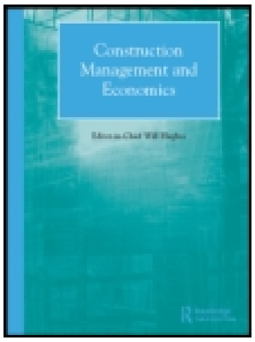

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A study of a plan-do-check-act method used in less industrialized activities: two cases from industrialized housebuilding

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In construction projects, a large number of deviations are usually found during inspections and adjusted in a reactive manner. For projects to become proactive, root causes need to be identified and eliminated as a part of a process of continuous improvement (CI). Plan-do-check-act (PDCA) methods are part of CI and have been used with success within the manufacturing industry for decades. Research studies of PDCA in construction are less common, which could be explained by the past dominance of the project-based nature of construction compared to the process-based nature of manufacture. Industrialized construction, however, has changed this picture somewhat, and it is of interest to find out how well it works for less industrialized activities in construction. A PDCA method was tested in two cases selected from one medium-sized Swedish industrialized housebuilder, which uses a building system based on offsite manufactured modules. Empirical results are based on systematic data gathered through interviews and participant observations. Results from the two cases show that the PDCA method worked even when processes were divided into industrialized parts within a factory and non-industrial parts at the construction site although this might lead to temporary corrective actions rather than permanent process actions.

Keywords: A3 visualization, continuous improvement, industrialized housebuilding, plan-do-check-act cycle.

Introduction

In construction projects, a large number of deviations are usually found during inspections and adjusted in a reactive manner (Chong and Low, 2005). This applies to industrialized housebuilders and is one reason that a process of continuous improvement (CI) is needed. The purpose of CI is the identification, reduction and elimination of sub-optimal processes, i.e. efficiency, with a focus on continuous incremental steps rather than major innovation leaps (Bessant *et al.*, 2001). Industrialized housebuilding has high levels of repetition compared to traditional (*in situ*) construction, which increases the opportunities to control work processes (Tam *et al.*, 2007). Industrialized housebuilding is defined here as a building system in which one actor takes sole responsibility for the entire process from sale to finished building. The benefits and possibilities of using industrialized methods in construction have been reported by several authors, including Pan *et al.* (2007) and Johnsson and Meiling (2009). Benefits include better opportunities for standardized work, improved quality and cost and time reduction. Although several companies have created industrialized work and production processes, these organizations are still by tradition project-based. This represents a gap between the projects and the industrialized process which needs to be reduced to achieve higher effectiveness.

A key characteristic of CI is the capability to handle improvements of processes according to Deming's (1986) plan-do-check-act (PDCA) cycle. Deming's research was based on Shewhart's (1939) research results from the manufacturing industry; Shewhart based his statements of process improvement on a cycle described as hypothesis (plan), experiment (do),

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evaluation (check). This threefold continuous improvement cycle was further developed by Deming (1986) and formalized as PDCA by the Japanese automotive industry in the 1950s (Deming, 1986). The four steps of the PDCA cycle can be described as:

- **Plan**: Study the current situation and develop solutions for improvement.
- **Do**: Take measures on a trial basis.
- **Check**: Investigate the effect of changes.
- **Act**: Start standardizing on a permanent basis.

As for the broader concept of CI, only a few studies in industrial housebuilding using CI can be found. Nahmens and Ikuma (2009) show that a number of actors in the industrialized housing industry have CI programmes. Söderholm (2010) describes how CI improves the design process and Meiling *et al.* (2011) investigate prerequisites for successful CI. With specific reference to PDCA methods, there is a clear need for research that investigates the use of these methods in industrialized housebuilding. Since PDCA originates from the manufacturing industry, it is of interest to find out how well it works for less industrialized activities in construction.

We present a PDCA method used in two cases by a Swedish industrialized housebuilding company. The two cases are different and the PDCA method worked better for the first case than the second, which had a greater share of less industrialized activities. We analyse and discuss the reasons for this difference.

PDCA methods

The four stages of PDCA can be broken down into more specific routines, as shown in Figure 1.

An important characteristic of PDCA is the emphasis on the planning stage, for which several quality tools have been developed, such as the Ishikawa diagram, Pareto chart and scatter diagram (Bergman and Klefsjö, 2003). To develop improvement actions, the underlying causes of problems can be identified by conducting root cause analysis. Examples of methods that can be used to identify root causes are cause-and-effect analysis, the 'five whys' and fault tree analysis (Wilson *et al.*, 1993; Pyzdek, 2003). Furthermore, Sobek and Smalley (2008) emphasize the importance of communication and present the benefits of using the 'A3 format' together with the PDCA method. A3 promotes the logical thinking process, presenting results in a consistent manner and is visual and consistent across organizational units. A3 is a standard paper size measuring 297 × 420 mm^2 according to the international standard ISO 216 A series. A literature review of several existing PDCA methods is presented in Appendix A and outlined in Figure 2. The length of each row is dependent on the number of sub-steps for the P, D, C and A parts respectively.

A literature review reveals that PDCA methods generally show similarities and particularly emphasize the planning stage. In addition, they all involve capture of experience data, followed by transfer and evolution into standardized solutions. The methods link contextual information, such as where, why, what and when problems occur (Johnsson and Meiling, 2009) to analysis tools (such as statistical, root cause and risk analysis) and promote feedback to both internal and external customers. Of the presented methods (Appendix A), all but Juran (1992) incorporate each step of PDCA. Juran (1992) does not include standardization in the improvement cycle. Sobek and Smalley (2008) have an extensive 'plan' stage and state that there should be no or very few corrections left after the 'do' stage. In contrast, 'do' in Deming (1986) is more of a test. Spear and Bowen (1999) found that learning is increased if PDCA is conducted among people as close to the root cause as possible. It may be concluded that there is quite a clear similarity among the methods presented in Appendix A.

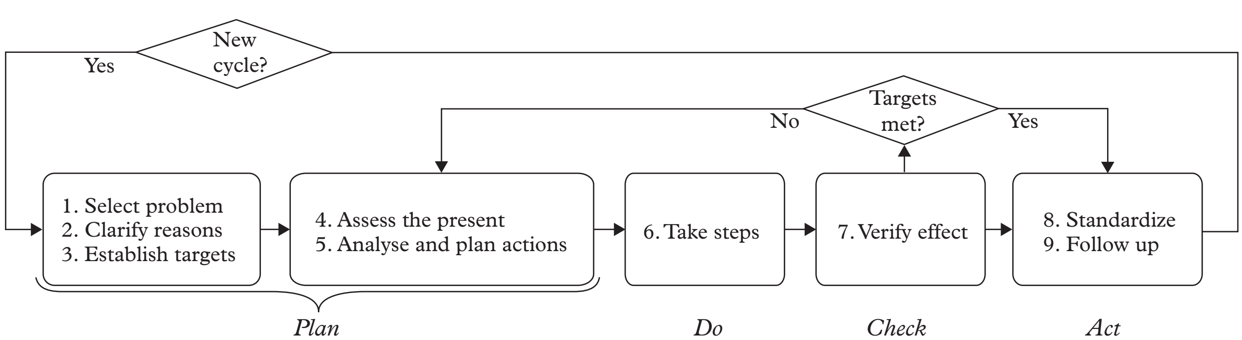

Figure 1 A PDCA cycle with sub-activities (from Neave and Deming, 1990)

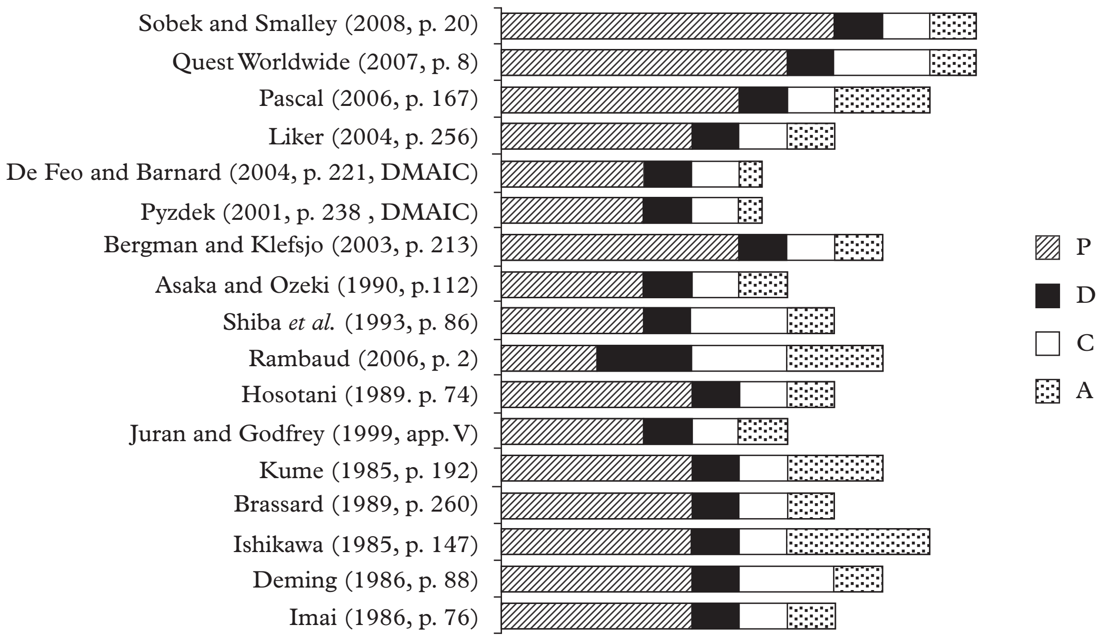

Figure 2 Summary of some existing PDCA methods

PDCA in construction

Tiwari and Sarathy (2012) used a PDCA cycle in a hospital expansion project and found that the method was resource-intensive. The cycle was used to create a pull plan that helped achieve the end goal of submitting design drawings to the permitting agency on time. Tiwari and Sarathy, however, note that there is room for improvement of the PDCA cycle.

Parrish *et al.* (2009) used a PDCA cycle in the process of developing a hospital. They used A3s to document the plan steps and help with conversations about how to 'do, check and act' to continuously improve tasks needed for the project goal. Neither study focused on PDCA in industrialized housebuilding, so there is still scope for such investigations. Of particular interest is to find out how well PDCA works for non-industrialized phases such as in situ assembly.

Research approach

A qualitative approach was chosen in this study as it is argued to be suitable for studying a phenomenon in its natural context, targeting rich descriptions of the phenomenon (Miles and Huberman, 1994). The approach enables multiple data collection methods and allows general conclusions to be drawn from a limited number of cases (Gummesson, 2000). However, it is also argued that qualitative methods yield information only on the particular cases studied, and that more general conclusions drawn from the cases are merely hypotheses (Denzin and Lincoln, 2005).

The present case study was based on two applications of a PDCA method. The case company was chosen for being an established actor in the construction market in Sweden. Since the company manages all six processes shown in Figure 4, an opportunity arose to introduce quality management tools and strategies developed in the manufacturing industry. In addition, this company had adopted over two years an overall improvement strategy of lean production with the overall goal to become a learning organization by means of CI. One of the authors acted as PDCA process leader and was in charge of communicating activities and documentation; the study is thus an example of participatory research. Empirical results are based on data gathered through interviews and participant observations from September 2009 to February 2010. Ten semi-structured interviews were conducted with four group managers and five *in situ* managers. The group manager interviews were conducted while walking around at the construction site. In that way, a group manager could directly show examples of the problem of interest. While each group manager was responsible for one *in situ* assembly, the *in situ* managers had responsibility for several *in situ* assemblies at the same time. The construction site (assembly *in situ*) was the main empirical source and revealed quality effects of upstream decisions. Nine assembly site visits were made to find module

A3 headings:

- Problem description, and goals (1, 4)
- Reasons for choosing the problem: assessing the present, and planned activities (2, 3)
- Concerns (5)
- Results: measures (6)
- Standardization (7)
- Control and adjustments (8, 9)

A3 disposition:

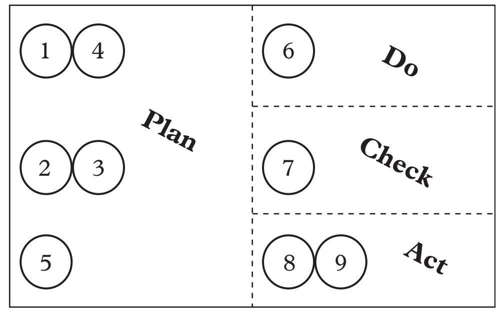

Figure 3 A3 headings and disposition

problems. Nine focus group meetings were conducted with participants from the two case examples.

The study was initiated from a list of problems, compiled from interviews with *in situ* managers. The list consisted of approximately 50 recurring problems within the company. Seven problem groups were compiled by the authors: (1) module size variations; (2) problems with holes and fireproofing; (3) material logistics; (4) window adjustments; (5) door adjustments; (6) module connections; and (7) unspecified quality problems. Photos were taken of all problems and presented at focus group meetings where priorities were set. This resulted in the choice of the two case examples.

Applied PDCA method

The PDCA method used was developed by the case company in dialogue with one of the authors. The method contains nine steps and was recognized by the authors to be in alignment with the overall PDCA structures summarized in Appendix A. The nine-step method is presented in Table 1.

An A3 report method, similar to the one suggested by Sobek and Jimmerson (2004), was developed to communicate results in improvement group meetings and to keep track of activities. The case examples were presented under the headings shown in Figure 3.

Table 1 The PDCA method used in the cases

Plan	1. Select problem	The problem should be described as precisely as possible, answering the questions: What? Which? Where?
	2. Clarify reasons	The cause for choosing the problem should be clearly stated, answering the questions: Why was the problem chosen? Is the problem essential? Is it relevant? The seven quality tools (Ishikawa diagram, check sheet, control chart, histogram, Pareto chart, scatter diagram and flowchart) and pictures could be used.
	3. Assess the present	The present situation should be studied and described from visits to the workplace. Answering the question: Under what circumstances did the problem occur? Facts should be presented.
	4. Establish goals	Goals should be realistic and quantified, based on facts and instructions from subordinates. Answering the questions: What will be achieved, at which level, and until when?
	5. Analyse	The probable factors causing the problem should be probed, finding root causes. Ideas for correcting the causes should be discovered. Again, the seven quality tools should be used.
Do	6. Take steps	Present a plan for chosen measures and implement. Measures are direct or indirect dependent on the severity of solutions. Indirect measures aim at solving problems with a larger scope, e.g. bad communication or indistinct roles. Measures must be connected to the analysis result; ad hoc implementation is prohibited.
Check	7. Verify effect	Did the measures have the sought effect?
Act	8. Standardize	The problem is not to reoccur before closure of the problem.
	9. Follow up	This is a debriefing stage, where the problem-solving process should be evaluated before starting with the next cycle.

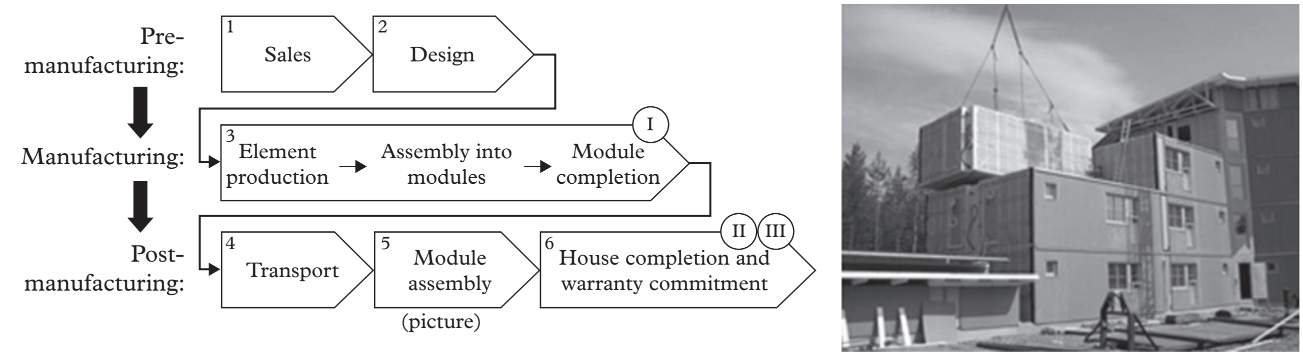

Figure 4 The industrialized timber-framed module manufacturing process

The A3 display headings relate to the nine-step PDCA method as described in Table 1. To signal the importance of planning, half of the A3 sheet is used for this purpose.

Industrialized housebuilding: the case company

The company (180 employees and a turnover of €70m) investigated in this paper uses a building system based on offsite manufactured modules, a form of production with a 10% market share among professional clients in Sweden, that is, clients purchasing commercial and multi-storey buildings (Stehn, 2008). Industrialized housebuilding based on timber-framed modules is executed in six major processes: sales; design; factory production; transport; assembly; and *in situ* completion (Figure 4). This system of processes is contained and managed within one company. Industrial housebuilding features both industrial (as in the manufacturing industry) processes and *in situ* processes (e.g. installation work). The building system comprises customized, prefabricated (⩾80% off site) timber modules, each with floor, roof and wall elements. The entire manufacturing process (for a 20-apartment house) involves 24 weeks of early client contacts, design for offer, offer negotiations and acceptance followed by a design phase of 20 weeks and a manufacturing phase of four weeks. Assembly of a house *in situ* takes one week, but the *in situ* finishing (installations, etc.) requires another four weeks. The completed modules are covered with moisture-proof tarpaulins before transport by truck to the assembly site. Defects are reported at three checkpoints in the process (Figure 4): (I) a factory audit before tarpaulin cover; (II) a final audit before tenants move into the building; and (III) a warranty audit after two years' occupancy.

Characteristics of defects detected at these three checkpoints are reported in Johnsson and Meiling (2009). Deviations are reported on a daily basis within the company in a visual and colour-coded manner to track their status. However, the main purpose is to ensure that deviations have been corrected before units are delivered to the customer. Problems and issues with respect to safety, quality, lead time and economy are reported and visualized on whiteboards in daily workgroup meetings. First, meetings of the factory production teams are held followed by production middle management meetings, then meetings between management of purchase, design and factory production, and finally top management meetings.

Two cases applying the PDCA method

The case examples were originally presented on A3 sheets but are here adjusted to journal format. The two cases were chosen from the list of around 50 recurring problems.

Case example 1

Adjustment of windows when finishing the house *in situ* is a common and time-consuming problem conducted just before the final quality audit. The adjustment often consumes time spent in fine-tuning the project before the client takes over. This problem involves several upstream processes such as sales, design and factory production besides *in situ* assembly. All assembly managers raised this as an urgent matter.

Case example 2

Problems with module connections in coinciding openings between modules arise during *in situ* assembly. The problem is selected because duplication of work is performed *in situ* and solutions are sub-optimized in factory production. Personnel from both design and factory struggle to maintain consistency towards *in situ* assembly with the result that several different solutions are produced in the factory, leading to a range of different solutions on site. Costly rework and repair are common consequences.

Findings: excerpts from the original A3 sheets

Case example 1: window adjustments

Select problem

This problem was raised by the assembly crews, i.e. tight working groups of five people with high proficiency in the building system. Adjustment of windows frequently occurs; adjustments are obstructed as window frames are fixed to the framework in the factory.

- Large number of quality control remarks in final audit (see Figure 5).
- Some adjustments are made twice, in the factory and at assembly *in situ*.
- Time-consuming and large-effort adjustments required *in situ*.

Clarify reasons

This problem is verified through exploitation of quality control notations. The notations were codified and presented in a Pareto chart, Figure 5.

The left vertical axis of the Pareto chart shows percentage defect based on eight projects with a total of 17 255 m^2 living area, from final audits with a total of 1698 defect notations. The right vertical axis shows accumulated percentage. Window corrections are very common; windows are expensive to purchase, as well as time-critical for delivery (early order point is required due to long delivery times from suppliers).

Assess the present

It was assumed by the module assembly crew that windows were mistreated in factory production. The Ishikawa chart in Figure 6 was presented at a group meeting when 15 people were gathered in one visit at the factory plant, together with design representatives.

A comment from one of the assembly workers: 'So you mean there is not one action in particular that will solve the problem, but a series of small actions will minimize it?' Another comment from the factory: 'Why are the windows adjusted several times before all major movements are conducted? This is not sound.' Comment from the purchase department representative: 'I would like to involve our suppliers in solving this problem.'

Establish goals

The goal of this improvement work is to minimize causes for adjustment and allow for efficient window adjustments *in situ*.

Analyse

Pivot windows are preferred by assembly workers because of their smooth mechanism. Wide windows are noted as being bent at the lower frame part. Currently, windows are mounted in cassettes before being installed in wall elements (Figure 7a and 7b), but this operation is not standardized and not yet equipped to handle double-threaded frame screws. Adjustments are conducted in the factory with individual methods. Side-suspended windows are adjusted at the hinges (Figure 7c) after dismounting the windows, with the risk of being bottom-adjusted (meaning that the window is adjusted as much as possible).

Pivot-mounted windows are adjusted by mounting an extra screw at the lower part of the frame. One of

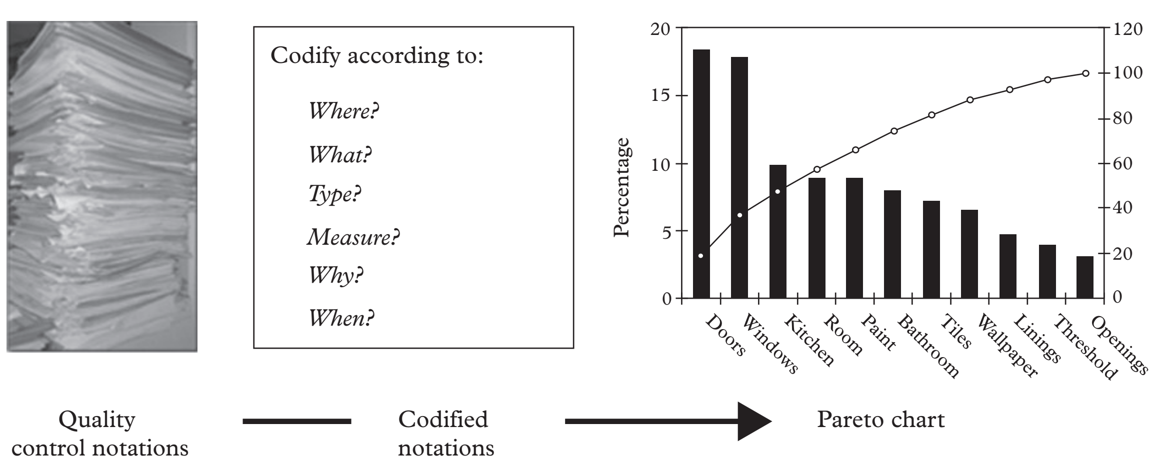

Figure 5 Quality control notations visualized in a Pareto chart

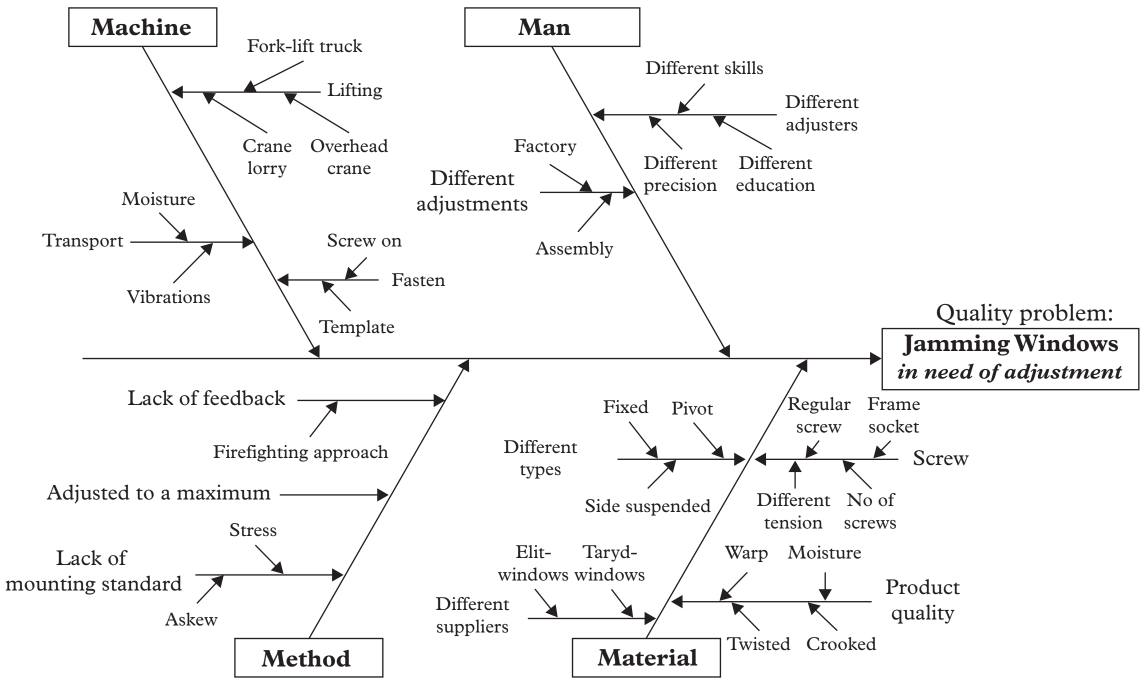

Figure 6 Ishikawa chart for the jamming windows

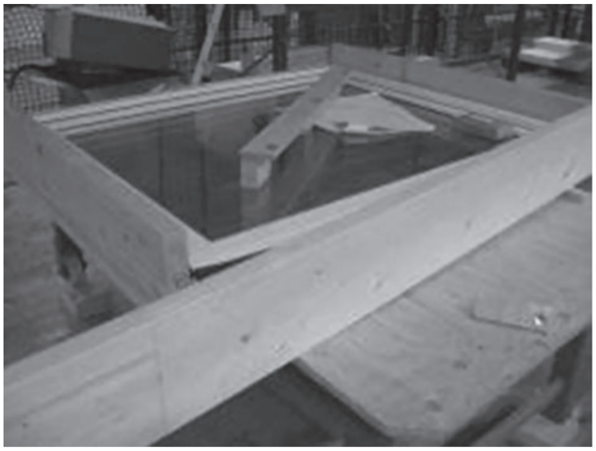

Figure 7a Windows mounted into cassettes

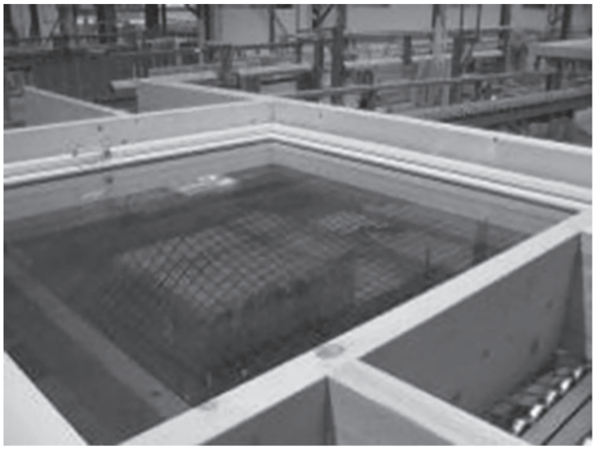

Figure 7b Cassettes in the factory

the group leaders asked: 'Is it wise to adjust any windows in the factory or should all windows be adjusted on site after assembly of modules?'

Take steps
One of the window suppliers conducts voluntary certification, meaning the window manufacturer's in-house inspection is reviewed by external, non-biased auditors. The certification schemes are based on national or international standards, to fulfil national and legal requirements. Hence, the manufacturer recommends a specific certified frame screw; there is no warranty when using regular screws. It is possible to use an off-centered socket thus avoiding opening the window when installing the socket. Analysis of the Ishikawa chart revealed:

- The cost for window adjustments is lower when purchasing pivot-mounted windows.
- Recommended frame screws from the supplier will be introduced in the next project, which will affect how work is performed at the window mounting station.
- The mounting procedure will be changed and standardized.

Figure 7c An often-adjusted hinge

New and improved installation methods will be implemented in the factory to facilitate use of supplier-recommended frame screws.

Verify effect

Windows assembled in the new way were measured on site to verify the effect of the new assembly process. The measurement showed that the windows were not jamming any longer.

Standardize

The work resulted in a suggested standard factory procedure for windows installation. The procedure implied that windows are temporarily fastened using a bracket which allows for installation of the double-threaded frame screws. The bracket is then removed.

Follow up

After a 10-week control period without any deviations, the standardized procedure was deemed successful.

Case example 2: openings

Select problem

A common in situ problem occurs when connecting the modules to each other. The problem is selected as duplication of work is performed on site and solutions are sub-optimized in factory production. Several different solutions are produced in the factory, which leads to several different solutions on site.

Clarify reasons

Several company representatives agreed that this problem was important since it caused a lot of unnecessary costs. This case did not show up as often during inspections as the windows did (see Figure 5), but the in situ workers knew about the problems with the openings because of all the work they had done to adjust the modules. The group managers agreed and had identified it as a costly issue.

Assess the present

Three different joint categories were targeted: (1) wall joints; (2) openings without a door; and (3) openings with a door (see Figure 8).

The current solutions were not requested from *in situ* assembly workers but used in the factory production, as drawings for detailed solutions were absent. Instructions for factory production occurred in several formats (as drawings, handmade comments on the drawings and as oral instructions), but no standard was presented. Also, the existence of two different floor cornices led to further confusion.

Establish goals

The goal was to standardize the three module openings.

Analyse

- How should details be communicated with the factory to make in situ completion less problematic?

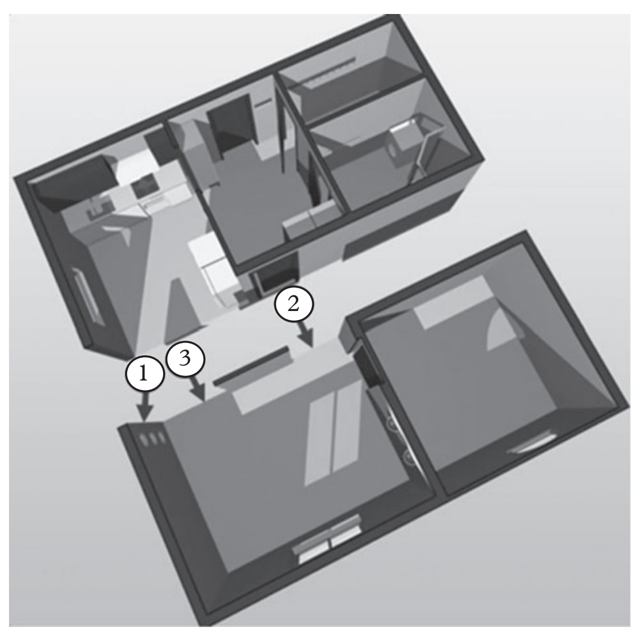

Figure 8a The three-joint categories

Figure 8b Coinciding opening

- Are current routines sufficient?
- Variation in module sizes should be measured.
- Type solutions could be identified from the interviews.
- It is important to create communication among design, factory production and in situ assembly.

Take steps

In total, 94 openings were measured. Mean values were according to drawings, but the difference in max and mean values was too large to find a standard solution. Instead, a set of type solutions was suggested to work for the majority of openings.

A series of actions was suggested to enhance communication between design and factory prior to production. The information from design needed to be more precise and simplified. Also design needed to start to define standard solutions. Both *in situ* managers and factory group leaders should be able to comment on project details before executing a new project. The design crew should regularly visit factory production and *in situ* assembly to get feedback on the drawings. Comment from one design engineer participating in the solution process: 'It seems to me we need to investigate how to find new ways to communicate design in a more production-friendly manner. Also we need to verify exactly how the assembly team solves problems *in situ*.' Two standardization candidates were chosen. Now the problem was limited to opening category 3 (see Figure 8a).

Verify effect

The two new connecting solutions were followed from designers, through factory to site, to see if the desired change was achieved. When this effect was indicated it was time for standardization.

Standardize

Figure 9 shows the two chosen type solutions.

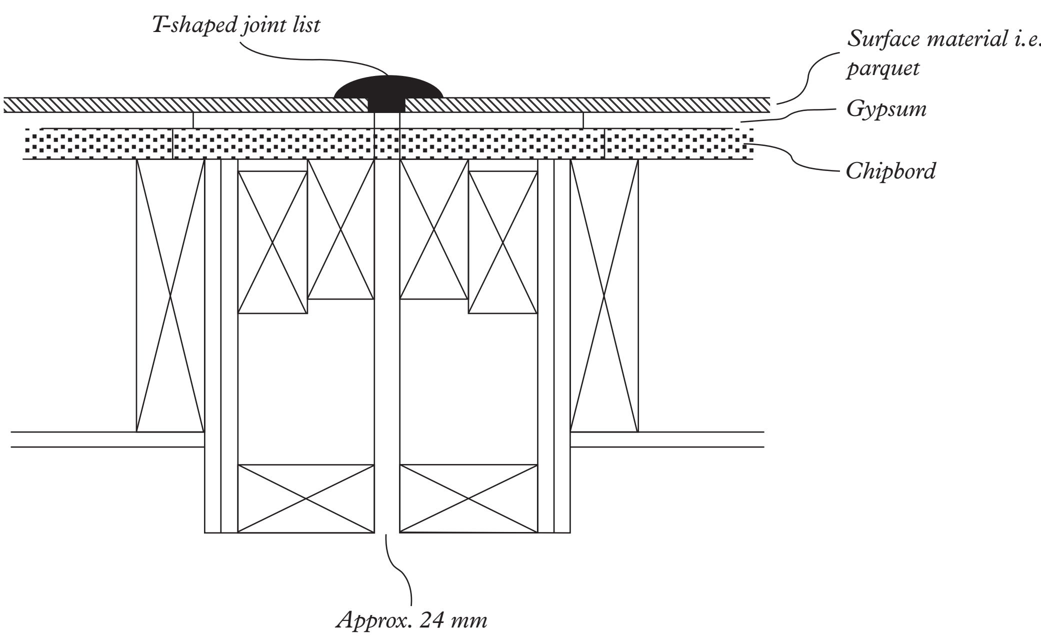

Figure 9a With joint list

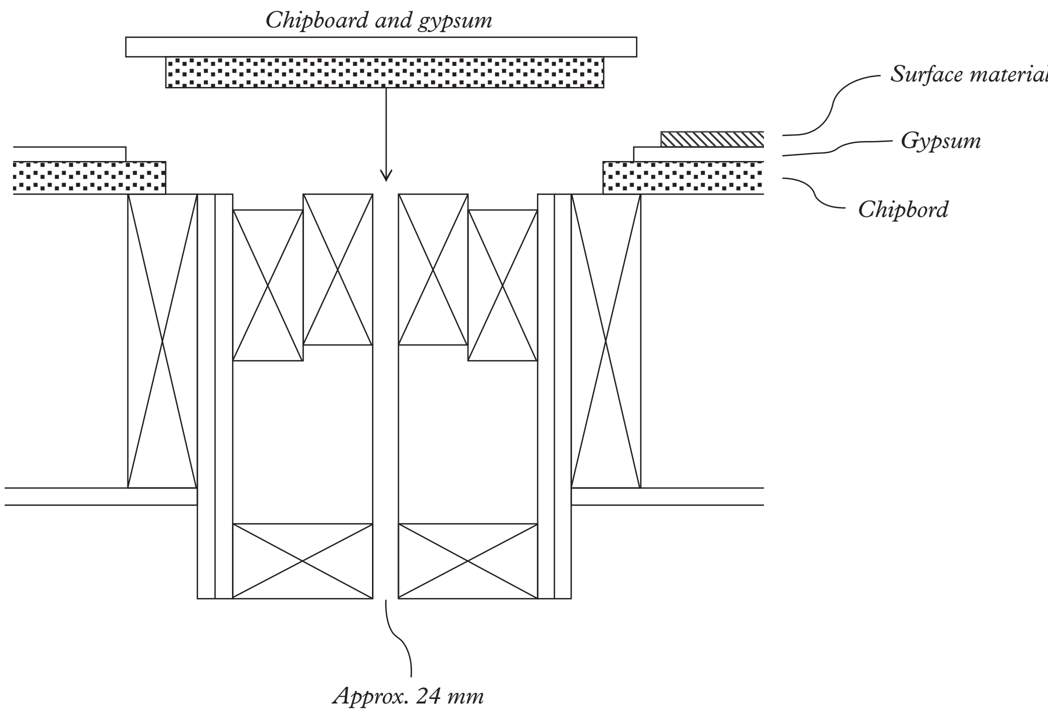

Figure 9b Seamless opening

Follow up

- The type solution with T-shaped joint list (Figure 9a) was found less flexible and therefore redeveloped into a wider flat list. The seamless opening solution (Figure 9b) was still used. Further openings should be defined to cope with other module connections.
- Enhanced communication will be made prior to the production, and improvement of all possible openings should be investigated.

The standard solutions are still too many because there are many types of openings and floor materials. Work is underway to reduce the number of solutions. The type solutions should be adjusted again to obtain more control over a larger set of standards that work in the whole process (design, production, assembly). Right now, there are solutions that are optimized for production but not for assembly and client. The reason for this is that some detail solutions (for example, hiding the splice in the door openings) are still missing.

Cross-case comparison and analysis

Comparison

Select problem
During the interviews with the group managers, the problems were described and examples shown by the group managers while walking around the site. This made it possible to describe the problem in both words and pictures in both cases.

Clarify reasons
The window case was chosen because it was a common problem during inspections (see the Pareto chart in Figure 5); it also seemed to be a delimited problem. The opening case did not show up as often during inspections (see Figure 5), but the in situ workers knew about the opening problems because of all the time they had spent on adjustment work. The group managers agreed and had identified it as a costly issue. So there were two different ways of clarifying the reasons.

Assess the present
The problems were assessed through site visits and interviews. During the site visits, windows were measured to find a correlation between the diagonal length and the problem of not being able to open the window. The distance between modules was also measured for a complete building to find the variation. Costs for adjusting the windows were also assessed. Discussions with the workers took place to obtain proposals for change that could be expected to make the client more satisfied. For the windows, this

led to an Ishikawa diagram; for the openings, the interviewees already had a clear picture of the root causes why the use of the seven quality tools was judged unnecessary.

Establish goals

Based on the results from the assessment of the present situation, a discussion began in the focus group meetings to identify goals. A balance had to be achieved between desired change effect and being realistic about achievements in the factory. For the windows, the case was to reduce the need for adjustments vs. practically being able to adjust on site. And for the opening case, the importance of knowing the variation of the openings was identified. Three opening categories were initially targeted, but only one of them was finally chosen because the PDCA effort took longer than expected.

Analyse

Since the reasons for the window case were not evident, the Ishikawa diagram was useful to break down the problem. The opening problem was easier to understand and break down since many people at the company were aware of the problem. During the focus group meetings, reasons were identified. Since there were so many solutions for connecting the module openings together, the need for a standard was evident.

Take steps

During the focus group meetings, actions were decided through discussion. For the window case, a new installation method (as well as choice of new screws) was defined while for the opening case, solutions were developed to connect the modules (as well as work change proposals). The window in itself was a limited problem compared to the larger module problem of why it was less time-demanding to change the process for window assembly. Instead, choosing connection solutions was a more limited problem and one that realistically fitted within the time frame of this research project.

Verify effect

Windows assembled in the new way were measured on site to verify the effect of the new assembly process. The new connecting solutions were followed from design, through factory to site, to see if the desired change was achieved. This made the opening verification less comprehensive since research project time was running out.

Standardize

When the effect of the window installation method was verified, the method was chosen as standard. This was also the case for the opening connectors (joints) where two were chosen as standard solutions.

Follow up

For the windows, no deviations in quality were found over a period of 10 weeks. For the openings, four projects were followed up. This led to cancelling one of the standard solutions and the development of a new solution for connecting the modules.

Analysis

The PDCA method has been known to work in the manufacturing industry for decades, with Toyota as one of the most well-known companies to have successfully employed it. So the question now is how well does PDCA work in the industrialized construction industry? In the cases analysed, PDCA worked better for the window case than the opening case. What are the reasons for this? And how can they help us find the limitations of the PDCA method?

In the window case, the problem lay in the choice of screws and the installation method and was repeated over and over by the same workers. In this sense, the solution was more explicit compared to the openings case since the changes needed were largely applicable to a single factory station: the window assembly station. Although it took some effort to identify the exact problem areas, this was achieved with significant help from the Ishikawa diagram.

In the opening case, the problem was less explicit since it lay in poor communication, lack of routines and missing standard solutions. The reason for not using a quality tool here was that the company representatives were sure that a standard technical solution was needed to mitigate this problem; this was rather than finding the root cause, since the exact root cause was deemed less explicit in nature. For this reason, only a temporary corrective action was applied rather than a permanent process action (see Juran and Godfrey, 1999, p. 41.4). The use of a quality tool such as the Ishikawa diagram would probably have broken down the problem into more explicit parts and could have led to a future permanent corrective action.

Reflection

The benefits of structured problem solving, according to Sobek and Smalley (2008) and Shiba and Walden

(2002), have been verified in this study, namely: learning through the problem-solving process, improving problem-solving skills and stabilizing production processes through standardization. However, once the most prominent problem has been found, causes identified and solutions formulated, actions should be applied to the identified process (Figure 10) rather than staying within the experience of the project personnel. There are no routines for this kind of experience feedback to bridge the gap between project and process as reported by Meiling and Johnsson (2008). PDCA methods could therefore act as a continuous bridge between the project and the process domains.

In the project domain, problems and reasons can be identified. It is notable in this study that each housing assembly manager was focused on getting the client to approve the building rather than focusing on enhancing the process. Construction projects generate experiences that can reveal which problem is the most prominent to be addressed.

Discussion and conclusions

The aim was to show how well PDCA works in industrialized construction. PDCA was used in two case examples: the window case and the opening case. The cases show that PDCA can be used to identify root causes and thereby reduce deviations. This is also supported by the literature (e.g. Imai, 1986) for the manufacturing industry.

PDCA in industrialized construction is less well investigated. Of special interest here was to find how well PDCA works for companies that are partly industrialized since many industrialized construction companies still have non-industrialized activities such as in situ assembly.

PDCA worked well in the window case for several reasons. The main one was that the problem could be isolated to a specific part of the process, namely the window assembly station. Another reason was that this part was industrialized: all work was standardized and performed by the same work teams in consistently the same way. A third reason was that the time needed for this case was within the time frame of the research project, which made it easier to allocate time for quality tools. Important to note is that the Ishikawa diagram contributed significantly to isolate the problem and thus find the root causes.

The opening case offered more of a challenge for the PDCA method, which can be explained as follows. First, this problem included a larger share of non-industrialized activities, namely the in situ assembly. Even though the window problem also was connected to the in situ assembly, more resources were spent on site dealing with the opening problem. And the in situ assembly involved more different people and less standardized work methods, making the root cause harder to find. Even if much of the work was still done in the factory, the root causes would not be as easily isolated as in the window case since the act of building the whole module involved a much larger number of operations. Also, as noted in the analysis, the focus group participants probably felt that the effort to eliminate the opening root causes was out of reach while a temporary corrective action that mitigated the problem was preferable. Even if the root causes were pinpointed more specifically, the decision might still have been to take temporary corrective action as permanent process actions might have been too resource-demanding, as also noted by Tiwari and Sarathy (2012) regarding the PDCA method in general.

When engaged in analyses aiming to find root causes, it is vital to identify the internal process and engage people close to the problem. This is manageable in the factory, as well as in the individual housing project with *in situ* personnel. However, projects are finalized *in situ*, while several new projects are managed in the factory production plant and thus projects are distanced by time and geographical remoteness. This gap could be bridged by means of PDCA, but without managerial support it will not happen.

PDCA in module prefabrication has been shown to promote enhanced process knowledge about upstream and downstream effects of problems, thus contributing

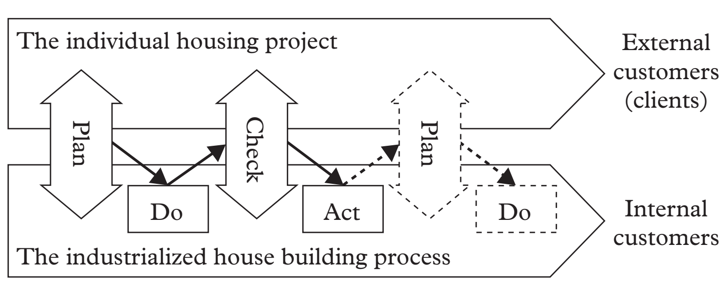

Figure 10 Project and process domains

to an overall goal of improving business results. Simple things make PDCA effective: a stepwise structure for problem solving and the use of pictures and diagrams to visualize the problem and give an overview. Also important is the involvement of people in doing the problem solving (systematic approach to the method). It is critical not to spend time on a problem that is out of reach, and it is better to let people close to the problem context solve the problem. Maintaining a strategy of improvement is a challenge for industrialized housebuilding firms.

The management of PDCA in the case examples was supervised by one of the authors. As yet, there is no decision to appoint and train problem-solving managers, or even make one person responsible for communication within the company. Moreover, many of the 'problems' experienced are in relationships with internal customers, where often the answers from personnel lie in changing how work is done in other departments. Perhaps the biggest challenge is to change the culture. Companies should consider moving away from the prevailing firefighting, quick-fix state of mind and persist with the planning stage of PDCA. Probably the greatest value in using this method is that participants are forced to put an effort into the 'plan' phase instead of almost directly going to the 'do' phase, as is quite common within the construction industry. In the 'plan' phase, the company is motivated to gather a lot of information that has not been documented before. The planning phase of the PDCA method turned into a learning experience for these construction workers. They were just not accustomed to sampling information and pondering over root causes. A change proposal for the chosen PDCA in this study includes indicating which quality tool to choose for each particular situation. Another reflection is that in order to get to the last steps of the PDCA it is important to make assumptions rather than always try to find more exact facts. Knowing who knows information is also an important enabler for the flow of the PDCA. By using PDCA, the problem can become one problem shared by many people, increasing the motivation to solve the problem as a team effort.

To conclude, the cases showed that the PDCA method can work for less industrialized processes although finding root causes and embarking on permanent process actions is likely to be too resource-demanding.

References

Asaka, T. and Ozeki, K. (1990) *Handbook of Quality Tools: The Japanese Approach*, Productivity Press, Cambridge, MA.

Bergman, B. and Klefsjö, B. (2003) *Quality from Customer Needs to Customer Satisfaction*, Studentlitteratur, Lund, Sweden.

Bessant, J., Caffyn, S. and Gallagher, M. (2001) An evolutionary model of continuous improvement behaviour. *Technovation*, **21**, 67–77.

Brassard, M. (1989) *The Memory Jogger Plus+*, GOAL/QPC, Salem, MA.

Chong, W.-K. and Low, S.-P. (2005) Assessment of defects at construction and occupancy stages. *Journal of Performance of Constructed Facilities*, **19**(4), 283–9.

De Feo, J.A. and Barnard, W.W. (2004) *Juran Institute's Six Sigma: Breakthrough and Beyond*, McGraw-Hill, New York.

Deming, W.E. (1986) *Out of the Crisis*, Massachusetts Institute of Technology Center for Advanced Engineering Study, Cambridge, MA.

Denzin, N.K. and Lincoln, Y.S. (2005) *The Sage Handbook of Qualitative Research*, Sage, Thousand Oaks, CA.

Gummesson, E. (2000) *Qualitative Methods in Management Research*, 2nd edn, Sage, Thousand Oaks, CA.

Hosotani, K. (1989) *The QC Problem Solving Approach: Solving Workplace Problems the Japanese Way*, Productivity Press, Madras.

Imai, M. (1986) *Kaizen: The Key to Japan's Competitive Success*, McGraw-Hill, New York.

Ishikawa, K. (1985) *What Is Total Quality Control?*, The Japanese Way, Prentice Hall, Englewood Cliffs, NJ.

Johnsson, H. and Meiling, J. (2009) Defects in offsite construction. *Construction Management and Economics*, **27**(7), 667–81.

Juran, J.M. (1992) *Juran on Quality by Design: The New Steps for Planning Quality into Goods and Services*, Free Press, New York.

Juran, J.M. and Godfrey, A.B. (1999) *Juran's Quality Handbook*, 5th edn, Appendix V, McGraw-Hill, available at http://www.academia.edu/download/30979708/Jurans_Quality_Handbook.PDF (accessed 18 June 2013).

Kume, H. (1985) *Statistical Methods for Quality Improvement*, Association for Overseas Technical Scholarship (AOTS), Tokyo.

Liker, J.K. (2004) *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York.

Meiling, J. and Johnsson, H. (2008) Feedback in industrialised housing: why does it not happen?, in Dainty, A. (ed.) *Proceedings of the 24th ARCOM Annual Conference*, Cardiff, 1–3 September, ARCOM, Reading, Vol. 1, pp. 145–154.

Meiling, J., Backlund, F. and Johnsson, H. (2011) Managing for continuous improvement in off-site construction: an assessment of lean management principles. *Engineering, Construction and Architectural Management*, ECAM-Nov-2010-0096, 141–158.

Miles, M.B. and Huberman, A.M. (1994) *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd edn, Sage, Thousand Oaks, CA.

Nahmens, I. and Ikuma, L.H. (2009) An empirical examination of the relationship between lean construction and safety in the industrialized housing industry. *Lean Construction Journal*, **2009**, 1–12.

Neave, H.R. and Deming, W.E. (1990) *The Deming Dimension*, SPC Press, Knoxville, TN.

Pan, W., Gibb, A.G.F. and Dainty, A.R.J. (2007) Perspectives of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, **25**, 183–94.

Parrish, K., Tommelein, I.D. and Ballard, G. (2009) Use of A3 reports to focus design and construction conversations, in *Building a Sustainable Future: Proceedings of the Construction Research Congress, 2009*, pp. 360–9.

Pascal, D. (2006) *Getting the Right Things Done: A Leader's Guide to Planning and Execution*, Lean Enterprise, Cambridge, MA.

Pyzdek, T. (2001) *The Six Sigma Handbook: A Complete Guide for Greenbelts, Black Belts, and Managers at All Levels*, McGraw-Hill, New York.

Pyzdek, T. (2003) *The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels*, McGraw-Hill, New York.

Quest Worldwide (2007) *Solve That Problem*, Quest Worldwide, Godalming, Surrey.

Rambaud, L. (2006) *8D Structured Problem Solving: A Desk Reference for Creating High Quality 8D Reports*, PHRED Solutions, Breckenridge, CO.

Shewhart, W.A. (1939) *Statistical Method from the Viewpoint of Quality Control*, Dover, New York.

Shiba, S., Graham, A. and Walden, D. (1993) *A New American TQM: Four Practical Revolutions in Management*, Productivity Press, Portland, OR.

Shiba, S. and Walden, D. (2002) Quality process improvement tools and techniques. Paper for the Massachusetts Institute of Technology and Center for Quality of Management, Revision 6, available at http://bit.ly/N9W5Ol (accessed 18 June 2013).

Sobek, D.K. and Jimmerson, C. (2004) A3 reports: tool for process improvement. Paper presented at the 2004 Industrial Engineering Research Conference, Houston, TX, 16-18 May, available at http://bit.ly/1ftAqYt (accessed 14 May 2010).

Sobek, D.K. and Smalley, A. (2008) *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System*, CRC Press, New York.

Söderholm, E. (2010) Applicability of continuous improvements in industrialised construction design process, Licentiate thesis, Department of Civil and Environmental Engineering Division of Structural Engineering, Timber Structures, Luleå University of Technology, Sweden.

Spear, S. and Bowen, H.K. (1999) Decoding the DNA of the Toyota production system. *Harvard Business Review*, **77**(5), 97–106.

Stehn, L. (2008) *Byggandet av flervåningshus i trä: erfarenheter efter tre års observation av träbyggandets utveckling: ett samverkansprojekt inom Nationella träbyggnadsstrategins fortbildningsprogram* [Multi-storey housing in timber: experiences from three years studying the development of timber housing], School of Technology and Design, Växjö University.

Tam, V.W.Y., Tam, C.M., Zeng, S.X. and Ng, W.C.Y. (2007) Towards adoption of prefabrication in construction. *Building and Environment*, **42**(10), 3642–54.

Tiwari, S. and Sarathy, P. (2012) Pull planning as a mechanism to deliver constructible design. Paper presented at IGLC 2012: 20th Conference of the International Group for Lean Construction, San Diego, CA, 17–22 July.

Wilson, P.F., Dell, L.D. and Andersson, G.F. (1993) *Root Cause Analysis: A Tool for Total Quality Management*, ASQC, Milwaukee, WI.

Appendix A

A selection of existing methods for stepwise problem solving

PDCA methods	Plan	Do	Check	Act
Asaka and Ozeki (1990, p. 112)	Understand problem Set target Factor analysis Discuss improvement measures	Implementation of plan	Evaluate improvement result	Make improvement permanent
Bergman and Klefsjö (2003, p. 213)	Identify project Appoint improvement team Problem analysis Look for causes Evaluate the result	Take steps	Measure and evaluate results	Make permanent the improved quality level
Brassard (1989, p. 260)	Select problem Describe current process Describe possible causes Develop effective solutions and plan	Implement solutions	Review and evaluate result	Reflect and act on learnings
De Feo and Barnard (2004, p. 221) DMAIC (Six Sigma)	Define: identify potential project Measure: map and measure the problem process Analyse: input and output variables	Improve: plan, conduct, optimize, evaluate, implement	Control: documented improvements and implement new process	*(New process)*
Deming (1986, p. 88)	Find improvement opportunity What data are available? Are new observations needed? Plan a test	Carry out the test	Observe the effects Study the results	Compile lesson learnt
Hosotani (1989, p. 74)	Select topic Understand situation and set targets Plan activities Analyse causes	Consider and implement counter-measures	Check results	Standardize and establish control
Imai (1986, p. 76)	Definition of problem Analysis of problem Identification of causes Planning counter-measures	Implementation of solution	Confirmation of result	Standardization

(Continued)

Table A1 (*Continued*)

PDCA methods	Plan	Do	Check	Act
Ishikawa (1985, p. 147)	Deciding on a problem (theme)	Establishing measures and implementation	Evaluating results	Standardization
	Clarifying as to why the theme is chosen			Investigating remaining problems
	Assessing the present situation			Planning for the future
	Analysis; probing into causes			
Juran (1992, p. 401)	Identify problems	Test remedy	Establish controls	–
	Describe symptoms			
	Theorize as to causes			
	Test theories by data collection and analysis			
	Identify causes			
	Propose remedy			
	Design remedy			
Kume (1985, p. 192)	Identification of problem	Eliminate causes	Confirm actions	Standardize
	Investigate and collect information			
	Analysis; find main causes			Evaluate actions and plan for future
Liker (2004, p. 256)	Problem perception	Counter-measure; neutralize harm	Evaluate measures	Standardize
	Clarify problem			
	Locate point of cause			
	Reveal root causes			
Pascal (2006, p. 167)	Sense the problem	Implement counter-measures	Evaluate effect	Standardize and train
	Problem statement			
	Collect and analyse data			Reflect and improve the process
	Casual analysis			
	Select and plan counter-measures			
Pyzdek (2001, p. 238) DMAIC	Define goals of improvement activity	Improve system	Control new system and standardize	*(Standardize)*
	Measure existing system			
	Define gap between goals and performance			
Quest Worldwide (2007, p. 8)	Define requirements and identify the problem	Implement your plan	Track progress and sort out problems	Review your success and learning
	Gather data			
	Analyse problem			
	Generate ideas and options		Make things stick	
	Make decisions			
	Plan for action			

Rambaud (2006, p. 2) '8 D'	Form a problem-solving team (1)	Implement and verify interim containment actions (3)	Define and verify root causes (4)	Prevent recurrence (7)
	Describe and define the problem (2)	Implement permanent corrective actions (6)	Verify correction actions (5)	Congratulate your team (8)
Shiba *et al.* (1993, p. 86)	Select theme Collect and analyse data Analyse cause	Plan and implement solution	Evaluate effects Standardize solution	Reflect on process
Sobek and Smalley (2008, p. 20)	Problem perceived Grasp current situation Identify root causes Devise counter-measures, visualize future state Create implementation plan Create follow-up Obtain approval	Execute the implementation plan	Execute follow-up plan	Establish process standard