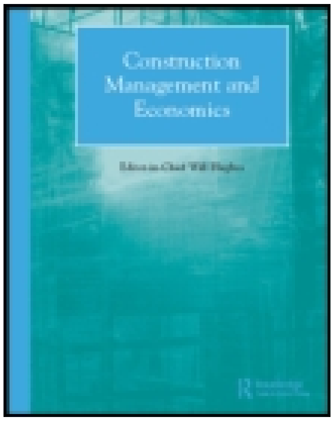

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Method-based learning: a case in the asphalt construction industry

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Method-based learning: a case in the asphalt construction industry

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Traditional working practices in the construction industry rely heavily on the onsite experience and craftsmanship (the tacit knowledge) of operators and teams. This results in implicit learning and lengthy learning cycles. The aims of the research are to develop a deeper insight into construction processes and to instigate a change from current implicit learning to explicit method-based learning. To change to explicit method-based learning, Kolb's experiential learning model was introduced into current practices and 'explicating the process' was added to this learning cycle. Further 'reflective observation' and 'abstract conceptualization' were incorporated explicitly during an actual road construction project using feedback sessions with an asphalting team. The adopted learning framework was found to be applicable and useful in the quest for enhanced learning capabilities and improved process control. Fusing Kolb's learning model with onsite collected data was vital in explicating tacit knowledge and implicit processes. The approach enabled a meaningful discussion with operators to unravel their intentions and reasoning behind the chosen strategies. Explicit method-based learning, as here, leads to improved quality awareness, better understanding of the processes and their interdependencies, and improved communication with and within the asphalting team.

Keywords: Action research, experiential learning, information technology, roads, tacit knowledge.

Introduction

Significant changes are currently occurring which are changing the roles of agencies (clients) and contractors in the construction industry. Agencies are shifting towards service-level agreements with lengthy guarantee periods (Minchin *et al.*, 2008). Within these new roles and contracts, contractors are directly confronted with any quality shortcomings that emerge during the guarantee period. These changes urge contractors to develop a deeper insight into onsite processes (Dorée, 2004; Ang *et al.*, 2005; Sijpersma and Buur, 2005). Also, it is becoming increasingly important for contractors to improve process and quality control during onsite construction operations.

With the emergence of the internet, pervasive networks and the rapid progress in technologies, one might expect contractors to embrace new information and communications technology (ICT) opportunities for performance enhancement. However, in reality, the construction process is carried out still mainly without the use of high-tech instruments to monitor key process parameters. Also, in spite of the significance of the onsite process, the major part of the literature deals with the characteristics of a construction project from a material perspective, while limited focus has been on the systematic mapping and analysis of onsite construction processes. In general, contractors know what activities are undertaken on site at a certain time, but the actual onsite operational activities performed and decisions taken are not systematically mapped. This makes it difficult for contractors to relate the onsite operational activities to the final quality of the construction. As such, it is nearly impossible to identify or distinguish between good and poor operational practices and to improve process control.

If the construction process is not explicit, the causes of any failure to meet the required specifications cannot

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be traced back to actual operational strategies on the construction site. Also, as in many domains in the construction industry, the current operational strategies rely heavily on the skills and experience of operators, engineers and managers on the construction site. This results in implicit learning based on tacit knowledge and lengthy learning cycles.

To enhance learning and to improve the construction process, as well as to achieve improved process and quality control, it is essential to move away from the current implicit individual lengthy learning towards explicit and method-based learning. Given that current practices largely depend upon the onsite experience of operators, it seemed appropriate to adopt and introduce the experiential learning lens of Kolb (1984) to current practices. Consequently, a method to instigate a change towards explicit method-based learning was proposed and its merits were demonstrated during the construction of an asphalt highway in the Netherlands.

The asphalt industry plays a vital role in the global transportation infrastructure. It helps drive economic growth and social well-being in both developed, as well as developing, countries. World production of asphalt in 2007 was estimated at around 1.6 trillion metric tonnes, with Europe producing about 435 million metric tonnes per year. Europe's annual public investment in highway, street and bridge construction totals some € 80 billion compared to €55 billion per year in the USA. Collectively, the asphalt industries of the USA and Europe employ approximately 400000 workers (European Asphalt Pavement Association, 2011).

In spite of its obvious importance, the asphalt industry is still relatively underdeveloped and a low-tech domain. Most of the scientific and other literature for the industry deals with material characteristics while there is little systematic mapping and analysis of onsite processes and their effects on the quality of the asphalt layer (Leech and Selves, 1976; El-Halim *et al.*, 1993; Huerne, 2004; Miller, 2010). This makes it inherently difficult to improve process control and enhance learning competencies. Therefore, testing and improving learning methods in construction, as well as improving the learning competency of operators on site, are relevant for both the scientific community and the industry as a whole.

This research discusses the conceptual background relating to learning in the construction industry and the transition from tacit to explicit knowledge. The various phases of the adopted learning model are described for the highway project selected for this research, drawing up conclusions and suggestions for future research for road construction and for the construction industry in general.

Conceptual background

Learning in the construction industry

Nowadays, much attention is given to how organizations learn (Chan *et al.*, 2005) or how learning takes place between projects (Bakker *et al.*, 2011). These investigations are driven by the intention to improve operations in the industry which has often been criticized for its poor performance and learning culture (Hartmann and Dorée, 2013).

Various learning approaches are described in the literature, such as a sender/receiver approach, action learning and social learning. Many of these studies assume that there is a knowledgeable sender that is willing and, maybe even more importantly, able to share that knowledge with a receiver who can absorb that knowledge through an effective communication channel between the sender and the receiver. However, because the operational processes in construction generally are not explicit, it is difficult for the sender (operator) to share such knowledge. Also, the implicit knowledge embedded in the experience and craftsmanship of operators is very often not easy to verbalize.

In our research, we take the view that learning takes place through interaction between people, rather than in the human mind only as social learning theory claims (Easterby-Smith *et al.*, 2000).

Kolb (1984) described experiential learning as a perspective on learning in which experience plays a central role. This differs from the cognitive view that emphasizes acquisition, manipulation and recall of abstract symbols, from the behavioural view that denies any role for consciousness and subjective experience, and from the constructionism view of psychology that views learning as a reconstruction rather than as a transmission of knowledge.

Kolb (1984, p. 38) examined experiential learning from an educational perspective and defined learning as 'the process whereby knowledge is created through the transformation of experience'. This definition emphasizes, first, that learning is best conceived of as a process and not in terms of outcomes, so ideas and thoughts are formed and re-formed through experience; secondly, that learning is grounded in experience whereby knowledge is continuously derived from and tested out in the experience of the learner. Kolb (1984) showed statistically that there are various learning styles through which people learn. For example, some people grasp new information through experiencing the qualities of the world: they rely on their senses and immerse themselves in concrete reality. Others tend to perceive, grasp or take hold of new information through symbolic representations or by abstract conceptualization: thinking about, analysing or systematically planning, rather than using sensation as a guide. Similarly, in transforming or processing experience, some people tend to carefully watch others who are involved in the experience and reflect on what happens. Meanwhile, others choose to jump right in and actively start doing things (Kolb *et al.*, 2001). Kolb identified four statistically prevalent learning styles: diverging, assimilating, converging and accommodating.

Opportunities for operational-level reflection provided by a known communication channel are rare in the construction industry, because the focus is on production, rather than on learning and reflection. As a result, learning as a team is nigh on impossible. Also, operators receive little feedback on their work, or on the work and results of others. Although reflective practice models might be seen as necessary in the construction industry, in practice they are often lacking (Orange *et al.*, 2005). For example, most roller operators report that they are not informed about the final density of the completed layer, before, during or after site operations, despite its importance for the final quality of the asphalt layer. This illustrates a significant shortcoming in terms of quality control and shows the absence of closing the feedback loop (Montgomery, 2005). As such, the outcome negatively affects any learning that might have occurred otherwise.

Several researchers have confirmed the importance of reflection and they stress that reflection is important in facilitating and contributing to learning (Schon, 1983; Boud and Walker, 1998; Harrison *et al.*, 2003). In terms of reflective practice models, the concepts of single and double loop learning are also relevant (Argyris and Schön, 1978). Single loop learning occurs when a practitioner continues to rely on current strategies, techniques or policies, even after an error has occurred and a correction has been made. Double loop learning involves the modification of objectives and strategies, so that when a similar situation arises a new context is considered. Again, if the operational strategies and key parameters are not explicit, it becomes harder to adopt double loop learning and to adjust strategies to a new practical setting.

The key to the effectiveness of various learning practices, such as project-to-project and organizational learning, in construction is the component that occurs at the operational and team level. However, current operational-level learning practices are based mostly on the hands-on experience and craftsmanship of operators. Ideally, operational parameters, such as the number of roller passes, should be determined by asphalt technologists and mix designers so that field engineers can give clear guidance to the operators. However, standardized procedures to determine the number of roller passes and temperature windows for compaction are lacking, and instructions in textbooks are vague or even absent. Sometimes the number of roller passes is determined from various test sections and onsite trial and error, but this is both ineffective and uncertain as it is unknown whether the previously gained experience is relevant to a different practical setting. Therefore, decisions regarding onsite operational activities are still mainly taken by the operators rather than field engineers offering clear guidance based on information from management or technologists. So, in practice, to improve process quality, operators have to draw on their inherent skills and craftsmanship and use their experience to actively and informally experiment with how various new strategies might influence quality parameters (Figure 1). Using this approach, operators may, based on their experience from previous construction projects, individually and implicitly learn and improve quality. However, this process is based on limited observations and data, and with many changing variables, thus resulting in lengthy learning cycles.

These informal and implicit characteristics of the construction industry make learning and improving difficult. To improve process and quality control, a change is needed from individual implicit learning to an explicit and method-based learning approach. By *method-based* learning, we mean structured and systematic learning based on explicit data.

The experiential learning cycle of Kolb (1984) was adopted in an attempt to move from individual implicit learning towards explicit method-based learning. According to Kolb (1984), experiential learning centres on the transformation of information into knowledge, an event that takes place after a situation has occurred. It entails a practitioner reflecting on that experience, then gaining a general understanding of the concepts encountered during that experience and, afterwards, testing these general understandings in a new situation. Several other authors have also argued that learning takes place in this sequence (Brock and Cameron, 1999; Daft, 2000).

The experiential learning model is well known and has been applied frequently in management education (Vince, 1998). However, it has not very often been applied explicitly in construction. A notable exception is Lowe and Skitmore (1994), who did apply it to cost estimating in construction in order to understand what types of experience are vital for cost estimating and how experience can be utilized. They found that the

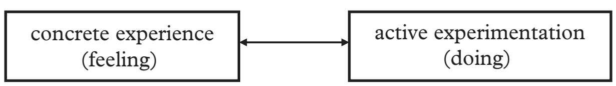

Figure 1 Current individual implicit learning in the construction industry

utilization of concrete experience in cost estimating increased while the use of reflective observation decreased. Based on experiential learning theory, they proposed the introduction of feedback and self-monitoring systems as a mechanism to improve the accuracy of pre-tender estimates.

In terms of Kolb's learning model, current learning processes in the asphalt industry mainly concentrate on the 'concrete experience' and 'active experimentation' parts of the experiential learning cycle. The 'reflective observation' and 'abstract conceptualization' aspects are neglected mostly because the operational strategies and key parameters are not explicit and are not systematically monitored and mapped. Therefore, in our research, we have added 'monitoring the process (explicating)' to Kolb's experiential learning cycle (Figure 2). Further, a comparison can be made between the concrete experience (feeling) of the operators and the monitored process (data). In addition, 'reflective observation' and 'abstract conceptualization' should be added to the enacted learning cycle in order to improve quality and process control and to develop additional learning and reflective competencies within construction teams. Feedback sessions were conducted with operators in order to introduce these competencies and to open up a communication channel between the operators and the field engineers. In this way, learning can take place with the field engineer learning to give improved guidance to operators and with the operators learning how to improve the actual operations, together improving road quality. We enabled various learning styles during the feedback sessions with operators, who mainly learn through experience, becoming involved with university graduates trained to critically reflect and who are able to transform the operators' experiences into abstract concepts and make plans for experimentation.

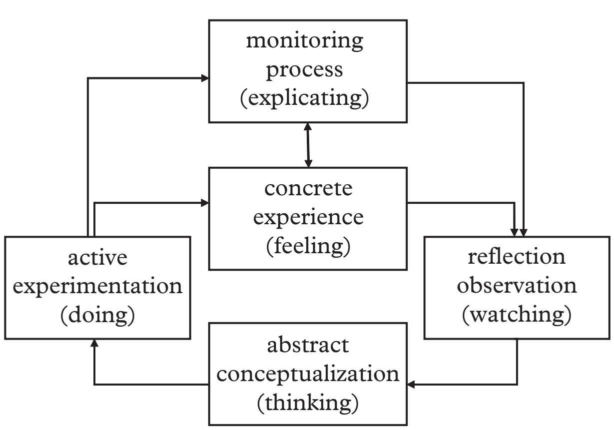

Figure 2 Monitoring the process (explicating) added in the experiential learning cycle after Kolb (1984)

From tacit to explicit knowledge

Given that current operational strategies rely heavily on the onsite skills and experiences of operators, who have implicitly learnt from their experience in previous projects, it is important that, in the quest towards method-based learning, the operators' implicit and tacit knowledge is made explicit.

The concept of tacit knowledge is used widely in the construction management domain (Gherardi and Nicolini, 2000; Bresnen *et al.*, 2005; Ewenstein and Whyte, 2007; Styhre, 2009). Although there is discussion on how the concept should be defined (Styhre, 2009), there is consensus on the importance of this type of knowledge. Some researchers claim that tacit knowledge is, by definition, what cannot be turned into explicit knowledge (Gourlay, 2006). However, in line with Nonaka and Takeuchi (1995), we believe that a transition from tacit knowledge to explicit knowledge is essential in the cycle of knowledge creation. Nonaka and Takeuchi (1995) developed a knowledge management model that focuses on knowledge spirals in the transformation of tacit knowledge into explicit knowledge, and used this to explain why Japanese companies became world leaders in the automotive and electronics industries. In this model, knowledge follows a cycle in which implicit knowledge is 'extracted' to become explicit knowledge, and this explicit knowledge is 're-internalized' into implicit knowledge as the basis for innovation and learning.

The focus in our research is on the challenge to discover an operator's tacit knowledge and convert this into information and visualizations that can be communicated within the asphalt team and within contracting organizations.

New technologies may encourage a more explicit and method-based approach. However, many technologies fail to be commercially adopted due to an insufficient understanding of the current operational strategies and as a result, there is a lack of evidence of added value (El-Halim and Haas, 2004). This evidence is often lacking because the operational strategies are not explicit. The various causalities involved result in a vicious circle of both 'no adoption of technologies' and 'no understanding of current operational strategies'.

Various studies using new technologies have been initiated to map the asphalt construction process. Several experiments to map parts of the process have been conducted in recent years: Krishnamurthy *et al.* (1998) developed an automated paving system for asphalt compaction operations; Gowda *et al.*, 1998 described and modelled a holistic enhancement of the production analysis of paving operations; Peyret *et al.* (2000) used a high-precision real-time field application of the global positioning system (GPS) in positioning asphalt machinery; Navon and Shpatnitsky, 2005 developed a model for automated monitoring of road construction; Commuri *et al.*, (2011) developed a neural network-based intelligent compaction analyser for estimating compaction quality; and Beainy *et al.* (2012) developed a quality assurance tool using an intelligent asphalt compaction analyser. Although some experiments were developed into industrial applications, few have become accepted widely by the industry for application on asphalt construction sites. For example, some equipment manufacturers now provide GPS as an option for clients but, as yet, GPS does not play a part in operational strategies and working practice in asphalt processes. While new features and functions have been added to the equipment, such as temperature and density measurements, most operators acknowledge that still they hardly make use of this available technology (Miller, 2010).

Previous interviews indicated that operators are uncomfortable with new technologies (Huerne *et al.*, 2007). The adoption of technology may also be hindered by the scepticism and reluctance of the operators who feel that their workmanship is being devalued or that management could use the technology to track their movements and possibly use it punitively. The conclusion to draw is that, in asphalt construction, new technologies must be harmonized and better aligned with the actual needs of the operators if they are to be adopted and fully integrated into operational strategies and methods.

To change implicit knowledge about onsite operational activities and key parameters into explicit knowledge and also to break down barriers to technology adoption, we introduced various technologies into the construction process.

Method

Aims

Two issues are addressed in this research. First, that onsite asphalt construction processes are low-tech with an apparent reluctance on the part of operators to adopt new technologies. These processes, in the main, are not explicit and the onsite knowledge of operators is mostly implicit. Secondly, that market conditions are currently encouraging contractors to enhance process improvement and learning. This is difficult given the current experience-based learning practices based on limited data and projects.

The aims of our research are: (1) to adopt the method-based learning approach of Kolb (1984) and to include 'reflective practice' and 'abstract conceptualization' in current learning practices by conducting feedback sessions with operators where they can reflect on their work and their collaboration with others; and (2) to enable operators to learn explicitly, using a monitored and explicated process (based on data), rather than the current implicit experience and craftsmanship-based approach.

The goal of this paper is to demonstrate the adopted method-based learning framework in actual use in a road construction project. During the construction of a Dutch highway, the learning phases were incorporated into current practices and the full experiential learning cycle was observed. Two nights of asphalting were monitored and observed, separated by a one-week gap during which a feedback session was held.

Methodology

Various studies show that practitioners often struggle or fail to adopt research findings (Dopson *et al.*, 2002; Rynes *et al.*, 2001; Van de Ven, 2007). The gap between scientific findings and practical application is often very real. Stokes (1997) suggests that the classic distinction between 'basic' research, intended to develop general knowledge and understanding performed without practical ends, and 'applied' research, performed in the service of some immediate end, is both inaccurate and counter-productive. Stokes, therefore, proposed a 'user-inspired' research domain undertaken as a quest for basic understanding (rigour) but with consideration given to use (relevance). This study is conducted within this research domain, where method-based learning theory is developed and further tested, alongside considering the implementation of enhanced practical learning competencies. Today, Van de Ven's engaged scholarship seems the most relevant concept to apply in this research domain. Engaged scholarship is a participative form of research for obtaining the advice and perspectives of key stakeholders, in this case practitioners and researchers. It is argued that an engaged research approach produces knowledge that is more penetrating and insightful than when practitioners and researchers work on the problems alone (Van de Ven, 2007).

The philosophical lens used for the research presented in this paper is pragmatism (going back to Peirce, 1995), with various important concepts of this philosophy influencing our research. First, we believe that meaningful new theories are built upon the existing experimental knowledge of practitioners. So, if we want to improve practice, experimental and tacit knowledge provides a rich foundation to on which to build but this needs to be explicated first. Further, the motives of practitioners along with their experiences, sensations and emotions are vital and have to be considered. All this knowledge is intrinsically embedded in practice and, therefore, theory and practice are inseparably interrelated (Hartmann *et al.*, 2009). Thus, experience and practical knowledge will be extracted by observing day-to-day practice.

To validate whether a theory that is built on the practitioners' concepts is a good theory or not is only possible if it is tested in a practical setting. This gets to the heart of pragmatic inquiry: pragmatic researchers believe that a system is only good if it works in practice (Rescher, 2000). New theory should be evaluated and legitimatized according to its success or efficacy when applied and implemented in practice.

The focus in this study is on describing the experiential knowledge of practitioners within a specific setting and avoiding the development of over-generalized theory that will be too abstract for any given local context. Knowledge is developed based on reasonable and plausible beliefs through testing and experimentation in practice. Each of these beliefs may turn out to be false at any time. This is not a quest for perfect knowledge, but rather the aim is to constantly improve knowledge by implementing cyclic feedback loops which repeatedly replace previous knowledge with new knowledge and then assess how well the new systems work in practice. This allows persistent improvement to practice and evaluates how well the improvements work in practice and, at the same time, enables increasingly stable theories to emerge.

An action research strategy, combined with this pragmatic philosophical stance, seems appropriate in aiming to diminish the gap between theory and practice (Van de Ven, 2007; Sexton and Lu, 2009). Also, it will further develop method-based learning theory and implement emerging theory to enhance learning competencies, at both the individual and team levels.

Our action research approach involved the researcher, innovative technologies and asphalt operators in the research process. The designed action research approach alternated progressive steps of (1) asking asphalt operators about the planned process through questionnaire surveys; (2) explicating the actual construction processes using off-the-shelf technologies; and (3) feedback with the operators about the explicated processes.

This approach quantitatively and qualitatively explores the asphalt construction process and identifies opportunities for learning and process improvement. Explicit, quantitative data facilitate practitioners in synthesizing and verbalizing their tacit knowledge and promote learning processes. By utilizing a qualitative approach (i.e. feedback sessions with operators) we aim to understand the asphalt construction process from the subjective perspective of the operators and the team involved.

The complexities in the construction process can only be captured by describing what really happens when operators are doing their job and incorporating the context in which they operate, as well as their frame of reference. The asphalt operators were challenged to make sense (as in Weick, 1995) of their process choices and the results. Weick (1995) used the term 'sensemaking' to refer to how the unknown can be structured to be able to act in it. Sensemaking involves coming up with a plausible understanding, a map, of a shifting world; testing this map with others through data collection, action and conversation; and then refining, or abandoning, the map depending on its credibility. The level of analysis in our study is the operational and team level of the onsite construction processes, i.e. asphalt temperatures during the process and onsite compaction operations.

The next paragraphs discuss the methods used for data collection in more detail.

Methods for data collection

The methods used for data collection in this research were questionnaire surveys, monitoring and observing the construction process, and feedback sessions with operators.

Questionnaire surveys were used to explicate the planned process of operators and certain technologies (GPS, laser, infrared) were used to explicate the actual construction process (concrete experience). Next, a feedback session was organized with the asphalt team. In this session, the intentions and reasoning of the operators regarding the process 'as constructed' were made explicit (reflective observation). Based on the 'as constructed' process and the feedback, possible learning aspects and improvements were addressed (abstract conceptualization). During the second asphalting night, any changes in strategies, quality and process awareness and learning effects were experimented with and monitored (active experimentation). These data collection methods and their outputs are summarized in Table 1.

Questionnaire survey

Before the construction task started, a questionnaire survey was conducted with operators on how they planned to conduct their tasks. The questionnaires aimed to make the planned process explicit regarding certain parameters that could be measured during actual construction. The researcher explained the context of the questions to the operators and the operators individually completed the questionnaires.

Table 1 Data collection phases, methods and output

Data collection phase	Data collection method	Output
Explicating the planned process (1)	Questionnaires to operators	Planned and predicted process (1)
Monitoring the process 'as constructed' (1)	D-GPS, laser linescanner, infrared cameras, thermocouples, density gauge, weather station	Process 'as constructed' (1)
Reflective observation	Feedback session recordings	Reflection by operators on the planned process and process 'as constructed'
Abstract conceptualization	Feedback session recordings	List with changes and improvements for future projects
Explicating the planned process (2)	Questionnaires to operators	Planned and predicted process (2)
Monitoring the process 'as constructed' (2)	D-GPS, laser linescanner, infrared cameras, thermocouples, density gauge, weather station	Process 'as constructed' (2)

Note: *The numbers indicate the construction night (night 1 and night 2).

Two questionnaire surveys were conducted: one for all the operators of the asphalt team, and one about compacting operations specifically for the roller operators. The purpose of these questionnaires was to explicate the operators' planned processes. At first, it was difficult for the operators to answer these kinds of questions because usually they do not think explicitly about these parameters. Normally, they instinctively manage them based on their experience and skills. Nevertheless, the operators tried to verbalize their thoughts.

The questions addressed to all the operators were about: (1) the cooling process of the asphalt mixture; (2) the cooling process during paver stops; and (3) general aspects, such as the optimal paver speed, the expected difference between the surface and in-asphalt temperature given a specific asphalt mixture, layer thickness and weather conditions. The questions directed at the roller operators alone were about: (1) their own planned process; and (2) the process of their colleagues. The level of analysis of these questions covered the number of roller passes and the temperature window they planned to compact in. The questions posed are shown in Appendices 1 and 2.

Monitoring and observing the construction process

The actual working methods and operational strategies were monitored and explicated 'as constructed' (concrete experiences). We used the previously developed 'Process Quality improvement' (PQi) measurement framework (Miller, 2010) to map the actual working methods and make the construction process explicit. In this framework, the operational activities are made explicit using several technologies, such as (differential GPS) D-GPS to record machinery movements, and a laser linescanner, infrared cameras and thermocouples to record asphalt temperatures during the construction process. Both of these are important parameters in determining asphalt quality. In some locations, the changes in density after each roller pass and the cooling process of the asphalt mixture were measured. Also, data were collected about the weather and all the essential actions undertaken during the process are recorded in a logbook to aid better understanding and to place things in a proper context. The aim of the PQi-framework is to improve the 'process quality' by closely monitoring asphalt construction works and making operational behaviour explicit.

This framework had already gone through various implementation phases (Miller, 2010). First, the technologies were introduced and tested. Having identified the useful technologies, a structured framework to collect systematically the same set of variables in various projects was developed. Finally, this framework was scaled-up (broad implementation) to 11 contractors in the Netherlands so that we could start to generalize about the implementation of the framework. More information about the technologies used and the systematic way in which data were collected, analysed and mapped have been described in Miller (2010). The preliminary results were presented at the annual conference of the Association of Researchers in Construction Management (ARCOM) in 2008 (Miller *et al.*, 2008).

Feedback session

With measurements made and the asphalt construction process made explicit, we then used feedback sessions to help understanding of the team's views of the key process parameters monitored, i.e. the asphalt temperatures and compaction variability, as well as to develop further insights into the construction processes.

The monitored data were visualized in a structured format using Matlab, AsphaltOpen and MS Excel so that the information would be understandable to the asphalt team (Miller *et al*., 2011). These explicit data, converted into a series of visualizations and animations, were combined with the operators' viewpoints to explore the perspective of those closest to the process (the construction teams). During these sessions, the researchers acted as facilitators who only asked questions, generated discussions and challenged individuals to think differently. Thus, a participative dialogue inquiry was undertaken, rather than a sender/receiver approach where the researchers would have expounded on what was found and the asphalt team listened. For many operators, the feedback session was a first opportunity to study and reflect on the results of their own operational practices (in the form of the animations, temperature and compaction plots) based on an explicitly monitored process and discuss these practices as a team.

All the members of the construction team attended the feedback session: the site supervisor, paver operators, screed operators, roller operators, and general workers. Also attending were the laboratory technicians responsible for density measurements, the field engineers, the responsible project managers, and the regional asphalt managers/directors.

The feedback session was recorded with a voice-recorder and transcribed afterwards. The results were coded into various themes as they related to operational behaviour and to the key construction parameters presented at the feedback session.

Learning cycle results: Dutch highway project

Project description

The object in the case study was the construction of the A15 highway as part of improving the connection between the Port of Rotterdam and the rest of the Netherlands. A consortium of three contractors was responsible not only for the construction but also for maintenance until 2035. Therefore, controlling the process and the quality was essential to prevent problems (shortcomings) during the maintenance period. Construction work took place overnight (between 11 pm and 6 am) and there was a lot of pressure on the project. In response, the contractor had increased the production from 2000 up to 3000 tonnes per night. The carriageway was approximately 15 metres wide and about 1000 metres were laid each night. The 70 mm thick asphalt layer was constructed using an AC 16 bind (40/60 pen). During both the nights surveyed, the same asphalt team was involved in constructing the asphalt layers. The construction took place under relatively mild circumstances: 8-10 C and 3-7 km/hr wind speed. The asphalt plant was approximately 25 km from the construction site but there were enough trucks for logistics not to be a problem.

The full experiential learning cycle, for both researchers and operators, is discussed below based on the explicated process.

Concrete experience

The laying temperature of the asphalt mixture, the cooling process and temperature variability are key quality parameters (Miller, 2010). Despite this, operators receive virtually no information during the construction process about these temperatures and their variability. So, in general, operators estimate the temperatures based on their experience and relate this to the weather, the specific mixture and layer thickness and then decide on their rolling process.

Before the measurement process, questionnaires were distributed among seven operators seeking their estimates of the temperatures. Then, during construction, four sets of measurements were made using thermocouples and infrared cameras to monitor the cooling process 'as constructed'. The operators' predictions and the measurements are shown in Table 2.

Table 2 Predicted and actual asphalt temperatures and cooling rates of measurement night 1

Parameter	Predicted range (7 operators)	As constructed (4 measurements)
Cooling to 120 °C (min.)	10–30	8–17
Cooling to 90 °C (min.)	24–60	22–38
Cooling to 60 °C (min.)	30–90	57–80
Difference surface and in-asphalt temperature °(C)	17–25	8–15
Temperature drop truck change °(C)	5–8	5–10
Temperature drop during 3 min. paver stop °(C)	10–12	10–20
Temperature drop during 7 min. paver stop °(C)	14–20	25–35
Temperature drop during 15 min. paver stop °(C)	20–30	35–50

Interestingly, the measured cooling times to 120 ˚C, 90 ˚C and 60 ˚C all correspond reasonably well with the operators' predictions. However, the range of predictions was certainly wide. For example, one operator predicted that cooling to 60 C would take 30 minutes, while another predicted 90 minutes. Such differences certainly influence decisions regarding the operational rolling strategy.

The difference between the surface and the in-asphalt temperatures was slightly overestimated by the operators. This is important because the operators' decisions are mainly influenced by what they believe the in-asphalt temperature to be, while during the construction process, it is mainly the surface temperature that is measured. Temperature drops during truck changes and paver stops were accurately predicted for short stops, but underestimated for longer (7 and 15 minutes) stops.

In addition, the questionnaires sought information on the planned operational strategies regarding the number of roller passes and the temperature windows in which one could compact before the measurement phase. During the construction process, the actual number of roller passes and the prevailing temperatures when compacting were determined using D-GPS, infrared cameras and thermocouples.

The planned operational strategies and the actual operational strategies are shown in Table 3. The data show that operators were able to predict the number of roller passes to be made by their own roller quite accurately, but predicting the number of roller passes their colleagues would make appeared difficult. For example, operator 3 expected to make five or six roller passes himself, and during the measurement night he made between four and seven passes on the various parts of the new surface. However, the same operator predicted that the other operators would complete 10 roller passes but, in practice, operator 1 made four to six roller passes and operator 2 made seven to nine passes. The data also show that the temperature windows were somewhat difficult to predict, especially for the second roller.

The analysis shows that the estimates, based on 'concrete experience', made by the operators correspond quite well with the process 'as constructed' in terms of their own operations (albeit that the estimates covered wide ranges). However, it was clearly difficult for operators to estimate what their colleagues were doing during the construction process. This makes it difficult to anticipate during the process and, because asphalting is a collaborative process, this will negatively influence controls employed to manage the process.

Reflective observation

A key step in explicit method-based learning is providing feedback to the operators, here to the asphalt team and for them to learn from this feedback (Kolb, 1984; Miller, 2010). The measured data were provided to the asphalt team during the feedback session, so that they could reflect on their own operations. These sessions enabled teams to determine improvements in the asphalting process, both in their individual tasks and in their collaborative work. Here, the measured quantitative data are used to make the operational behaviour explicit. The qualitative data from the feedback sessions tell the story from the operators' viewpoints. The session lasted approximately one hour. The results from measuring the process 'as constructed' were printed out and given to everybody so they could look at the findings themselves. This included the asphalt team, project managers, people involved in the preparation and the technologists. The observations and reflections are summarized in Table 4.

Abstract conceptualization

The observations and reflections were distilled into 'abstract concepts' that helped produce plans for action that could be 'actively experimented' with during the second night of study. Plans at the operational, project, organizational and research levels were distinguished.

Table 3 Expected and actual number of roller passes and temperature windows for compaction of measurement night 1

Parameter	Prediction operator 1	Prediction operator 2	Prediction operator 3	As constructed (4 measurements)
Number of roller passes Roller 1	2–3	2–3	10	4–6
Number of roller passes Roller 2	4	6–8	10	7–9
Number of roller passes Roller 3	3–4	2–3	5–6	4–7
Temperature window Roller 1	150–120 ˚C	140–120 ˚C	145–90 ˚C	150–125 ˚C
Temperature window Roller 2	130–90 ˚C	110–80 ˚C	90–70 ˚C	130–95 ˚C
Temperature window Roller 3	90–60 ˚C	70–50 ˚C	70–50 ˚C	90–60 ˚C

Table 4 Observations and reflections of the operators of the asphalt team

Topic	Observation	Reflection asphalt team
Initial surface temperature	In general, the surface temperature behind the paver was 160 °C. During a truck change it cools by 5–10 °C. If the paver has to stop, the temperature decreases quickly (by up to 40 °C).	It is well known that the temperature decreases by 5–10 °C during truck changes. The rapid temperature drop by 40 °C during paver stops was more than expected and underestimated. If they are aware of lower temperatures, they will start compacting more quickly.
Cooling	The predictions of the operators agreed well with the measured cooling curves. Nevertheless, the range of predictions is rather large. The variability in the cooling curves is rather large, making it difficult to predict the temperature during the process.	The differences in predictions are mainly caused by the variations in experience. Predictions by inexperienced operators are the least accurate. The operators knew this and stressed that this makes their work difficult. Real-time temperature information would certainly help the operators to improve the quality of their operations.
Compaction strategy	Operators can fairly accurately predict the passes they will have to make but are less good at predicting the passes their colleagues will make.	It is difficult enough to do their own compaction consistently with so many changing variables, such as weather, layer thickness and temperature. Real-time info about their colleagues' work and results could improve quality.
	The influence of the third roller on the final density is unclear. There is hardly any change in density despite the large number of roller passes.	Normally only two rollers are used in such projects rather than three. However, here, the project consortium insisted that three rollers were used to compact the asphalt.
	Rollers 1 and 2 were used consistently, but the spread in the number of passes by Roller 3 is rather large.	The reason for the variability with the third roller is that the operator cannot see where the roller has been. The first and second roller operators can see this through prints of the roll in the asphalt.
Cores and quality	The correlation between the onsite nuclear measured density and the core density determined in the laboratory is good (within 1%).	The correlation is rather good, but a technician is not always present at the site and sometimes at the wrong times, such as the end of the night. This can be improved.
Paver speed	The speed of the paver is higher than in many other projects and above the expected speed.	The increased speed of the paver is not the operators' choice, but stipulated by the consortium due to production pressures.
	Interesting reasoning is that, if the paver increases speed, the rollers have to work faster, but should be further away from the paver to operate in the same temperature window.	The asphalt team found this reasoning difficult to understand. Training that address various scenarios could possibly help to improve this understanding. This training may be done in an 'asphalt simulator' in a 3D software environment.
Monitoring	The measurements provided the asphalt team with more information and formed a good basis for reflecting on the process.	The data often confirmed the team's gut feelings. To understand the process better, more measurements should be conducted with various mixtures and different conditions.

Operational level (asphalt team)

- The asphalt temperature is important throughout the whole construction process. Therefore, asphalt temperature information should be available in real time and communicated between the technologists and the operators.
- Currently, asphalt technologists only systematically measure the density during compaction, plus ad hoc temperatures. These technologists should also systematically measure the temperature and the number of roller passes and communicate these with the operators.

- The three-drum roller (the third roller in the process) is used to create an even surface. This has little influence on the density of the asphalt mixture but, if used at too low an asphalt temperature, could create micro-cracks. Although, it is well known that the purpose of this finishing roller is to make the surface even rather than increase the density, it remains unclear how these additional roller passes at lower temperatures influence the final mechanical properties other than the density. This requires additional research under better controlled circumstances. Nevertheless, the asphalt team proposed making fewer roller passes with the three-drum roller during the next measurement session.

Project management level (work preparation and coordination)

- The managers realize that asphalt temperature is important for the operators. They also acknowledge that real-time information is essential to improve the process. The managers now consider that buying infrared pistols for every roller operator (a low-cost option) would be worthwhile and they will further try to convince the company to buy high-end equipment to continuously monitor real-time temperatures.
- The managers also recognize that it is difficult for the three-drum roller operator to see where he has been. They acknowledge that GPS-based equipment could help to resolve this problem. However, they argued that this would be a significant investment and required more support from within the company and the consortium. The data collected could help convince people about the need for new equipment.

Organizational level (company)

- At the organizational level, it was acknowledged that production pressures could lead to communication and quality issues, especially if there is little feedback. For example, while a higher speed may be possible, the operators lack experience of working at higher speeds. Training and scenario-playing could possibly improve this understanding and experience.
- There is hardly any feedback between the laboratory and the technologists, despite both conducting density measurements. Feedback cycles should be included in quality control to compare the onsite nuclear-measured density and the lab-determined density so as to improve instructions and guidance for roller operators.

Research level (research and development)

- The data collected should all be geo-referenced. Using geo-referenced data creates a historic record of how the road was constructed, how it behaves during usage, and where early damage might originate.
- Using the PQi framework, density measurements are taken after every roller pass. However, adopting this strategy makes it impossible to understand what happens with the asphalt between operations. Therefore, during the next testing night, measurements should also be taken between the roller passes.
- Providing the individual operators with the graphical data on paper in the feedback sessions worked well. Previous feedback sessions had been held using a beamer but operators seem to be able to focus better when they have all the graphs and information in front of them.

The action plans for the project management and organizational levels have more of a mid- to long-term perspective, whereas most of the operational-level plans could quickly be made operational. During the second night of measurement, some of the short-term action plans were experimented with as discussed in the following section.

Active experimentation

During the second measurement night, questionnaires were again used to establish how the operators planned to carry out their work. The construction process was again monitored and observed. These plans were compared to the predictions made for the first night. Two plans drawn up during the abstract conceptualization phase were experimented with during the second night, namely:

(1) fewer passes with the three-drum roller combined with density measurements between roller passes; and
(2) feedback and greater communication during the process to see if this led to improved predictions and understanding of the process.

Figures 3 and 4 show the monitored roller passes and density progression for the different type of rollers on night 1 and night 2 respectively. These figures show that the three-drum roller made fewer roller passes during the second measurement night (two compared with seven on the first night), an aspect discussed during the feedback session. Figure 4 also shows the density measurements made between the roller passes (the circular markers).

These measurements show that, even between the roller passes, the asphalt mixture is still settling and expanding. As such, measuring between the roller passes does provide valuable knowledge about the asphalt behaviour during compaction. This observation is in line with the findings of Huerne (2004) and the Asphalt Institute (2007) who also reported the plastic-elastic behaviour of asphalt during compaction.

We do not know which of the compaction strategies is better since no mechanical properties were determined as this was not the focus of the research. However, this example shows that, based on the explicated process, it is possible for operators to change their behaviour and to experiment actively. Based on the operators' experimentation, the new process can then be either adopted or rejected.

The second element of the active experimentation was to test whether feedback and greater communication during the process would lead to improved predictions and understanding about the process.

More intensive communication was observed during the second measurement night (mainly as a result of its value being recognized during the organized feedback session, rather than through instructions to operators). Roller operators communicated about temperatures and the number of roller passes undertaken. The technologist also communicated in more detail. In addition to the traditional reporting of density, the number of roller passes and the temperatures were also communicated.

The findings related to the predictions of the operators and the actual constructed processes on the second night are shown in Tables 5 and 6. Based on these questionnaires and measurements, we conclude that, following the feedback session, the operators had improved their predictions of temperatures, cooling and number of roller passes when compared to the first measurement night. The predictions made by the operators regarding temperature and cooling are now all within the range of those measured during actual construction and also fall within smaller bands. In terms of the number of roller passes and the temperature windows for compaction, most of the predictions corresponded with, or were very close to, the actual construction process.

Reflection and discussion

The pragmatic aim of this research was to instigate a change towards explicit method-based learning in paving practice. To encourage a change towards method-based learning, the learning model of Kolb (1984) was adopted and 'monitoring the process (explicating)' was added as an additional step in this learning cycle. Using various technologies, such as GPS, laser, and infrared, it has become possible to monitor key parameters and operations in the construction process

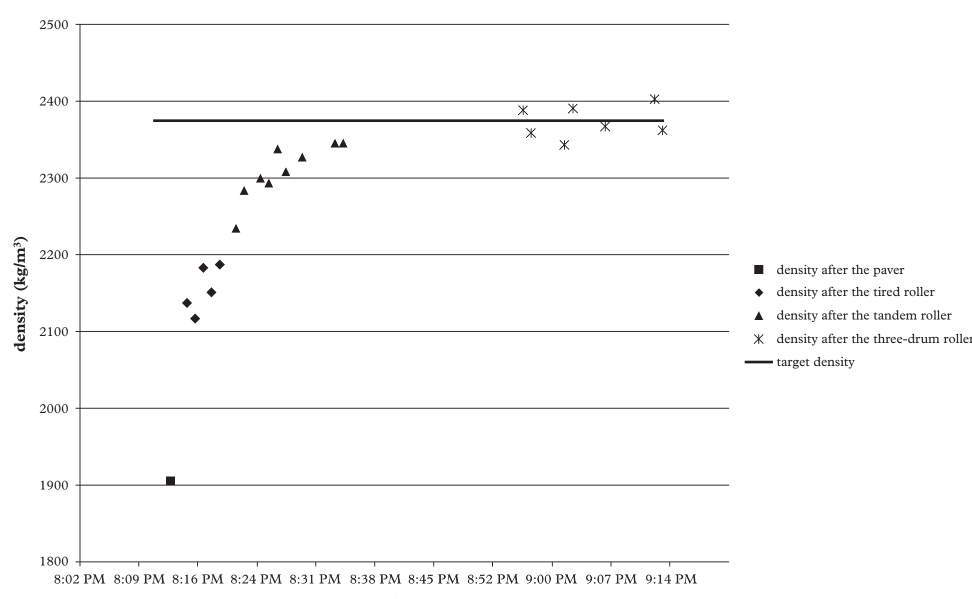

Figure 3 Density after each roller pass of the first measurement night

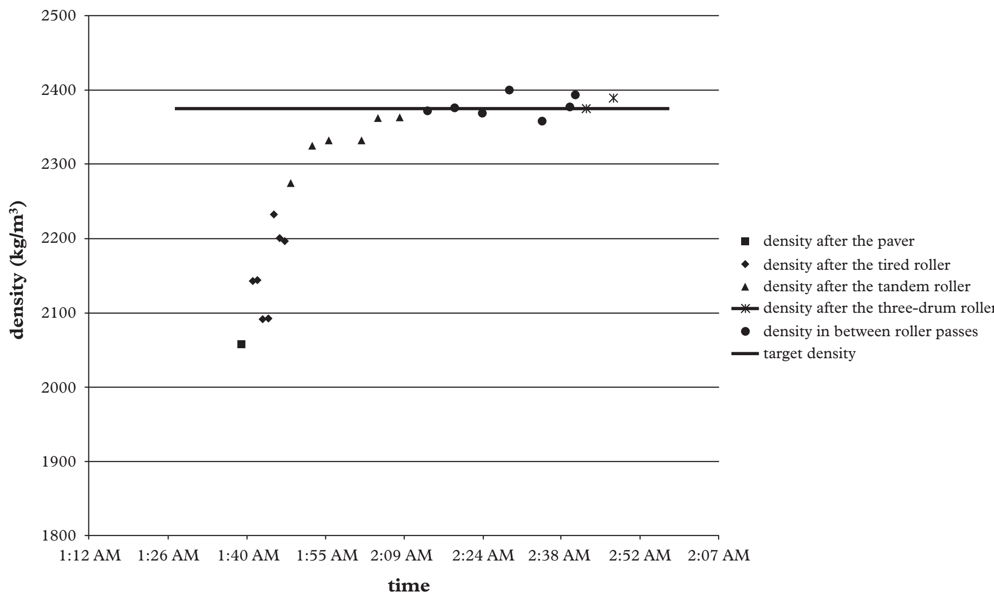

Figure 4 Density after each roller pass of the second measurement night

and explicitly map them. This enables a change from implicit to explicit learning and hence the possibility of breaking down the barriers to technology adoption.

By explicating the 'as constructed' process, it became possible to have meaningful discussions with the team's operators in a feedback session, and this helped unravel the intentions and reasoning of the chosen strategies. Transparency in the process and operational choices were created using these technologies and well-designed visuals helped individual operators in sensemaking about the construction processes and their interdependencies. Some roller operators seem to be alone on the 'island of their machine' during the construction process and focused solely on their individual task. However, asphalt paving is a collaborative task (Asphalt Institute, 2007), and therefore, while individual learning is relevant, learning as a team is as vital. For example, a field engineer may be able to offer improved guidance to operators and the operators can improve the quality of their operations. Both an explicated process and an opportunity to discuss the process during feedback sessions are helpful in this team-learning process. Further research may develop other and better methods for improved collective and collaborative learning.

The introduction of our approach, including the use of new technologies, helped to break through the vicious 'no understanding, no adoption' circle, in which the failure to adopt technologies can be attributed to insufficient understanding of operational strategies, and there is insufficient understanding of operational strategies because the technologies are not adopted. The use of these new technologies has become feasible as ICT has become increasingly available and affordable. However, having data gathered in a structured and systematic way and then synthesized with the needs of the practitioners proved very helpful in creating an improved appreciation of the value of the technologies.

In addition to the framework proposed by Miller (2010) to monitor the onsite processes using various

Table 5 Predicted and actual asphalt temperatures and cooling rates of measurement night 2

Parameter	Prediction range (7 operators)	As constructed (4 measuements)
Cooling to 120 °C (min.)	10–20	12–17
Cooling to 90 °C (min.)	20–40	19–29
Cooling to 60 °C (min.)	40–80	47–56
Difference surface and in-asphalt temperature °(C)	10–20	7–15
Temperature drop truck change °(C)	5–10	5–10
Temperature drop during 3 min. paver stop °(C)	10–20	10–20
Temperature drop during 7 min. paver stop °(C)	20–40	20–30
Temperature drop during 15 min. paver stop °(C)	30–60	30–50

Table 6 Expected and actual number of roller passes and temperature windows for compaction of measurement night 2

Parameter	Prediction operator 1	Prediction operator 2	Prediction operator 3	As constructed (4 measurements)
Number of roller passes Roller 1	6–7	3–4	5	4–7
Number of roller passes Roller 2	7–8	5–6	6	6–7
Number of roller passes Roller 3	4	2–3	2–3	2–4
Temperature window Roller 1	150–20 °C	150–30 °C	150–30 °C	150–25 °C
Temperature window Roller 2	130–80 °C	130–90 °C	130–90 °C	135–90 °C
Temperature window Roller 3	70–50 °C	70–50 °C	70–50 °C	70–60 °C

technologies, we introduced questionnaire surveys to determine the process planned by the operators. This helped us in analysing the differences between what they initially planned and what they actually did.

In conclusion, the technologies and the questionnaire surveys were invaluable in enriching the data and opening communication channels to facilitate a transition towards learning based on an explicit construction process. This is a valuable contribution in demonstrating the successful application and use of the learning model of Kolb (1984) in the construction industry.

The demonstration of the action research strategy with alternative steps of technology introduction, explicating operational strategies and undertaking feedback with operators, showed that this strategy is applicable and helpful in the quest for improved learning methods and competencies in practice. Through monitoring the process (explicating) and discussing operational choices with the asphalt team, the tacit knowledge represented in the everyday practice of operators becomes explicit. This research strategy provides an opening for the further development of process tools and a better understanding of the operational strategies. It also demonstrated the importance of combining quantitative process data with qualitative heuristics gleaned from operators. It helped uncover the enormous wealth of tacit knowledge and experience within the operators.

The adopted experiential learning lens applied to the act of learning is not dissimilar from the constructionism view of learning, which could also be explored in further research. The constructivist theories of psychology view learning as the reconstruction rather than the transmission of knowledge (Papert and Harel, 1991). Constructionist learning is motivated by the theory that individual learners construct mental models to understand the world around them, meaning that learning is most effective when people are active in making tangible objects in the real world (learning-by-making). In this learning-by-making view, it would also be relevant to examine how knowledge is assembled through the act of performance and how craftsmanship as described by Sennett (2008) influences performance and learning competencies.

The explicit method-based learning approach adopted may also be applicable to other traditional experience-driven practices in the construction industry. For example, in the sub-surface domain (i.e. laying pipes, cables and sewers), where the process is similarly not explicit, multiple stakeholders influence the process and coordination is becoming increasingly important. Technologies to explicate the location of cables and sewers could help to improve the coordination and scheduling of projects. Further research is also planned to study behavioural changes after a second or further learning cycle. The learning styles defined by Kolb (2005) for various types of people could be useful in studying these learning cycles. Knowing and understanding the different learning styles may shorten the learning curve.

In addition, it has been observed that certain asphalting teams perform better than others under certain circumstances. Further research is planned to understand why certain teams perform better than others. A possible lens to investigate this is the perspective of 'mindful organizing' (Weick *et al.*, 1999; Weick and Sutcliffe, 2007) or 'high-reliability crews' (Mitropoulos *et al.*, 2009). Identifying the rules and work practices of high-performing asphalt crews could help to achieve higher levels of production, quality and safety across the sector. This would be a valuable step towards improved process and quality control.

Finally, if the construction process is explicit, and good and poor operational strategies can be distinguished, then opportunities for training in a virtual construction site arise (Vasenev *et al.*, 2012, 2013). Similar to training tools such as flight simulators, roller simulator serious 'games' could be developed that draw directly on actual monitored projects and the discussions involving operators and teams around the operational strategies.

Conclusions

Various changes are taking place in the construction industry. Integration of maintenance, lifecycle involvement and longer guarantee periods make it increasingly important for contractors to control the construction process and improve quality control. However, current construction processes rely heavily on the skills and onsite experience of operators. This essentially results in individual implicit learning and lengthy learning cycles.

In this research, the experiential learning theory of Kolb (1984) was introduced to usher in a change towards explicit method-based learning. An additional step, monitoring onsite construction processes (explicating), was added to the learning cycle as part of moving from implicit to explicit learning and its merits have been demonstrated in the asphalt construction industry. Onsite processes were monitored with new technologies to build a data-rich understanding of the process. Key processes and factors were explicated using D-GPS, a laser linescanner and infrared cameras. Questionnaire surveys, interviews and feedback sessions were used for sensemaking and learning about the construction processes for both individual operators and teams.

The introduction of Kolb's learning cycle fused with onsite data collection was critical in explicating the tacit knowledge and implicit processes. The adopted learning framework was shown to be relevant, applicable and useful in highway construction. The research demonstrated the value of an engaged research approach, as well as the potential for introducing new sensor and information and communications technologies in current traditional working practices. A rigorous, structured and systematic data collection process was essential in using these technologies and in the engaged research approach. The explicit method-based learning framework led to improved awareness of the quality and value of communications with and within the asphalt team. It responded to the lack of explicit learning and reflection in the construction industry. It is a method that can develop the learning and reflective competencies of both individuals and teams. Finally, the research approach and the method-based learning framework offer opportunities for making experience-driven practices more professional in the construction industry.

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Appendix 1 Questionnaire survey for all the operators and the field engineers (translated from Dutch)

Questions for all the operators and the field engineers	
0	Project Date Asphalt mixture Position Years of experience
1	How long do you expect it will take the in-asphalt temperature to cool down to 120 °C (in minutes)?
2	How long do you expect it will take the in-asphalt temperature to cool down to 90 °C (in minutes)?
3	How long do you expect it will take the in-asphalt temperature to cool down to 60 °C (in minutes)?
4	What is the optimal paving speed according to you (in metres per minute)?
5	What is the average difference between the surface temperature and the in-asphalt temperature during the construction process according to you?
6	How much will the surface temperature drop during a truck change (in °C)?
7	How much will the surface temperature drop during a paver stop of 3 minutes (in °C)?
8	How much will the surface temperature drop during a paver stop of 7 minutes (in °C)?
9	How much will the surface temperature drop during a paver stop of 15 minutes (in °C)?
10	What is the target density and what are the most important points of interest for this specific asphalt mixture?

Appendix 2 Questionnaire survey for the roller operators (translated from Dutch)

Questions for all the roller operators	
0	Project Date Asphalt mixture Which roller operator Years of experience
1	How many roller passes do you expect the different rollers will make (in number): Pneumatic tyre roller (roller 1) Tandem roller (roller 2) Three-drum roller (roller 3)
2	In which temperature windows do you expect these roller passes will be conducted (between … °C and … °C): Pneumatic tyre roller (roller 1) Tandem roller (roller 2) Three-drum roller (roller 3)
3	What density progression do you expect the different rollers will make (in percentage degree of compaction): Pneumatic tyre roller (roller 1) Tandem roller (roller 2) Three-drum roller (roller 3)
4	What is the compaction distance of the different rollers behind the paver (between … meters and … meters): Pneumatic tyre roller (roller 1) Tandem roller (roller 2) Three-drum roller (roller 3)