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Abstract. This article describes an approach for utilizing Product Configuration Systems (PCS) for quantifying project costs in project-based companies. It presents a case study demonstrating a method of quantifying costs in a way that makes it possible to configure cost- and time estimates. Piecework costs, material costs and sub-supplier costs are used as principle cost elements and linked to structural and process elements to facilitate configuration. The cost data are used by the PCS to generate fast and accurate cost-estimates, quotations, time estimates and cost summaries. The described cost quantification principles have been used in a Scandinavian SME (Small and Medium-sized Enterprise) since the 90's, but have since 2011 been adopted to be used in a configuration system. A longitudinal case study was conducted to compare cost and time-estimation accuracy before and after implementation. We conclude that the proposed method for grouping costs, combined with a PCS, can be used in project-based construction industries to make more accurate estimates of project costs. Reasons for improved accuracy are, according to company experts, the increased documentation and visibility of cost-estimates, dynamic allocation of variable costs, version control of cost-agreements and the ability to handle an increased level of cost details.

1 Introduction

Cost-estimation accuracy in project-based companies can be a challenge that often results in cost overruns of construction projects[1]. To respond to these challenges, a wide range of cost-estimation techniques have been developed to increase accuracy, ranging from simple estimation techniques to applied artificial intelligence. However, the most recently developed methods have not been adopted to the extent that would be expected, partly due to lack of understanding of new methods, but also by lack of trust in the benefits of such methods [2]. Product configuration systems have proven useful to improve time performance, error rates and profitability in a wide range of companies. [3–7] Some use has been made of the generation of cost-estimates by means of rule-based expert systems within the field of product configuration. Examples of cost-estimates generated by PCS are catamaran-type leisure boats in Korea [8], and optimization of the cost and scheduling of heavy earthmoving operations [9]. A PCS was developed by Chan [10] to predict the price and manufacturability of six commonly used component designs. The component designs generated by the PCS were afterwards validated by sourcing prices from real manufacturers and confirmed the reliability of predictions from the expert system[10]. Cost-estimation of metal casts has been developed by use of fuzzy reasoning systems[11]. Cost-accuracy has been reported as an observed benefit in industry by use of PCS[12]. This article is a case study investigating an implementation of a PCS to improve cost-estimation accuracy in a project-based construction company. In order to investigate the effects of a PCS, we followed a case company using a PCS to generate cost-estimates and quotations. Based on the believe that PCS can improve cost-estimation accuracy in the construction industry, the following proposition was tested:

Proposition
Implementation of PCS can improve cost-estimation accuracy in project-based construction companies

To test the propositions a collaboration with a case company that had changed from a traditional cost-estimation approach to a PCS was followed in a longitudinal case study. Access to the content of the PCS calculation principles and domain experts for clarifying questions was during the period in order to provide us with an understanding of the most important reasons behind any changes in cost-estimation accuracy. We sought to increase understanding of how a PCS adds value to a company and what reasons might be behind increases in cost-estimate accuracy. The paper is structured as follows: (1) Literature review of current cost-estimation practices in project-based industries; (2) Research methods; (3) Description of how to model cost-elements in a PCS; (4) Case describing the use of a PCS for cost-estimation, its impact on cost-accuracy and possible explanations; (5) Discussion of the results; and finally (6) Conclusions.

2 Literature review of cost-estimation techniques

Cost estimation is important to project management as it provides information for resource management, decision-making and cost scheduling [13]. Cost over-runs are a common problem in project-based companies when cost-estimates lack accuracy [1]. Numerous methods have been proposed for cost-estimation and numerous textbooks are readily available on the topic. Often the focus is on the principles and processes involved in cost estimation. The general suggestion is to break costs down into such elements as labour, materials and plant costs and add some percentage for contingency [14,15]. The process of estimation is to produce a statement of the approximate quantity of material, time and cost to perform construction work. In 1989 Carr [13] identified a need to

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establish cost-estimating principles and stipulated that a proposal in the construction industry must include an estimate that is close to reality, a suitable level of detail, and all relevant items, without adding extra and use quality documentation as a basis for business decisions. Furthermore, the cost-estimate should distinguish between direct and indirect costs and variable and fixed costs. Additionally some way of handling contingency should be in place to mitigate unforeseen circumstances [13]. Multiple methods for cost-estimation exist; they can be divided into Bottom-up and Top-down approaches. Bottom-up estimating (or resource-driven estimating) includes breaking down a project to its distinct parts in a 'work breakdown structure'. The aim is to reach a level of detail where costs are relatively stable and most costs are included. It is generally agreed that the bottom-up approach is quite accurate, but it is also time consuming [16]. Top-down (or parametric estimating) relies on past projects and reviews and modifies earlier projects by scaling and estimating expected costs [17]. Advanced methods have been developed and classified in four types of cost estimation modelling: Experience based (algorithms, heuristics, expert system programming), simulation (heuristics, experts models, decision rules), parametric (regression, Bayesian, statistical models, decision rules) and discrete state (Linear programming, classical optimization, network, PERT, CPM) [18]. Much research has been conducted within Case Based Reasoning (CBR) as it allows recall and reuse of knowledge from prior projects [19]. Rule-based experts systems have failed to meet the need that construction managers have to handle complexity and CBR has emerged as an alternative[20]. A system that integrates CBR and rule based expert systems was developed for cost-estimation of refurbishing of houses and it was concluded that the combinatorial approach is beneficial but not commercially viable due to the complexity of such an approach [21]. In practice, cost-estimation methods depend on the nature and type of organization and are not very standardized [22]. A survey of 84 very small to large firms in the UK [2] were asked about current cost estimating practices and the study concluded that the most used methods were of a relatively simple nature, such as estimation of standard procedure, comparison with past projects and comparison with finished parts projects. Intuition and simple arithmetic formulas are also widely used. Most of the advanced cost-estimation methods have not been adopted by industry. Reasons listed for lack of adaptation are that the companies are not familiar with recent methods, companies lack time and knowledge and they doubt whether the new techniques can be of benefit to the construction industry. The study also concluded that companies mainly use cost-estimation for construction planning and not for construction evaluation [2]. This article seeks to add a case to the evidence that a PCS can offer benefits to the construction industry both by offering opportunities for increased cost-accuracy, but also by making it easier to use cost-estimate data for construction evaluation.

3 Research Method

This research was based on a case study of a project based construction company that generates cost-estimates and quotation letters. It was a longitudinal case study that observed changes in cost-estimate accuracy occurring in a company that have changed from a standard cost-estimate approach to a PCS. The longitudinal case study was chosen due to the ability for the researcher to watch a changes unfold in real time [23]. Data on cost-estimations and actual costs were provided by the company. The data were analysed by researchers by comparing pre-project cost-estimations with realized costs in order to test the proposition. The cost-estimates from 2009 were generated by standard methods and those from 2014, which were generated with PCS, were compared to the actual costs of the given projects. The possible reasons for the results were investigated qualitatively in interviews with two different company experts who had both used the system and taken part in the development. The interviews were performed individually to prevent interviewees from offering the same explanation or affecting each other. Published studies of cost-estimation in construction industry were reviewed in order to identify best practices, to document that the principles used in the case company resemble current practice and to identify similar use of computer aided cost-estimation, in order to provide context.

3.1 Cost-estimation model based on configuration

The proposed principles for cost-estimation by means of PCS resemble standard cost estimation processes as described in text books on cost-estimations by breaking down cost elements into smaller cost elements such as labour, materials and plant costs [15]. This approach resembles the bottom-up approach to cost-estimation, which is believed to be accurate and complete but also time consuming [16]. The time taken for a detailed bottom-up approach is acceptable for mass-produced products and the effort invested in making detailed estimations is justified, since they can be reused. Multiple cases of knowledge based configurations of bills of materials and processing times exists in make-to-order companies [11,24,25] However, few accounts have been published of knowledge based product configuration systems designed to configure entire projects, including detailed costing information. No relevant reports were found on configuration of cost summaries in the research databases SCOPUS and Web of Science. The key words searched were "expert system" ,"configuration" ,"decision support", "reasoning system" in combination with "cost summary", "cost overview", "Cost accounting". Cost-accounting, among other activities, is used to take decisions on pricing and on the introduction of new products and discontinuing of products [26]. The detailed level of cost-information influences product cost decisions. The more complex the product the more difficult it is to include product costing feedback, so more accurate costing information provides benefits in forecasting [27]. The currently proposed cost-estimation model for projects divides cost elements into three different categories; piecework cost (salary), materials costs and subcontractor costs. The piecework costs represent the agreed cost for a worker to perform a given piece of work. The cost of having the worker perform the work corresponds to the time expenditure for a construction process. The material cost represents the costs of materials for a given project. The subcontractor costs are fixed price agreements with subcontractors to solve a given task. These costs are believed to be enough to give a complete picture of a cost-estimate and are in line with current practice [14,15]. In PCS the costs are assigned to parts or process descriptions that can be selected in the configuration system in order to configure a project. Additionally, parts and processes contain account descriptions designated according to cost-type and supplier information. The account descriptions can be used to

generate a cost summary of all expenditure in a project with a description of supplier and the expected total sum. The cost summary enables companies to compare cost-estimates with actual costs at a detailed level, with little effort. The cost-summary enables the company to use the cost-estimations for evaluation, which is currently not standard practice [2]. Evaluations of cost data and accurate cost databases are believed to be a key factor for success in the improvement of cost-estimations in building projects and firms will have to find some means of retaining the knowledge and experience from past projects [28].

4 Background of the case company

The case company in this study was a Scandinavian company that sourced construction components and provided system deliveries as service installations. The company was classed as a SME and in 2015 it had a turnover of 34 million € and approximately 130 employees. In 2015 the company bid on 1319 projects and won 229 projects which in total represents production, sourcing and assembly of 3001 individual products. The customers are typically a group of people buying installations in a community where the customers buy the product individually but share the costs of installation. The average project cost was 148.471 € and the average cost per product was 11.329 €. An average of project costs in 2013 were distributed between assembly workers (25%), materials (52%), subcontractors (11%) and additional costs for setup and removal of each construction site (12%). The ratio of expenses had not changed much since then. Since 2015 the company had used a configuration system to generate cost-estimates and quotations for projects. The projects were all deliveries of similar products, but in many customer specific variants from a few different product families. The configuration system was based on component selection with assigned salary costs, materials costs and subcontractor costs. (Section 3.2) The cost-estimation techniques used by the case company were roughly the same before and after implementation of a PCS. The main difference was in the visibility and documentation of cost-estimates, automation of changes in quotations and a slightly improved detail level in cost contributions.

4.1 Configuration of cost-elements

A schematic representation of the proposed PCS shows a system overview including user inputs, PCS knowledge and generated outputs. (Figure 1). The user inputs was an interface with a drop-down menu on which the salesman could select elements to specify product design and work process. The knowledge of the configuration system was represented by parts or processes to be selected connected with a group of cost-elements; piecework cost, material cost and subcontractor costs. Every part or process element in the configuration system could hold one or more of the cost-elements dependent on the characteristics of the chosen element, i.e. a chosen component could include information on both piecework-costs and materials costs. This was because some parts of the construction project included both a work process to be performed and a material to be used for the process. The knowledge about the processes, materials and subcontractor costs was handled in the PCS and a finite solution space could be defined and handled by an inference engine.

The PCS could handle changing project costs by adding or removing project elements according to changes in the required product and thereby easily create revisions and changes in cost-estimates and output documents. In order to handle the complexity of construction projects special open entry fields were used in the configurator with the possibility to describe non-standard elements. Non-standard elements might consist of any of the three types of costs and was a flexible way of adding non-standard process and costing knowledge. The total sum of piecework-, material- and subcontractor costs was used to generate the output of the PCS. For internal use, the case company generated time-estimates (total salary cost estimate divided by hourly fee gives an approximate assembly time) and cost summaries according to expected expenses from specific suppliers and subcontractor agreements. The cost summary helped to evaluate accuracy and identify billing mistakes. For external use, quotation letters were generated for customer, each containing a fixed price based on a configured cost-estimate. The time-estimate and the time-schedule were based on the estimated salary cost, so the accuracy of the configuration was of great importance for overall project cost accuracy. An under-estimate in salary and thus time-estimates could result in increased expenses due to overtime rent of machinery and other very variable costs.

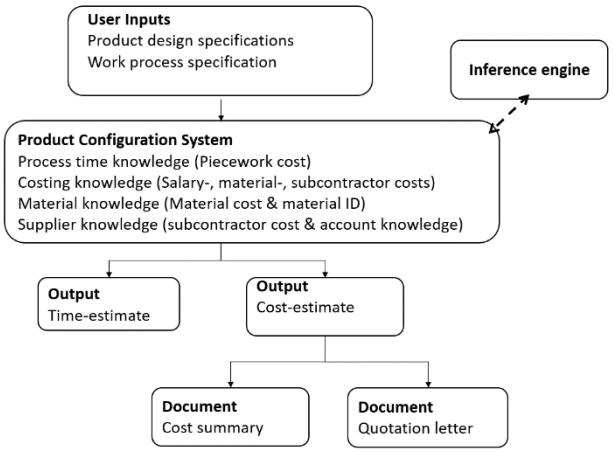

Figure 1 Overview of PCS and outputs delivered

4.2 Analysis of cost-estimate accuracy before and after implementation of a PCS

The case company performed an analysis of the cost accuracy of the major cost elements of 55 cases in 2009, corresponding to 12 months of operations, in order to review and improve the current cost-estimation process. The deviations were calculated per major cost element, as defined in (1).

$$\textbf{Cost deviation} = \textbf{Actual cost} - \textbf{Estimated cost} \quad (1)$$

If the actual cost of a project is higher than the estimated cost, the cost deviation will be negative. If the actual cost is lower than the estimated the result is a positive deviation. If a project exceeds the cost estimate it shows a negative deviation on the graph and in case of a lower price than estimated a positive deviation. In 2009 fluctuations in the deviations in cost-estimates could be observed and only few projects where completed at a cost close to the

estimation (Figure 2). It can be seen that the fluctuations move in both positive and negative directions but when deviating the different cost elements generally move in the same direction. This indicates a tendency to over-estimate or under-estimate a complete project and not just parts of it. Furthermore, the tendency is that most deviations are negative meaning that the cost-estimators most likely to have underestimated project costs when there are deviations. The conclusion from the investigation was that increased cost accuracy was identified as an area that must be improved. Based on the analysis it was decided by the case company to invest in a PCS to generate quotations, in order to improve accuracy. (Section 4.1)

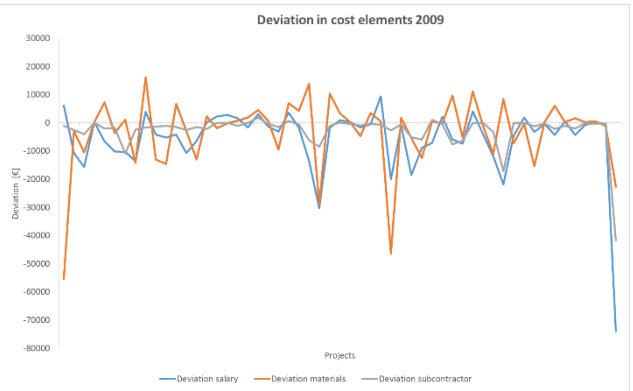

Figure 2 Deviations in cost elements 2009

In 2014 another analysis of 42 cases corresponding to 4 months of operations were performed to evaluate the effect of the PCS. Less fluctuation in the deviations of cost estimates were observed in 2014, resulting in better accuracy (Figure 3). The line had straightened around zero indicating that the deviations had been reduced. There were still three major outliers in salary and subcontractor categories. In order to understand them, expert interviews were conducted to clarify the cause. In those particular cases the company was experiencing a shortage of workers to complete the projects and was forced to complete the projects by using subcontractors. The deviations in salary and sub-contractor costs equalized each other and the consequence was therefore not negative to the company's profit.

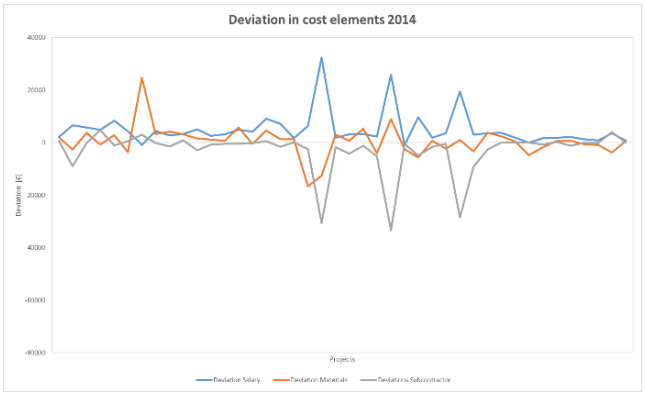

Figure 3 Deviations in cost elements 2014

An overview of the sum of the actual costs and estimated costs can be seen in Table 1. Note that the total sum of salary and subcontractor costs does not hit the target very precisely, which is related to the prior explanation of the outliers. In the rest of the article the data set has been corrected to exclude the three cases to make a better representation of the actual distribution of the deviations. From this point in the article only 39 cases are included in the 2014 analysis.

	estimated costs		actual costs	
	2009	2014	2009	2014
# projects	55	42	55	42
Sum of salary	1963	714	2224	501
Sum of materials	5004	1749	5173	1726
Sum of subcontractor	410	199	592	331
Total Sum	7377	2662	7989	2558

Table 1 Sum of total cost elements in 1000 € (2009 & 2014)

Reason for deviations in 2009 were according to the company a lack of standardized solutions, too little detail on cost elements and lack of control of expenses in relation to external use of consultants for gaining approval for products. Reasons for deviations in 2014 were according to the company late changes in the order resulting in a change in price. Positive deviations in the materials category were explained by a change in product design resulting in a positive deviation due to a lower final price.

4.4.1 Comparison of individual cost elements accuracy

All of the cost-element deviations were plotted in a column diagram and rank-ordered from the greatest negative deviation to the greatest positive deviation on identical scales per cost-element. A reduction in under-estimated cases was observed across all cost elements in 2014. Most notable are the salary and materials estimates, which showed substantial reductions in under-estimates. The subcontractor category still suffered from a tendency to underestimate costs.

4.4.2 Comparison of salary costs

In 2009 the deviations were significantly more likely to be negative (39 negative projects) than the estimates made supported by a PCS in 2014 with 3 negative projects (Figure 4). In 2014 deviations continued to occur but with positive deviations and with a significantly smaller magnitude. The greatest negative deviation in 2009 was approximately 75.000 €, while the greatest negative deviation in 2014 was approximately 1.000 €. This is a significant difference in miscalculations and of great importance to the profitability of the case company, as it will help to avoid losing money, but also to calculate correct time-schedules and subcontractor costs that are dependent on the number of days needed to complete the work.

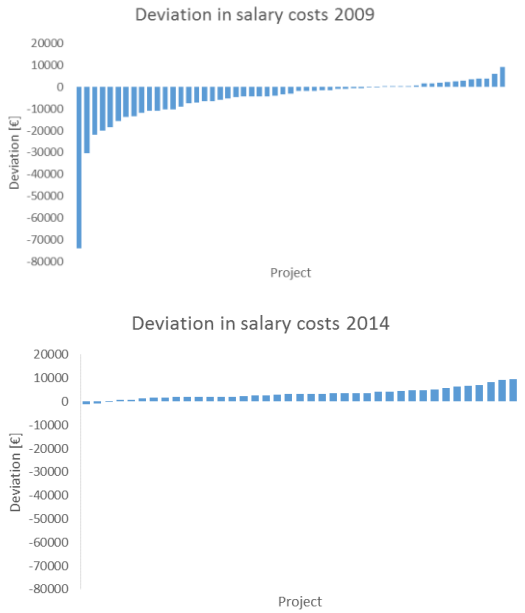

Figure 4 Comparison of salary cost-estimates 2009 and 2014

4.4.3 Comparison of material costs

In 2009 significantly more negative cost-estimates were made than in 2014 when they were supported by the PCS. In 2014 negative deviations continued to occur, but the magnitude of the misestimates was much smaller than in 2009. In 2014 the distribution was evenly distributed around zero deviation, indicating that the estimates were closer to the target than before. The deviation graphs reveal greater accuracy and process control.

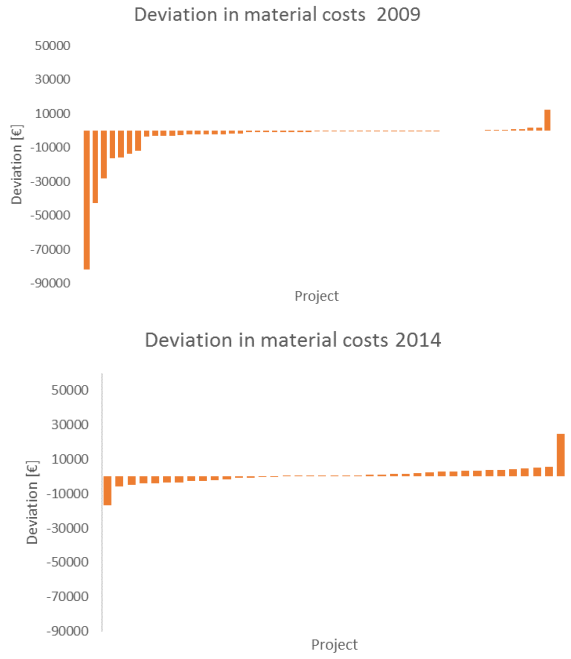

Figure 5 Comparison of material cost-estimates 2009 and 2014

4.4.4 Comparison of subcontractor costs

In 2009 some negative deviations occurred and the tendency was to underestimate subcontractor costs. In 2014 fewer deviations occurred but there was still a tendency to underestimate subcontractor costs. Experts at the company suggested that one reasonable explanation was that the PCS cannot handle all subcontractor costs as they are not as standardized as the salary and materials category. Another reasonable explanation offered was that the subcontractor costs are often variable costs that depend on the time-schedule, so an incorrect salary estimate would lead to an incorrect time schedule, resulting in increased sub-contractor costs. This means that the improved sub-contractor costs might be a "knock-on" effect from improved salary-cost estimation.

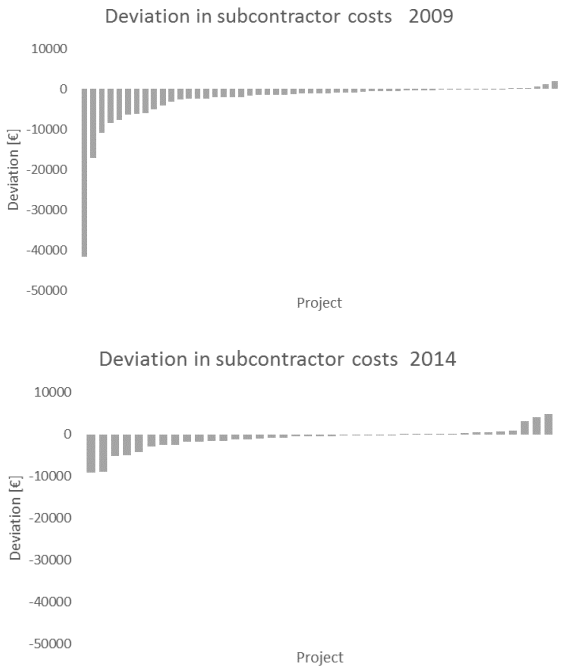

Figure 6 Comparison of subcontractor cost-estimates 2009 and 2014

4.4.5 Summary of cost deviations

Sections 4.4.2, 4.4.3 and 4.4.4. summarize evidence that the cost-estimate accuracy improved significantly within all cost-elements. Table 2 gives an overview of the percentage of under-estimates of projects from before and after implementation of the PCS. Most notable is the increased accuracy in the salary-cost and materials-cost categories. As the salary costs and materials costs together constitute 72% of average total expenses in a typical project, the gains in cost-estimate accuracy contribute to the case company's profitability.

	Salary cost		Material Costs		Subcontractor Cost	
	2009	2014	2009	2014	2009	2014
Under-estimate	71%	8%	76%	38%	89%	67%

Table 2 Percentage of project-costs under-estimated 2009 & 2014

The total amount of money in the two categories of under-estimates and over-estimates can be seen in Table 3. In 2009, the financial loss due to under-estimates were significant, with a total loss of €693.000. In 2014 the financial gain on improved accuracy and compensation by over-estimations was €122.000. It is important to note that the absolute sums are not based on the same number of projects of comparable sizes, so they are not directly comparable. A comparison of the positive and negative deviations from Table 3 was compared to the actual cost of projects from Table 1 and can be seen in Table 4. The data show an improvement moving from a tendency to lose money on under-estimates to earning money on over-estimates. This had a significant impact on profitability, assuming that the company was still competitive at the new cost-estimates. The number of ingoing orders in the case company had in fact increased during the time period investigated.

	Salary cost		Material Costs		Subcontractor Cost	
	2009	2014	2009	2014	2009	2014
Under-estimate	-351.5	-1.9	-249.7	-53.4	-156.5	-53.9
Over-Estimate	42.6	137.1	18.4	78.9	3.6	15.2
Total Sum	-308.9	135.2	-231.3	25.4	-152.8	-38.7

Table 3 Sum of total deviations in 1000 € (2009 & 2014)

	Salary cost		Material Costs		Subcontractor Cost	
	2009	2014	2009	2014	2009	2014
Under-estimate	-15,8%	-0,4%	-4,8%	-3,1%	-26,4%	-16,3%
Over-Estimate	1,9%	27,4%	0,4%	4,6%	0,6%	4,6%

Table 4 Percentage of over- and under-estimated deviations in relation to sum of actual cost-elements in all projects

4.3 Reasons for improved accuracy according to case company

In order to understand the reasons behind the improved accuracy in the different cost elements, semi-structured interviews were conducted and the graphs from Section 4.4 were presented with an open question asking *"what are your explanation for the difference in accuracy between 2009 and 2014?"* Two different interviews were conducted with the head of sales and the head of R&D. The head of sales stated that there was no doubt the PCS had helped to increase the accuracy of cost-estimations by standardizing product solutions. He added that before the PCS was implemented the head of economy had routinely reduced the expected actual cost by 4% on any quotation for certain products due to a clear tendency to deviate in a negative direction. The increased visibility of cost elements created by a cost summary page were identified as a tool that enabled evaluation of costs and updates of prices and had helped to reduce deviations and make sure correct prices were used. It was also pointed out that the level of detail of the prices in the different cost elements had been improved due to the ability to handle prices automatically. The interview with the head of sales credited the following three critical features of the PCS with its success:

- Increased visibility and documentation of cost elements in cost-estimates, by means of cost summaries
- Version control of cost agreements maintained in a single system
- Increased level of detail in cost elements

The head of R&D stated that the old calculation system was tedious and it was difficult to handle cost updates from suppliers and version control. The result was that cost-estimates were often calculated on the basis of different price agreements and resulted in incorrect cost-estimates. He also pointed out that when a project changed in the old system, it was a major task to change all variable aspects of the project, and that this often resulted in mistakes being made. He stated that another reason for the improved accuracy was the visual and easy overview of possible standard solutions, which helped the sales representative to sell products that were already registered as a standard product with known and agreed costs. Yet another reason was the possibility to handle and maintain a higher level of detail in the cost-elements. The interview with the head of R&D credited the following three critical features of the PCS for its success:

- Dynamic allocation of variable costs
- Version control of cost agreements maintained in a single system
- Increased level of detail in cost elements

Afterwards, when the head of sales and head of R&D were brought together to discuss the data on accuracy they agreed that all aspects mentioned were important reasons for the increased accuracy and refinement of cost-estimations.

5 Discussion

The focus of this work was to investigate how a PCS can be used to quantify project costs in project based construction companies. A method for grouping of costs has been presented that respects best practice as documented in the literature but adds a way to calculate time-estimates and cost summaries. The method used by the company made it possible to configure cost-estimates and generate quotations, time-estimates and cost summaries in a single PCS. The automatic generation of documents proved to be a useful way to improve cost accuracy. These findings complement the existing literature on automation in the construction industry by adding a case of successful implementation of rule-based expert system with tangible benefits. The possible reasons mentioned by company experts indicate that a PCS might be a new and viable way to improve cost-estimation evaluation. Another finding was that the PCS can help increase the level of detail and thereby obtain a suitable level of detail as described by Carr [13] without obscuring the user's over-view. The cost-estimation principles used by the case company resembled standard procedures for the construction industry and so the results are believed to be replicable in similar project based companies. However, the presented case study was of a single case company, which clearly limits the generalizability of the study. The case company operated within a defined product solution space which made the use of a rule based expert system feasible. The analysis was based on a limited number of projects and the sample size from 2009 was larger than from 2014. It might be that some outliers occurred

among the cases in 2014 that were not considered, and that this might alter the conclusions. However, the data in combination with expert interviews strongly indicates that there is a connection between the implementation of a PCS and cost-estimation accuracy. Future studies should seek to implement similar solutions in other companies in the construction industry to validate the present results.

6 Conclusion

The purpose of this case study was to investigate cost-estimation accuracy in a longitudinal study and assess the impact of the implementation of a PCS on cost accuracy. It was concluded that the cost estimations did improve quantitatively, showing fewer and smaller deviations and fewer negative under-estimations among all cost-elements. The reasons for these improvements were investigated qualitatively in open interviews with company experts who considered their implementation of a PCS was the main reason for improved cost-accuracy. The reasons behind the improved accuracy could according to these company experts be explained by the increased documentation and visibility of cost-estimates, dynamic allocation of variable costs, version control of cost-agreements and the ability to handle an increased level of costing details.

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