TOWARDS A FEEDBACK MODEL FOR OFFSITE CONSTRUCTION

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There is a need for efficient experience feedback in the construction industry, which encompasses companies that use a wide spectrum of on- and off-site production methods to produce (inter alia) roads, bridges and railways, as well as low- and high-rise buildings. The rationale for developing and implementing methods for experience feedback is well documented, and regardless of the choice of production strategy common denominators are needs to recognise defects and to apply a continuous quality improvement program that incorporates learning from mistakes. The purpose of this paper is to present ongoing work regarding experience feedback, with the ultimate aim to close the feedback loops in off-site housing sales, design and production. An indoor production process at a Swedish housing company is probed. The investigated company utilises off-site module manufacturing, a production form with a 15 % market share among professional clients in Sweden (recurrent clients purchasing commercial and multi-storey buildings). This production form appears to be well-suited for implementing experience feedback, since control is already required in the production process. Based on a literature review and case examples a model for experience feedback is proposed. The feedback model is executed in a logical control structure with four levels: (1) plan and learn, (2) capture and assign to targets, (3) analyse and prioritise, solve and assess, (4) implement and use feedback. Theoretical considerations and empirical data show how analysis of error-detection can enhance possibilities for prioritising improvement actions as well as identifying feedback targets.

Keywords: experience feedback, off-site manufacturing, knowledge management.

INTRODUCTION

Housing production companies currently face intense competition and a failing market. Modern, off-site construction methods could possibly ease some of the pressure on them since they are thought to have the potential to increase efficiency, control and quality, while reducing costs. The benefits and possibilities of using off-site methods – notably low costs and high quality levels compared to in-situ construction – have been reported by several authors, including Pan and Gibb (2008), Pan *et al.* (2008) and Johnsson and Meiling (2009). The opportunities off-site manufacture provides in this respect have been heavily promoted, but it should be recognised that manufacturing off-site is not a panacea and does not inevitably lead to effectiveness and efficiency (Gibb 2001). Furthermore, a number of perceived barriers for choosing off-site manufacturing strategies among British house builders have been documented by Pan *et al.* (2007), including a lack of trust in the methods. Lack of

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trust among clients, in terms of life cycle costing, have also been noted and investigated by (Levander and Stehn 2007). Hence, a number of problems associated with off-site construction need to be addressed before it can fulfil its apparent potential. In Meiling and Johnsson (2008) it is suggested that off-site module manufacturing would benefit more from experience feedback than traditional construction, since there are higher levels of repetition and control is already required in production. The importance of the latter in regard to the defect recovery process and learning is also emphasised by Love and Josephson (2004). Love *et al.* (2000) argue for continuous improvements as a vehicle to lead construction companies into learning from their mistakes and become learning organisations. Effective and efficient communication of experience data can nurture improvements, and simultaneously support learning in organisations (Kärnä and Junnonen 2005). Hence, there is a strong rational for constructing a working model for systematically developing and implementing experience feedback procedures that can promote continuous improvements in terms of both off-site efficiency and effectiveness.

It has been reported from the Swedish construction sector that information does not reach the people that need it, and/or in an appropriate format, resulting in lack of quality, low profitability and weak co-operation in the companies (Industrifakta 2007, Josephson and Hammarlund 1999). Information is captured in various formats, e.g. documents, databases and people, but is seldom readily available, as feedback, since people are not aware of its existence (Blessing and Wallace 2000). Presumably another problem is that even when people are aware of the existence of relevant data, the information they specifically require is buried in large amounts of data that they do not have the time or skill to filter. Thus, there is need for better "Knowledge Management" (KM), i.e. more coherent strategies for creating a learning organisation by managing the creation, handling and use of knowledge. According to Kamara *et al.* (2003), there is a lack of proactive KM strategies within the construction industry and companies often rely on people as experience carriers between projects and departments. There are also more specific models concerned with the capture and reuse of experience data, for instance those presented by (Lin *et al.* 2006, Stokes 2001, Kamara *et al.* 2003), but these studies do not specifically address the analysis of experience data to be captured. Thus, there is a need for further research about how to prioritise capture of experience data, and to develop a better understanding of where the experience is needed, who needs access to it, and the form in which it should be delivered.

Theoretical considerations and empirical data are presented here showing the need for analysis (and compilation in a suitable format) of experience data. Based on these findings a model that focuses on prioritising experience data capture in regard to continuous improvements is proposed.

EXPERIENCE FEEDBACK APPROACHES

The rationale for implementing and executing a system for reusing experience can be found within quality management theories, including Lean Production, Total Quality Management (TQM) and Six Sigma theories (Dahlgaard and Dahlgaard-Park 2006). Tools for this purpose are organised in TQM and Six Sigma procedures within the PDCA (Plan, Do, Check, Act) learning cycle and the DMAIC (Define, Measure, Analyse, Improve, Control) problem-solving cycle, respectively (Pyzdek 2003). However, the constituents of experience feedback are explained by principles of Knowledge Management (KM), since it is ultimately a learning issue (Henry 1974).

Experience feedback is not KM per se, but is described as a KM initiative by various authors, e.g. Carrillo *et al.* (2003). Kamara *et al.* (2003), Ingirige *et al.* (2002), and Lee *et al.* (2005) all note six benefits of live knowledge capture, namely it: (1) avoids the need to reinvent old solutions, (2) facilitates innovation, (3) increases agility, (4) improves teamwork, (5) improves supply chain integration, and (6) improves project performance. Thus, several managerial theories can facilitate attempts to distil principles of experience feedback, all of which have aspects of knowledge as a common denominator. It should be noted that knowledge can be divided into tacit and explicit forms, both of which (and the interactions between them) are important (Kamara *et al.* 2002b). A key process is the "evolution" of knowledge, i.e. the process whereby contextualised data are transformed via interpretation into information, knowledge and eventually wisdom through the discernment of relations, patterns and principles (Ackoff 1989). Thus, data, information and knowledge can be regarded as forming a hierarchical model – the DIKW model (Fricke 2009, Ackoff 1989) – of enhanced understanding in which wisdom is the ultimate kind. This paper considers ways to foster the evolution of knowledge and wisdom from data and information in the off-site construction industry that may provide a sound, rational basis for a task-performing system, as described by Kamara *et al.* (2002a). Post-project evaluation, or debriefing described by Gameson *et al.* (2008), is a common approach for experience capture in construction projects according to Orange at al. (1999), but it is argued to be insufficient since inadequate time is allocated for this purpose. Further drawbacks associated with post-project evaluation include the common dispersal of workgroups after project completion, and the inevitable time lags between relevant experiences and data capture (Tan *et al.* 2007). In these respects, live capture of experience data may provide a better basis for the formulation of explicit knowledge and thus promote the efficiency of continuous improvement activities in organisations. To facilitate the continuous management of knowledge and thus promote improvements, several working models have been developed.

Knowledge lifecycles and models

Several knowledge life-cycle models have been proposed to assist management of the life (and evolution) of knowledge, three of which will be mentioned here. Blessing and Wallace (2000) propose a knowledge life-cycle representing the evolution of knowledge for an individual, a team and a company with the overall mission to support the design process. The knowledge life-cycle serves as a basis for the capture, analysis and use of experiences in a knowledge-generating manner, meaning that the quality of knowledge will increase as the cycle is used. Outside sources may contribute additional life-cycle knowledge as they interact. This model recognises the importance of capturing both knowledge and context in real time, making it available as soon as it is reported. This is difficult to apply in housing production since real-time capture in this manner implies use of a computer-based knowledge system. In Methodology and tools Oriented to Knowledge-based engineering Applications, the MOKA method (Stokes 2001), a life-cycle for knowledge-based engineering applications is described according to the following steps: identify, justify, capture, formalise, package and activate. The first step, justify, involves identifying opportunities for experience feedback. However, ways in which this identification should be conducted are not described in detail. A tripartite model for live data capture is presented by Kamara *et al.* (2003) and Tan *et al.* (2007) including use of: (1) ICT tools, (2) a working system and (3) an assigned knowledge manager.

There is also a wide spectrum of types of project knowledge, e.g. knowledge regarding processes, costing, legal requirements, best practices, lessons learned (who knows what) etc. In addition, each category could be sub-divided into more detailed kinds of knowledge, hence there is a need for demarcation. The conceptual framework presented by Kamara *et al.* (2003) and the technique presented by Tan *et al.* (2007) do not detail the kinds of knowledge that should be captured. Further, they do not address the hierarchal relations of understanding and the different levels of data-information-knowledge-and wisdom recognised by authors such as (Ackoff 1989), or therefore the associated implications regarding the importance of facilitating interpretation of data etc. In contrast, Lin *et al.* (2006) present a map-based knowledge management concept for construction that is network-based and is argued to help in identifying critical knowledge areas, since all knowledge is abstracted and summarised in maps created in the following phases: knowledge determination, extraction, attribution, linking, and validation.'

There is a need to develop robust models that include techniques for prioritising experience that should be fed back. There is also a need for models that help to identify destinations, i.e. people and places experience should be fed back to.

OFF-SITE TIMBER MODULE MANUFACTURING

Off-site timber module manufacture refers to the prefabrication ($\geq$80% off-site) of closed three-dimensional timber "modules", each with a floor, roof and wall elements. The off-site manufacturing phase for a single module is divided into three main stages: (1) wall, roof and floor element production, (2) module assembly and (3) module completion. The completed volumes are covered with moisture-proof tarpaulins before transport by truck to the construction site (Meiling and Johnsson 2008). Defects are reported at three control points: (1) a factory audit before tarpaulin cover, (2) a final audit before tenants move into the building, and (3) a warranty audit after two years occupancy. Characteristics of defects detected at these three control points are reported in Johnsson and Meiling (2009). Deviations are interactively reported in a visual manner, and colour-coded to track their status. The main purpose is to make sure that deviations have been corrected before units reach the customer.

Case examples

A case example, in this context, refers to a set of identified defects and the procedures use to address them (and similar defects in the future) that illustrate needs for enhanced analysis of experience data and indicate how enhanced systematic capture and analysis of experience data could help to improve quality. Two such sets are considered here.

Example 1
The first case example set consists of 2713 defects in 443 modules (used in eight housing projects) noted at three control points (factory, final and warranty audits), compiled and analysed by Johnsson and Meiling (2009). Structural errors accounted for 21% of these defects (578/2713), including cracks in corners and movements in the structure. Defects were of several types, for instance, cracks in weak sections and design errors such as misplacement of doors or poor choices of material. The standard procedure to deal with cracks was to apply putty and paint without reporting their extent other than as text in quality audits.

Example 2

The second example set, also from Johnsson and Meiling (2009), consists of 2415 defects noted in final audits of 877 modules used in 11 projects. The defects in these audits were classified according to the generic parts of the modules they affected, and their relative frequencies were graphically visualised. The analysis revealed that most defects were associated with walls, openings and interior installations. A further investigation is called for regarding prioritisation of quality improvement efforts.

PROPOSED MODEL

The proposed feedback model is inspired by lean theories and quality concepts, based on a belief in continuous improvements, minimising waste and satisfying internal and external customers. However, the model constituents are based on a KM framework of experience data capture, transfer and "evolution". In addition, the model links "contextual" information, such as where, why, what and when defects occur (Johnsson and Meiling 2009) to analysis "activities" (such as statistical, root cause and risk analysis) and feedback "targets" for both internal and external customers, in a feedback-generating loop. The core activities are to prioritise and identify targets for feedback through data capture, analysis and implementation stages, as illustrated in Figure 1.
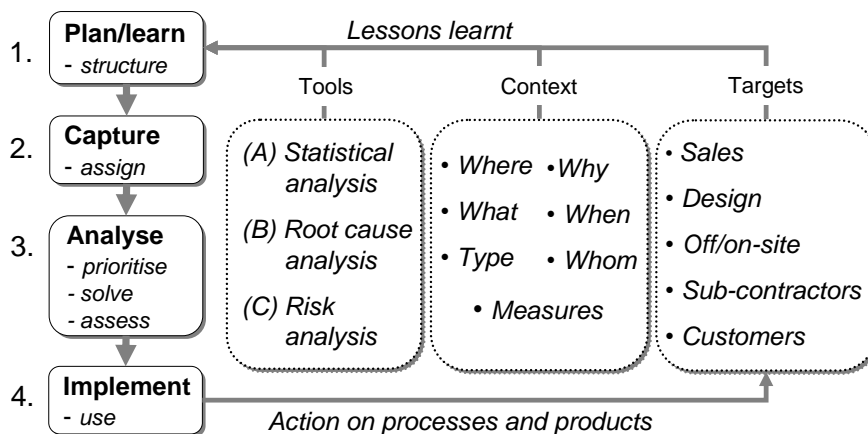

Figure 1: Proposed feedback model for capture and analysis of experience data.

1. Plan and learn

Experience feedback initiatives must be planned and coordinated in order to support the design, manufacturing and assembling processes. This is an iterative control phase preceding the live capture (2) and analysis (3) stage, in which each activity is evaluated in order (mainly) to balance context information and context data. This is where conformity between available knowledge and actually used knowledge is sought (Blessing and Wallace 2000). The planning stage should formalise the kind of experience data that is sought, i.e. clearly identify each class of defect, and associated details, in the construction process that should be recorded.

Structure
The structure of context data is dependent on the end user, who needs to be identified.

2. Capture

This is an ongoing activity in which context data regarding defects, anomalies and problems in selected processes are gathered. People, machinery and product output are all potential sources for capturing experience data.

Assign

All defects should be codified as they are discovered, and if possible assigned to a primary cause and target instance. Codification in a generic mode is demonstrated in Johnsson and Meiling (2009).

3. Analyse

Analysis is scheduled in the planning stage and the context data as well as the targets for feedback should be considered when selecting methods to be applied. Such analysis has three main purposes: (i) to facilitate choice of action decisions, i.e. to prioritise actions, (ii) to identify root causes of, and solve, chosen problems and (iii) to assess risks regarding chosen actions. This is not a static operation, providing a schedule that cannot be subsequently changed, but an activity that is open to allow continuous improvements and better integration with the capture of experience data so as to facilitate decisions and execution of fact-based actions. The methods that can be used include the statistical analysis, root cause and risk analysis procedures (for prioritisation, problem-solving and risk assessment, respectively) outlined below.

Prioritise: (A) The seven quality tools

The seven quality tools, originating from Kauro Ishikava, constitute a basis for presentation and statistical analysis of experience data (Bergman and Klefsjö 2003): (1) Ishikawa diagram, (2) Pareto chart, (3) Check sheet, (4) Control chart, (5) Flowchart, (6) Histogram, and (7) Scatter diagram.

Solve: (B) Root cause analysis, RCA

RCA encompasses various problem-solving methods aimed at identifying the ultimate, underlying causes of problems or events (Wilson *et al.* 1993). Some of the methods that can be used include:

- Cause and effect analysis (based, for instance, on Ishikawa diagrams). It is assumed that there is a causal chain of relationships linking an initial cause and its final effect. Thus, hypothetically, removal of the primal cause in the chain will make the problem disappear (Pyzdek 2003).
- Five whys. This technique was originally developed at Toyota industries and later adopted by lean production theorists as an approach to solve problems (Liker 2004).
- Failure modes and effect analysis, FMEA (IEC 1985b), is an inductive, mostly qualitative analysis method used to identify possible failures and predict effects of these failures on the system.
- Fault tree analysis, FTA (IEC 2006), is based on use of deductive logical diagrams that show relationships between system failures.

Assess: (C) Risk analysis and assessment

Risk assessment refers to the objective evaluation of risk, with clear consideration and presentation of assumptions and uncertainties. The process involves risk analysis (IEC 1985a), which is defined as a systematic use of available information to identify hazards. This is a wide, intensively researched subject area that is not further considered in this paper.

4. Implement

Implementation is the phase in which the feedback action should be executed in order to improve the process or product. Feedback of experience is the ultimate goal for the data capture and analysis efforts, thus this is where the data acquired are applied, and the overall exercise proves its value (if appropriately done).

Use

Captured experiences could have uses both in directing "fire-fighting measures" to correct defects in houses and modules that have already been produced, to satisfy customers, and in new process/products, after which further iterative cycles of experience feedback can be applied (Meiling and Johnsson 2008).

ANALYSIS

Table 1: Two case examples follow through the proposed feedback model

Model Stages:	Example 1: (Cracks)	Example 2: (Windows/doors)
1. Plan/learn (structure)	A decision is taken to investigate cracks, including their overall frequency and how they arise in production.'	Windows and doors are chosen for investigation because they are expensive and need to be ordered and installed at correct times.
2. Capture (assign)	1. Quality audits are gathered from earlier projects 2. Live capture of crack frequency at on-site assembly. Information is targeted to design.	1. Quality audits are gathered revealing high frequencies of defects related to windows and doors. 2. Live data capture at on-site assembly reveals high frequencies of adjustments for windows and doors.
3. Analyse (prioritise)		
A. Quality analysis	Histograms from quality audits reveal high frequency of cracks from post-production phase, implying importance.	A Pareto chart reveals "the vital few" (Juran and Gryna 1988) identified here as windows and doors
B. Root Cause Analysis	Cracks are traced back in production; cracks propagate during two lifts, one with a fork-lift truck in the factory and one with a crane at the construction site. Finally walls are dismounted in the factory, revealing the root cause of cracks to be a lack of standardised work because some craftsmen did not follow specifications for performing sheathing in weak sections, failing to mount strengthening plates in corners.	The purchase department chose to buy non-adjustable doors and production chose to mount windows without adjustment screws. These are questionable decisions since the modules move during transport and assembly, resulting in costly adjustments on-site.
C. Risk Assessment	High probability of reoccurrence if standardisation is not implemented.	High probability of reoccurrence if door hinges and window mountings are not changed.
4. Implement (use)	The off-site manufacturing process is targeted, and wall workstations are standardised.	Purchasing department is targeted, resulting in changes of subcontractors and new routines regarding material acceptance.

Two types of real quality problems that have been observed and documented, cracks (1) and poor fitting of windows/doors (2), are used here to illustrate how the proposed model could have been used to feedback experience data. A summary of how the proposed feedback model could have been applied to correct these two classes of faults is shown in table 1.

The Pareto chart mentioned in section 3 "Analyse" above is related to example 2 and displays the relative frequencies of defects originating from the indicated generic parts of wall, openings and interior installations accounting for 60% percent of all recorded defects in 11 housing projects (60% of 2415).

DISCUSSION AND CONCLUSIONS

Experience data is embedded in knowledge that is stored as information and data in handbooks, drawings, documents, electronic files and (especially), in the heads of individuals. From a design perspective there is a lack of working processes for preventing the reoccurrence of poor solutions, and from a production perspective a lack of tradition regarding routines for filing and compiling problem reports, and documenting deviations and defects (Meiling and Johnsson 2008). The gap between design and manufacture must be understood and eventually minimised in order to optimise product effectiveness in the construction trade, a problem also reported in other industries, e.g. the aviation and automobile industries (Blessing and Wallace 2000, Andersson and Isaksson 2008). For this purpose, relevant data must be acquired and analysed (i.e. a rational experience feedback process is required) since information and knowledge generated from experience only becomes useful in the improvement process when it has been contextualised. From a lean production perspective waste includes all activities and resources used that do not contribute to value for the end user, so compilation of experience data without a target and purpose should be avoided, to avoid creating an information overflow (Fricke 2009).

Based on theoretical studies and case examples from off-site manufacturing a novel feedback model is proposed. The model focuses on prioritising experience data capture and analysis, and incorporates techniques for prioritising the kinds of experience that should be fed back, determining the form in which experience data should be fed back and identifying the destination to which experience-based information should be fed. The proposed approach has similarities to the MOKA method (Stokes 2001) in this respect, since both incorporate refinement of data steps. Other models do not include support for identifying experience feedback, but focus on the importance of live capture of knowledge (Lin *et al.* 2006, Tan *et al.* 2007, Kamara *et al.* 2003). Through live capture and incorporation of contextualised data the proposed model will promote interaction between tacit and explicit knowledge, thus creating new knowledge, as described by Nonaka *et al.* (2000).Theoretical considerations and empirical data show how analysis of error-detection can enhance the scope for prioritising improvement efforts. In addition, it could facilitate identification of the appropriate receivers of specific kinds of information.

Future work

In future work the proposed model will be formalised and validated. In the next step the working feedback model will have to be synchronised to company production systems as well as to enterprise resource planning systems. Factory production is well suited for information gathering and anomaly reports, often using manual systems such as Kanban cards and note boards for live capture in Oriental countries, while ICT tools are typically used in the West (Nonaka *et al.* 1996). An interesting extension would be to expand live capture to on-site production with hand-held computers. A further logical step would be to extend experience data collection into the post-production phase, which would ultimately allow the development and implementation of a performance-based, lifecycle approach to the assessment and improvement of constructed assets.

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