inhibiting or promoting experience transfer between individuals, within an organization. As illustrated in Figure 1, factors, such as time, culture and awareness, are recognized to have impact on the experience transfer and learning ability. Knowing these factors increases the transferring ability in a learning system. On the other hand, factors such as situational learning, role constrained learning or fragmented learning could decrease the transferring ability. These factors are recognized to have significant impact on the AEC industry. The barriers for transferring abilities between external learning system and organizational learning are audience learning, opportunistic learning and superstitious learning. This paper will not discuss these barriers further.

Incomplete learning cycles	Application to the AEC industry
Role constrained	– the constrain of the individual's role break the link between individual action and

learning	learning Occur when individual learning has no effect on individual action because the circle is broken by the constrains of the individual's role, i.e. few demanding customers and the fact that the client or project owner buys bits and pieces in a process, not an end product as such. In addition, many of the participants in the process have limited knowledge about one another's work, and at the same time the individual participants in the project team and their roles vary from project to project.
Situational learning	– individual mental model does not change, due to forgetting of codification for later use Occurs when the individual forgets or does not codify the learning for later use. The link between individual learning and individual mental models is severed, e.g. crisis management. People start new projects without submitting post-work reports of the previous project, because of shortage of time. As well, "Ad-hoc" organizations with constantly new co-working constellations result in individually based and not organizationally based experience transfer
Fragmented learning	– link between shared mental model and individual mental model is broken There are many situations where individuals learn, but the organization as a whole does not. This happens when the link between the individual mental model and shared mental models is broken, e.g. turnover, decentralized organizations. The industry is *fragmented* with a great number of participants in every construction case. It is difficult to discern differences between the operational work tasks and the designer's work tasks. Often the collaboration is limited because of the many participants and geographic borders etc.

Table 1: Some of the learning breakdowns in the learning model adapted from Lê and Brønn (2007).

Individual learning

"*Learning is making useful changes in our minds*" (Minsky 1986 p.10), or "*Learning is construction or modifying representations of what is being experienced*" (Michalski et al 1986). Learning is a process that creates knowledge (Kolb 1984), in other words, "*increasing one's capacity to take effective action*" (Kim 1993 p. 38). The individual learning model by Kim (1993) consists of four stages – *observation, assessment, design and implementation* (OADI) and provides a link between individuals and organization. The learner first observes experiences and is evaluated in an assessment phase. From the assessment, the experiences are processed and applied to resolving an issue in the design stage. Then action is taken through implementation. As this is a dynamic process, the results of the implementation become experiences at a later time. This pattern can also be applied to learning at the organizational level.

As pointed out by Pfahl et al (2001) the individual competence dimension, i.e. subject-matter, problem solving and social competence, depends on the competence level of the individual and on the role the individual has in the organization (for example, whether the person is an expert practitioner or novice). Therefore, the experience transfer and learning activities must be adjusted to the roles and functions of the individuals (Sveiby et al 2002).

The organizational competence comprises of the competence of all employees in an organization. It is important to distinguish organizational competence and the relationships and roles of the participating employees in order to successfully implement collaborative and knowledge transfer activities. Individuals participating in the learning environment must acquire new knowledge and apply this knowledge. Individuals must transfer learning and experiences to action and share the knowledge and experience with other individuals. Transferring of experiences between individuals depends on many informal and formal cultural and organizational issues, i.e. collaboration plays an important role. The three main learning barriers faced by an individual in an organization are: role constrained learning, situational learning and fragmented learning. Time, culture and awareness play an important part in improving experience transfer and the transferring ability between individuals, i.e. the designer and operative and maintenance personnel.

RESEARCH METHODOLOGY

To develop a simulation model for organizational learning, this work follows closely the methodology based on a system dynamics approach. System dynamics can be defined as "*The investigation of the information-feedback characteristics of (managed) systems and the use of models for the design of improved organizational form and guiding policy*" (Forrester 1961).

The idea is to learn and understand how various factors or variables may influence a system. The objects and people in the system interact through feedback loops. Any changes of a factor or a variable in the system will affect other variables and the original factors. However, it is often very difficult to visualize the non-linear effects and feedback interactions in a complex system. System dynamics is a methodology to analyze such complex, large-scale, non-linear, partially qualitative dynamic socio-economic systems (Sterman 2000). There are a few simple but fundamental concepts in the system dynamics approach and the *iThink* ® language, made by ISEE systems (ISEE systems 2008), as show below.

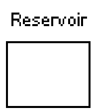
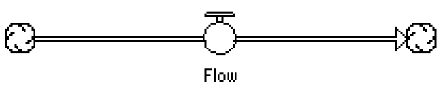
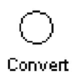
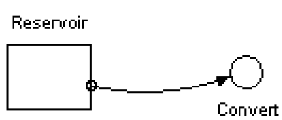
	Symbols, types of stocks and flows	Remarks
Nouns Stocks:		A stock accumulates the quantities or resources that flow into it, thus characterizes the state of the system.
Verbs Flows:		A flow is a change to a stock that occurs over time.
Convert		It holds values for constants, defines external inputs to the model, calculates algebraic relationships, and serves as the repository for graphical functions. In general, it converts inputs into outputs.
Connectors		The connector is to connect model elements. Can be the action connector and are signified by a solid, directed wire.

Table 2 Some fundamental concepts in the system dynamics approach.

The dynamic behavior of a system can be affected by feedback loops. Specifically, **positive feedback loops** that reinforce what is happening in the system, and **negative feedback loops** that provide self-correcting actions and, at times, stabilize the system or subsystem around certain parameter values. Additionally, there are two basic delays to be considered in a dynamic system. Firstly, **material delays,** that is a material outflow and it is related to the inflow of the material, but takes into account the delay time. The stock contains the quantity of the material in transit and the output (including consideration of the delay) becomes the flow. Secondly, **information delays** represent the gradual adjustment of perceptions or beliefs. An information delay typically takes the form of goal seeking, negative feedback, etc. For example, learning delays can be modeled as the gradual process of obtaining a desired level of expertise. Figure 2 shows the basic steps of the system dynamics approach for modeling a complex system (Rodrigues and Martis 2004, Richmond 2001). The first step is to identify and define the problem, in this case experience transfer and organizational learning, and the main features of the problem. Then, the system is conceptualized by modeling the features and the actions using causal loop diagrams. To develop a dynamic model, a set of features are chosen for simulation; flow diagrams and relationships are developed to facilitate the simulation. Last but not least, results are analyzed and policies are developed. This study focuses on the system conceptualization, model formulation and simulation steps for organizational learning and experience transfer.

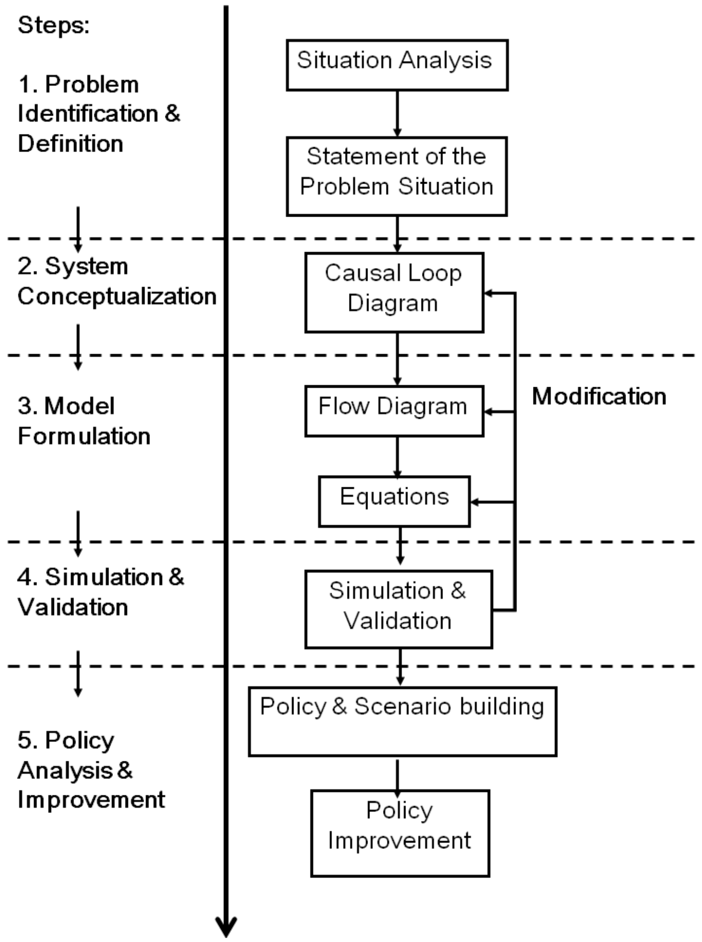


Figure 2 Research methodology

Situation analysis: The case – problem identification

All parameters that are handled in this paper are based on several extensive reviews of the experience transfer and learning processes at Statsbygg, the Public Construction and Property Management company in Norway. For instance, a survey of what conditions that inhibit, as well as promote experience transfer at Statsbygg, have been carried out (Lê 2006). Another survey of 383 buildings, or almost 1 million square meters of property, has revealed many common technical experiences at Statsbygg at the operation and maintenance stage (Lê 2006). This survey uncovers the typical technical experiences in buildings during the operation stage and identifies what worked, what did not work, the subsequent cost, and to whom the cost incurred (Lê 2006). The survey looked at positive as well as negative structural and construction failures, and at deficiencies experiences. This survey discovered that about 8 per cent of the experiences were related to positive experiences. Over 48 per cent of all experiences were negative experiences. These were related to structural and construction failures, which represented over 67 per cent of total known costs found in this survey. 17 per cent of the failures are the types that the users, the operation managers and the owner had to live with these problems daily, because the problems could not be solved. The survey also showed that feedback from the operational stage would be valuable, because over 74 per cent of the negative experiences were due to the fact that the problems were not identified in the earlier stages, but at the operation stage. . The organization, Statsbygg, had to cover two-thirds of these costs. Other studies have reported similar findings in Norway and Europe as well as in the US (Cain 2003, Gallaher et al 2004, Alptekin and Kanoglu 2003).

About 100 building projects, which were carried out between the years 1992-2002 at Statsbygg, were studied to gain a better understanding of project performance due to budget, time and quality issues (Lê 2006). Significant economic benefits can be realized through better cross-project communication, coordination, collaboration and interoperability. To gain better understanding of the experience transfer phenomena, detailed literature reviews have been conducted (Lê and Brønn 2007).

Many organizations have initiated and conducted experience transfer activities and knowledge management. At Statsbygg, the first systematic documented activities dated back to the early 1970’s. The basic question is why the same mistakes are repeated in many of these organizations, even in building projects that have become almost standardized. For example, when Statsbygg built 20 education buildings or 25-30 traffic stations during the 90’s, repetitive mistakes were found. Studies (Lê 2006) have shown that the operative personnel and the design team had not collaborated well. Some of the explanations are due to the differences of professional, cultural and organizational factors, which have inhibited the experience transfer at Statsbygg. Lack of openness, time shortage, individual priority issue and individual competency or awareness, are recognized to be major contributing factors hindering experience transfer. The willingness to listen, respect for others, and openness to alternative interpretations play very important roles in an organization (Fischer and Röben 2002, 2004). The key challenge is to examine the cultural and organizational features in order to understand the barrier or "glass-wall", which is created by communicational, organizational, cultural and social issues, between the designer and the operative and maintenance personnel. Furthermore, to realize how this "glass-wall" may impact on the costs of repair and redoing and operation breakdowns for the owners and users. Earlier surveys (Lê 2006) indicate that many of the failures and deficiencies are due to a lack of consideration for the users' or client/owner's value in the process. Every partaker is primarily interested in protecting their own work and their business value, and there is little interest in improving the performance of the entire project life cycle, resulting in marginal learning and experience transfer. All market actors are in fierce price competition, which is often counterproductive with respect to co-operation.

Causal Loop Diagrams

Causal loop diagrams are a part of systems thinking and are "*a diagram that aids in visualizing how interrelated variables affect one another*" (Wikipedia 2008a). They consist of causal links shown graphically by arrows that connect variables. These features can change over time. The diagrams show how one variable affects another, because each relation between a variable has a polarity, i.e. positive (+) or negative (-) on the arrow (Monga 2001, Sterman 2000). This indicates whether there is an increasing or decreasing relationship between two variables.

Figure 3 shows the *simplified* causal loop diagram for a collaborative experiential learning environment. The development is based on earlier work by Spear (1993) on collaborative learning. These are shown as dotted lines and grey items in the diagram. Spear's core model of collaborative learning consists of four main features. These are degree of collaborative culture, joint experimentation, willingness for public reflection and degree of shared insight. In addition, factors such as interpretation of actions as failures, number of diverse view points, potential for conflict, conflict avoidance, blame or defensive behaviors, fear of failures, and expectations will influence the four main features. Spear (1993) has further details. To incorporate the factors involved in collaborative culture, parameters such as openness, priority, shortage of time and individual competence/awareness are included. The level of details required to further describe each parameter depends on the need of the investigated organization. In this study, the parameters are decomposed at one or two levels, at the most to illustrate how the complexity can be systematically decomposed. For example, priority, a parameter that has impact on the degree of collaborative culture, is influenced by factors such as usefulness, time availability, satisfaction, amount of experience, degree of awareness, curiosity and responsibility/ownership. Casual loops in this paper have been simplified by choosing time availability and degree of awareness as the only two variables to have influence on priority. Even though other features, such as those listed above, are of great importance for other organizations, they were excluded because they did not have the same impact on Statsbygg (Lê 2006), and therefore will not have the same affect on the simulations. There are several ways of combining the features when decomposing this complex environment. Each of these features can further be divided if necessary. In order to support a learning environment, an individual needs to tolerate and respect errors or mistakes to some degree. In addition, the environment must provide support for interpreting of failures that can in turn advocate individual change and personal development. Selected features are discussed in the next section.

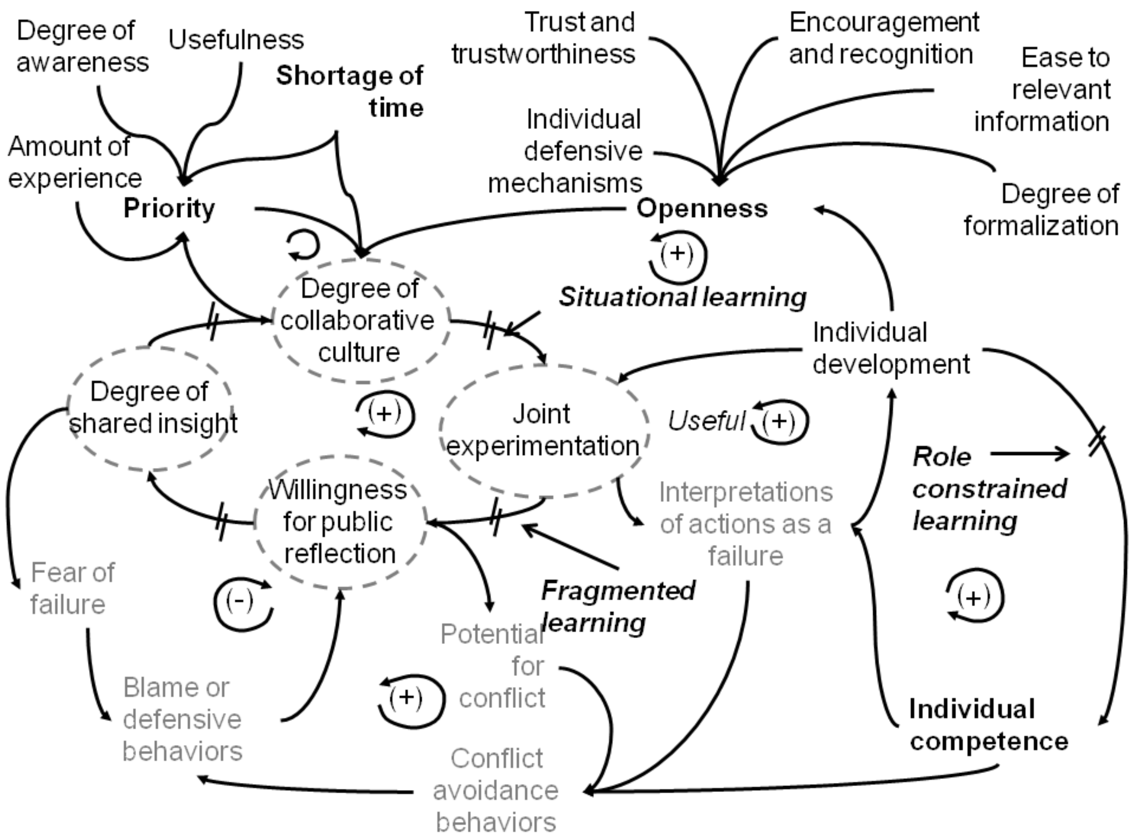


Figure 3 A simplified and temporary causal loop diagram for collaborative experience learning

Model formulation

The following describes some of the selected features related to the experience transfer rate that are incorporated in the model. The features are selected because they have been identified in previous work as significant for organizational learning at Statsbygg (Lê 2006). Furthermore, relationships are established for simulation and illustration of the principle.

Thus, all features are not included and handled in figures and identified relationships. Some are only mentioned in order to depict the complexity.

Previous studies (Lê 2006) have shown that the transferring rate decreases with increases in the mental and physical distances between the designer and the maintenance and operational personnel. A decreasing transferring rate also includes a decrease in the amount of relevant information being exchanged. In addition, the average experience load influences the transferring rate negatively. The following relationship is based on the findings and reflects the trends.

Relationship:

Experience Transferring rate=1/(*MD x PD x AEL)* where
MD = *Mental Distance* =1/*Openness*+1/*Priority* + 1/*Time* +1/*IndividualCompetence*, where
PD = *Physical Distance*
AEL = *Average Experience Load*

$$\text{Transferring rate} \wedge MD \wedge PD \wedge AEL \in \langle 0, 100\% \rangle$$

In this paper, only the parameters of *Mental Distance* are discussed further. The mental distance includes many other parameters than the ones selected, but *openness, priority, time* and *individual competence* are the basic parameters. In addition, other features such as *Physical Distance* can be dealt with by using the same methodology and principle of analysis. The physical distance comprises of an IT-tool, geographical distance and process. Sveiby et al (2002) have discussed these issues. Following are the decomposing of the selected features.

Time Availability

Shortage of time is one of the most critical factors affecting experience transfer and learning. The time availability factor is further influenced by the amount of information to be transferred, ease of access to information, and the time required handling the information (Lê 2006). Firstly, shortage of time depends on priority and resources. Often, individuals (particularly project managers) are subjected to shortage of time and start new projects without submitting post-work reports on the previous projects. The dilemma is to make priorities within the daily work tasks and activities for experience transfer (Aase 1997). In addition, the limitation of resources such as time and human capital has impact on making priority. Secondly, most AEC organizations lack system and plan for the use of the experience, for capturing experiences throughout the project's processes and for transferring the experiences to new projects. Such insufficient working methods and systems will increase the shortage of time to learn and transfer knowledge and experiences (Aase et al 2001). In addition, projects often involve uncertainties and possibilities for extra work etc. that contribute to shortage of time by need for focusing on the tasks at hand. Thirdly, information needed for the early stage planning, is imperfect and incomplete (Aase & Pedersen 1999). Last but not least, bureaucratization of the process may result in experience transfer systems that require too many demands for the individual's time. Such put into practice "top-down" solutions, where leaders believe the formal system as for instance IT-tools, will solve the problem of experience transfer (Aase 1997).

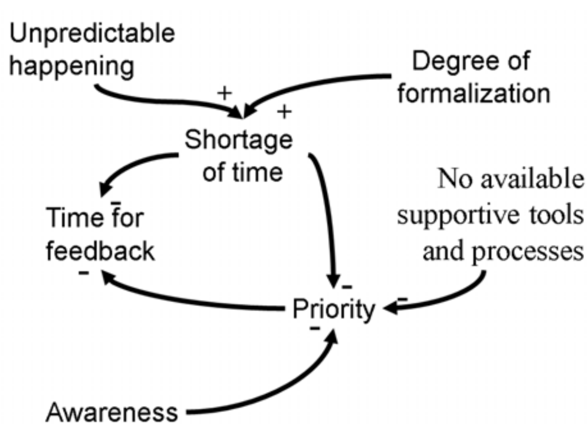


Figure 4 A simplified causal loop for time pressure and feedback

In previous studies (Lê 2006) it has been shown that the experience transferring rate increases when time is available. Therefore, time availability will have direct influence on the mental model. In other words, in this paper, amongst other features, the relationship is mental distance decreases with higher degree of time available.

Relationship:

$$\frac{1}{TimeAvailable}, \text{ where Time Available} \in <0\%, 100\%]$$

Openness and trust

As Dalluegue and Das Neves (1995) have pointed out, one of the main mechanisms of a successful learning organization is the climate of openness where mistakes are seen as learning opportunities and employees are not afraid of punishment or of being blamed (Nevis et al 1995). The basic characteristic of openness in an organization is the open communication about problems and experiences among the different departments in the organization. The organizational formation can support encourage team work with similar experience/tasks and sharing of knowledge. In such an environment, informal learning occurs daily and creates opportunity so that individuals can observe the operations in the upper management. In other words, openness depends on forgiveness, trust, encouragement, and recognition (Handy 2003). Enhancing communication would mean more feedback within the organization. Togetherness increases collaborative learning and creates synergy (Handy 2003). Easy access to relevant information will encourage openness in an organization. This positive feedback on openness is depicted in Figure 5.

Figure 5 Simplified causal loops for positive impact on openness

On the other hand, individual defensive mechanisms and formal organizational structure could pose negative impacts on openness, as depicted in Figure 6. Individual defensive mechanisms, for instance that people do not want to be wrong or to have others know they are wrong, are common in an organization. To learn, one has to accept feedback and criticism (Argyris 1994). The organization also may not want to focus on the cause of problem, because "face saving" is important (Argyris 1994). Another factor that may hinder openness is the hierarchical organizational structure and the degree of formalism. An organizational structure that is more "flat" and less hierarchy tends to be more responsive, efficient, and cost-effective (Handy 2003). Organizations that actively build learning cultures are therefore characterized by having a clear and consistent openness to experience, encouragement of responsible risk taking and willingness to acknowledge failures and to learn from them (McGill et al 1992).

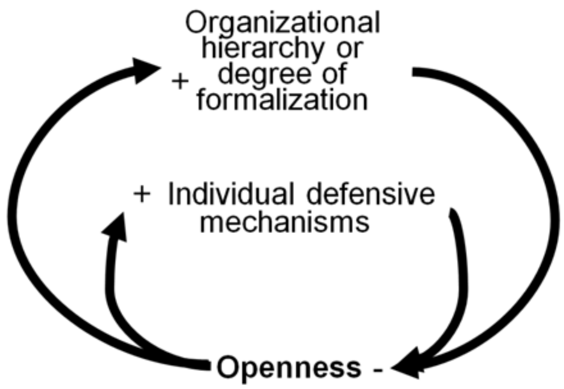


Figure 6 A simplified causal loop for negative impact on openness.

Previous studies (Lê 2006) have shown that an increasing degree of organizational formalism and individual defensive mechanisms will not encourage openness, while an increasing degree of trust and trustworthiness, ease to information, forgiveness and encouragements will increase openness. The positive causal loop will give the same reasoning, but opposite. The relationship is depicted as following.

Relationship:

1/*Openness*, where *Openness* = Degree of individual defensive mechanism x degree of organization formalization. *Openness* $\in$ *<1%, 100%]*

Priority

Priority is related to the degree of availability of time and awareness. Increases in these two factors will have a positive effect on increasing priority and subsequently the experience transfer rate. An increasing priority will reduce the mental distance as shown in the following relationship.

Relationship:

1/*Priority*, where *Priority* = Time pressure x awareness. *Priority* $\in$ *<0%, 100%>*

Individual competency

Individual competency depends on experience, quality of experience, and formal training (Sveiby et al 2002). As Pfahl et al (2001) have illustrated, a higher degree of individual competency indicates a lower need for guidance. Previous studies (Lê 2006) have shown that the individual competency level increases with time on a level and the firm's investment in competency enhancing activities. Increasing individual competency reduces the *Mental Distance*, as depicted in the relationship below.

Relationship:

I/IC, where IC= Individual competency $\in$ *<0%, 100%>*

Flow Diagram and simulation

The simulation starts with the experiences from buildings at the operation and maintenance stage that are about to be transferred to a next similar building project. In practice, some of the experiences will be lost, because of factors such as years of experience, relevance of information etc. Depending on the ability of an individual, experiences to be transferred can be conducted proactively or reactively. Experience transferring must take place in order to be able to influence a decision or a decision-making process, and consequently improve the quality of a building project and reduce the accumulative costs of errors. One main feature is transferring ability which consists of openness, time available, priority and awareness, and which is influenced by the mental distance and the physical distance. How many levels that are needed to decompose each feature mentioned above, is dependant on what needs to be analyzed and on the available data. The analyzed must take place in order to carry out adequate operationalizations for the invested organization. Operationalization is defined as *"the process of defining a fuzzy concept so as to make the concept measurable in form of variables consisting of specific observations."* (Wikipedia 2008b).

In order to illustrate how the flow model is being simulated, a simplified flow diagram as shown in Figure 7 is employed. This simulation model corresponds to the experience transfer process between the designer and the operative and maintenance personnel. In this model the experience transferability is influenced by the physical distance, which has not been decomposed in any further levels, mental distance, which is decomposed into one further level, and average experience load. Each experience is also influenced by fraction of proactive or reactive, the effort to use experience, and the average experience load which in turn is dependant on average time to handle the experience and experience gaining. They are also influenced by EEG (experience efficiency for reduction problem generation), or EER (experience efficiency for problem resolution). In order to reduce *the accumulate costs of errors*, the features *design and construction experience* and the feature *generating of experience* must be low. The argument for doing this simplification is that this model has an aim to illustrate the methodology and avoid too many guess-estimations.

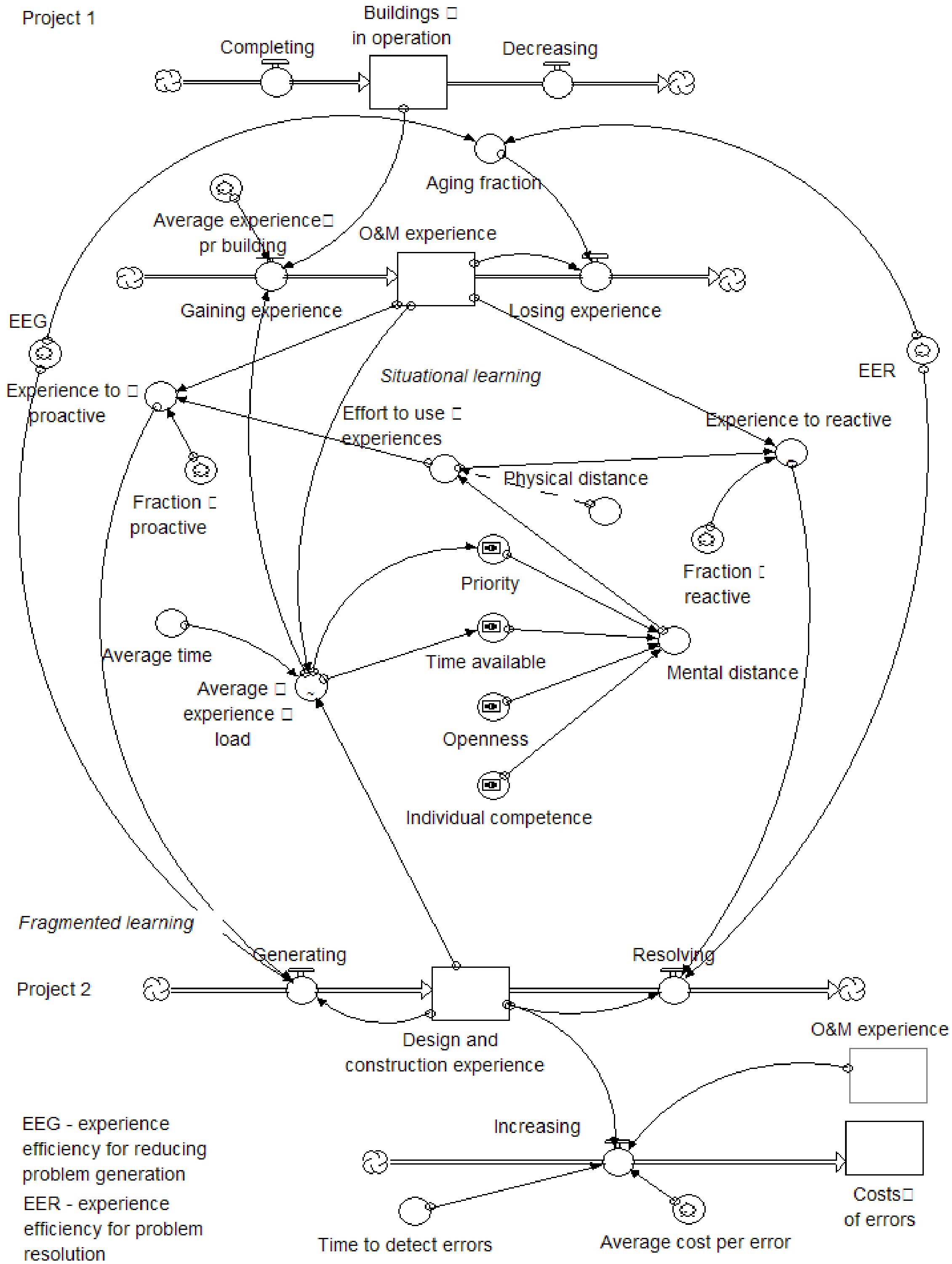


Figure 7 The temporary simplified flow diagram

Figure 7 shows the diagrams when the experience transfer ability in this case, i.e. openness, time available, priority and individual competence are on minimum and maximum. The results are presented in the section below.

Validation

In order to validate the model, different scenarios have been taken at various possible factors of openness, time available, priority and individual competence. The simulations did as well determine the development of the components as operative and maintenance experience, generating of experience in the design stage, and the design and construction experience.

These samples in the simulation were taken in the upper and lower cases and compared to trends uncovered in previous research by Lê (2006) at Statsbygg. The comparison between the simulated and the previously identified trends shows a good correlation, as expected, but they are not of high significance, since real data is not used. It must be emphasized that for a better analysis and real data collection is needed to improve the validation. In addition, the simulation period could be much longer in order to see the long-term perspective. Many of the components, as for instance operative and maintenance experience, are unchanged because the period is too short. Operationalization of the parameters can be used to measure the depth of some kind of soft values, such as awareness, priority, or trustworthiness, but these values cannot be directly measured by an outside observation, because these parameters are often intangible. Therefore, other indirect observations and measurements must be done in order to concretely express these parameters. The operationalization may therefore include incorrect reasoning. However, operationalization is a familiar method within social science studies as a part of the scientific method. In addition, Wiener's communication theory and feedback (Griffin 1997) and Osgood and Schramm's Circular Model 1954 may be used, but they are not considered to be directly applicable to this purpose. However, the theories can enrich the foundation for a better understanding. A replication and insight of information theory and the Shannon-Weaver's mathematical model of communication from 1947 will also improve this work.

RESULTS AND FINDINGS

The model was simulated for a period of 13 months (See X-axis in Figure 8), and was based on the following set of values; Average cost pr. error was NOK 100.000 (USD 15.000): Average experience pr. building was 47, which is based on a previous study of existing buildings in the operative and maintenance stage (Lê 2006); and people's characters are more prone to ad hoc like initiatives, than they are able to keep focus on fundamental solutions (Lê 2006). Fraction proactive was 0,3 (30%) and fraction reactive was 0,7 (70%). These are based on the results and reasoning from previous studies (Lê 2006). Finally, EEG (experience efficiency for reducing problem generation) and EER (experience efficiency for problem resolution) were 0,5 (50%). Following are the selected results of the performance scenarios in combinations with some facilitating factors for the mental distance.

Performance scenarios		The selected facilitating factors for the mental distance			
		Time pressure, T	Openness, O	Priority, P	Individual Competence, IC
Situational learning rate	Operative and maintenance experiences	Increasing T has no effect on the operative and maintenance experiences	Increasing O has no effect on the operative and maintenance experiences	Increasing P has no effect on the operative and maintenance experiences	Increasing IC has no effect on the operative and maintenance experiences
Fragmented learning rate	Total generating of experience in next project	Increasing T is increasing of total generating of experience in next project	Increasing O is increasing of total generating of experience in next project	Increasing P is increasing of total generating of experience in next project	Increasing IC is increasing of total generating of experience in next project
	Design and construction experience	Increasing T increases the design and construction experience	Increasing O increases the design and construction experience	Increasing P increases the design and construction experience	Increasing IC increases the design and construction experience

Table 3 Some selected results of the performance scenarios

CONCLUSIONS

The causal loops have made it easier to understand and handle the selected parameters that are involved in experience transfer, through decomposing this complex issue. The largest challenge was to find the parameters that are of importance to, and to decide which level is adequate for the case company. Various parameters are represented, and some of the results contribute to enlightenment. However, a computer-simulated model is a tool, but it is of limited use as the parameters change due to the focus of the user of the model. Using it with a "rational sense" and the story will be different from case to case. This study shows that time, openness, priority and individual competence have some impact on fragmented learning and situational learning. The simulations show that the maintenance and operationalization of experiences were not influenced by them, but do react as expected in the model. The simulation also show that an increasing of *time*, *openness*, *priority* and *individual competence*, the features of *the total generating of experience in the next project* and *experience of design and construction* will increase as well.

Contribution of the research

System dynamics is applied in industrial systems as business process re-engineering, customer service level for continuous improvement and financial analysis, forecasting, human resource planning, or organizational development. In addition, within production control system, supply chain management, and efficient consumer response, system dynamic is commonly used for strategic planning or total quality management etc (The System Thinker 2008). This work uses system dynamic in studying the dynamic of experience transfer in a multi-project environment for the AEC industry. When an organization has an opportunity to cover the whole life cycle of a construction, collaboration between individuals and organizations are more essential due to the opportunity to aggregate the total organizational knowledge. However, learning barriers is multi-faced. Role constrained learning and fragmented learning seem to have the greatest impact on experience transfer. In role constrained learning, individuals learn in their work but their position in the organization prevents them from utilizing their knowledge. In the case of fragmented learning, the inability of the organization to make the knowledge of competent individuals a part of the organization's mental model can also result in sub-par performance. Engineering disciplines require abilities of analysis, synthesis, designing, evaluation, experimentation, etc. However, managerial and leadership qualities are attached. The current competitive wave is competence in AEC industry. Therefore, this research not only argues for the use of system dynamics in collaborative learning system, but also draws the effects of selected facilitating factors and promoting parameters as time, openness, priority, and individual competence.

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