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Empirical study reveals deficits in the choice of formwork

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The choice of suitable construction techniques and methods must be made prior to construction commencing. Since a sub-optimal construction method ultimately results in sub-optimal construction processes and, in consequence, in increased costs, the choice of method should not depend on subjective criteria. Existing methods pay too little attention to uncertainties and bandwidths of the selection results and mostly do not verify the sensitivity of these results at all. In order to reduce complexity the existing methods restrict themselves on partial processes. As a consequence it is impossible to gain a holistic point of view. To overcome these limitations of the selection process an internationally-active formwork manufacturer and a big Swiss construction company interacted with the Institute for Construction Engineering and Management at ETH Zurich to develop a cybernetic, process-based and system-oriented decision model for the selection of formwork. To identify the initial position as well as the practical demands on the anticipated decision model an empirical study was conducted. This paper presents the results of the empirical study and the deficits associated with the state of the art of formwork selection.

Keywords: choice of formwork, integrated, project-specific, process-based.

1. Introduction

Due to the basic conditions of the Swiss construction market construction companies are forced more than ever to execute their projects as economically and efficiently as possible in order to strengthen their competitiveness and assure their survival in the market economy [1]. This is only possible if they strive for operational excellence respectively best-practice in the individual processes, for which systematic selection processes for the construction methods are required. Since formwork costs form an important part of costs of reinforced concrete works, the project-specific optimal formwork system has a significant relevance on the overall project result.

Since no company can afford sub-optimal construction methods, a research project was initiated by the Institute for Construction Management and Economics at ETH Zurich to develop a cybernetic, process-based and system-oriented decision model for the selection of formwork that incorporates interactive and interface-relevant influences caused by parallel processes. To identify the initial position as well as the practical demands on the model, an empirical study was conducted in regard to the selection criteria for the decision making model.

2. Research methodology

To analyze the state of practice, a combination of epistemological methods will be applied to obtain research results using qualitative social research and quantitative investigations [2, 3]. Therefore an research plan including general epistemological questions and an interview guideline was constructed. The hermeneutical spiral for this research project combined systematic literature research to achieve basic knowledge about selection criteria and interviews focusing on the building construction sector in German-speaking countries. The qualitative research was conducted by semi-structured and problem-oriented interviews. In the context of the quantitative research the interview partner were asked to weight the different selection criteria that were determined during the qualitative as well as the literature research. To secure the generalizability of the research results, the interview partners were chosen by strictly adopting the rules of qualitative sampling [4].

3. Findings from the study

The investigation needed to take into account the fact that the interviews were conducted both with a formwork manufacturer as supplier and construction companies as its customers. These players pursue differing economic goals – customers want to minimize overall costs, suppliers want to maximize sales – which is why they had to be evaluated separately. In addition, the study revealed the extent to which the supplier recognizes the customers’ goals and can generate maximum customer benefit in order to increase market shares and maximize profits. Based on a controlled methodically analysis four categories could be identified:

3.1 Systematics

Neither the interviewees of the supplier nor the ones of the customers adopt a cross-corporate standard systematic approach to selecting formwork systems. In addition to that only about 40% of the overall interviewees were able to describe a clear structure of the individual work steps and their sequence. Therefore it can be stated that not even the decision-finding processes of the individual engineers are based on a clear structure.
3.2 Subjectivity

It was found that all interviewees – both on side of the supplier as well as on side of the customers – base their decision-making process on personal experience and personal preferences. However only one third of them is aware that their intuitive handling prevents them from examining other, possibly better solutions.

![Figure 1. Comparison of selection criteria and their importance with indication of the mean values (standard deviation)](image)

The prioritization of the selection criteria varies from one agent to the next as can be read off the large standard deviation of the single criteria (Fig. 1). As such, the reproducibility of decisions is not given.

The high correlation of the mean values for supplier and customers shows, that the various criteria are weighted similarly by both sides, apart from a few exceptions like staff management and quality (Fig. 1). Therefore it can be stated, that the supplier recognizes the customers' goals and incorporates them already in his decision-making process.

In a second analysis the collected data was analysed regarding the various functional levels separately for supplier and customers. The weighting of the different selection criteria turned out to be more or less independent of the functional level on the part of the supplier, whereas the findings revealed marked differences in the weighting on the part of the customers.

Further selection criteria were listed and classified as relevant by the interview partners during the collection of qualitative data; on customer side, it were the flexibility of the formwork system and the foreman's preferences, the interview partners on supplier side listed the material availability, personal contacts and a basis of trust.

3.3 Inclusion of interfaces

Nearly 80% of the interviewees admitted to taking no or scarcely any internal (e.g. concrete works) and external (e.g. concrete versus finishing works) interfaces in account when selecting a formwork system. Since these interfaces often cause non value adding activities they reduce the project profitability and will therefore be considered in the anticipated decision model for the selection of formwork.

3.4 Inclusion of uncertainties

In practice there are generally two ways of dealing with uncertainties: The aspect of uncertainties is totally ignored or unrelated buffer times and defensive performance assumptions are used. Neither of the two alternatives seems to be ideal for guaranteeing economical and low-friction construction works.

4. Conclusion

Based on the evaluation of the qualitative and quantitative data collected, the study was able to prove that, generally speaking, neither theoretically existing knowledge nor a (standard) systematic approach are applied, nor are the internal and external interfaces taken into account when it comes to choosing systems. The study further revealed that any investigation of economic efficiency to date has been restricted to an analysis of the requisite stock volumes and the costs immediately associated with the formwork. Since no signs of a holistic approach were found in practice, the next steps will be to incorporate the associated internal and external interfaces and to integrate the technical and economic impacts of formwork system decisions on the overall process into the decision making process.

References


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Abstract

The choice of suitable construction techniques and methods must be made prior to construction commencing. Since sufficiently detailed plans are frequently not available at such an early phase, this decision – which significantly impacts the subsequent construction process – often has to be based on assumptions or suppositions. Since a sub-optimal construction method ultimately results in sub-optimal construction processes and, in consequence, in increased costs, the choice of method should not depend on subjective criteria. A rigorous application of the existing approaches to systematically and, as such, objectively choosing the optimal method should produce similar results, even if the issue is addressed by different people. Given the actual occurrences in the construction industry, and based on the authors’ experience as well as on a survey of representative construction companies, it can be assumed, however, that the existing approaches are, in practice, scarcely applied at all to selecting the optimal formwork.

An empirical study focusing on the state of the art in selecting project-specific formwork systems is therefore being conducted as a basis for inductively obtaining information. The study focuses, in particular, on the methods applied to selecting the formwork and on the requirements for a decision-making aid in practice. The study pinpointed four main faults: lack of objectiveness, mostly unstructured selection procedures, an inadequate consideration of reciprocal interferences as well as an inadequate consideration of uncertainties.

Keywords: Choice of formwork, integrated, project-specific, process-based.

1. Introduction

After many years of stagnation and decline respectively demand in the Swiss structural engineering market is meanwhile picking up again [1]. In spite of this positive trend existing overcapacities contribute towards an aggravating competitive environment [2]. To strengthen their competitiveness and assure their survival in the market economy, construction companies are forced more than ever to execute their projects as economically and efficiently as possible [3]. This is only possible if they strive for
operational excellence respectively best-practice in the individual processes, for which systematic selection processes are required.

Different analyses show that formwork costs form an important part of the shell construction costs of reinforced concrete buildings [4, 5, 6]. Figure 1 shows the cost distribution as revealed by an ad hoc survey of typical Swiss residential construction projects. The distribution demonstrates the relevance of the project-specific optimal formwork system for the overall project result [7].

![Figure 1. Cost distribution of formwork, reinforcement and concrete costs as revealed by an ad hoc survey of typical Swiss residential construction projects](image)

Attempts at structured selection processes can be found in different areas of application in the construction industry. The basic elements of the different methods - cost estimation, cost-benefit analysis and sensitivity analysis - are in most instances identical, solely their combination varies between e.g. Schmidt [8], Motzko [7] and Goger [9].

Current publications dealing with selection aids for formwork selection are limited to a list of selection criteria that should be taken into account, giving the decision makers neither a structured procedure nor any hint of how to weight the different criteria. Furthermore cost aspects are included only qualitatively in the selection process presented by e.g. Götz-Kottmann [10] and Spahr [11].

Generally, the developed methods pay too little attention to uncertainties and bandwidths and mostly do not verify the sensitivity of the selection results at all. Restriction to partial processes in order to reduce complexity has a more significant impact on the systematic and goal-oriented selection procedure. The consideration of interfaces and interactions with other, chronologically parallel processes becomes impossible. In addition to that, the simplification makes it difficult to determine the consequences of the selection on the overall process and, as such, to produce a holistic point of view.

Since no company can afford sub-optimal construction methods, a research project was initiated by the Institute for Construction Management and Economics at ETH Zurich to develop a cybernetic, process-based and system-oriented decision model for the
selection of formwork that incorporates interactive and interaction-relevant influences caused by parallel processes.

To detect the initial position as well as the practical demands on the model the following questions of cognition were asked:

- What is the state of practice respectively to what extent are the theoretical ideas of literature applied in practice?
- Do questions exist that have not previously been addressed by the existing processes but are relevant for formwork selection?
- What criteria influence formwork selection and to what extent?

2. Research methodology

To analyze the state of practice, a combination of empirical processes to obtain information using qualitative social research and quantitative investigations was chosen [12, 13]. Therefore an analysis plan including cognition objectives and an interview guideline was constructed. The interview guideline comprises the aspired purposes, the interview questions and the editing and evaluation methods.

The hermeneutical spiral for this research project to acquire knowledge about the state of practice of formwork selection combined systematic literature research to achieve basic knowledge about selection criteria and interviews. First of all, sample interviews were conducted to specify the crucial questions for the qualitative research as well as to refine the questionnaire for the quantitative research. The qualitative research was subsequently followed by semi-structured and problem-oriented interviews [14, 15]. The quantitative research requested the interview partner to weight the different selection criteria that were determined during the qualitative as well as the literature research. To secure the generalizability of the research results, the interview partners were chosen by strictly adopting the rules of qualitative sampling [14] so that the findings of the study can be regarded as being representative and assignable overall.

For the data preparation the interviews were transcribed and the qualitative empirically collected data concerning the procedure and criteria for formwork selection evaluated using an interpretative, qualitative analysis of the contents [16]. The quantitative data were evaluated using statistical methods. The results of the study are used in the course of the research work to define the criteria that must be integrated into the anticipated decision making model. Therefore the findings are inductively generalized.
3. Study approach and method

Since the main objective of the research project is the optimization of the formwork selection process, the research has to be restricted to an area with similar methods, structures and processes. Otherwise, it would only be possible to compare the different methods, but not to optimize them, as intended by the decision-making model. The study approach can be divided into four key elements: literature research, qualitative and quantitative procedures as well as validation and reliabilitation of the research results.

3.1 Literature research

Different approaches to similar problems inside and beyond the specific field of construction methods were analyzed in a systematic literature research process. Thus in addition to literature concerning solely formwork selection [e.g. 7, 17] and more universal selection methods for other construction methods like earthwork planning or shotcrete application [e.g. 9, 8] literature regarding selection methods in the stationary manufacturing industry was considered as well [e.g. 18, 19].

3.2 Qualitative procedure

To identify selection criteria not revealed by literature research, qualitative research in the form of semi-structured and problem-oriented interviews [15] was conducted in the context of the empirical study. Based on the initially defined questions of cognition the following topics were integrated into the interview guideline:

- Circumstances of formwork selection (project phase, time needed)
- General approaches to selecting formwork; definition of selection and exclusion criteria
- Basic principles of formwork selection (cost and performance values), methods for incorporating bandwidths and reciprocal impairments
- Decision-making aids and their application

Test interviews were conducted during the subsequent pilot phase to gain a basic understanding of the decision making process when selecting formwork and to refine the interview guideline respectively the key questions for collecting qualitative data and for the questionnaire for the collection of quantitative data. One of the main tasks of collecting actual data is the choice of interview partners. In order to allow generally
valid statements, these must be representative. The two-phase method that was selected first identified the companies to be examined, and then the actual interview partners. Since the decision making model is restricted to multi-story buildings with a reinforced concrete frame construction, the study focused on the market segment of residential and office buildings.

On the supply side, an internationally operating supplier of formwork with a share of about 40% of the Swiss market and about 30% of the German market was chosen for the analysis. Given the trend away from purchasing and towards renting formwork, all companies that work with rental formwork now are, in principle, clients. Given this large basic population, the generalizability of the findings can be deemed to be guaranteed. Subsequently, branch offices were selected at random, where the individual interview partners were identified on the basis of maximum contrast in terms of functional level.

On the client side, the selection was based on the assumption that large construction companies apply good practice in terms of method and formwork selection in order to generate profits and strengthen their position in the market. In view of this consideration, three companies each were chosen at random from the list of Germany’s five largest, and Switzerland's five largest construction companies. The interview partners were selected on the basis of their relevance for the research project and with a view to achieving maximum contrast, again, in terms of functional level.

3.4 Collation of quantitative data

The basic idea behind collecting quantitative data was to allow the interview partners to weight the selection criteria addressed in the interviews. The pilot interviews revealed, however, that the majority were only able to list a few criteria. In consequence, supplementary literature research was conducted in order to collate logical criteria deemed by the relevant authors to be pertinent, and to present these in list form.

The criteria were evaluated during the course of the interviews after conclusion of the issues surrounding the general formwork selection procedure, including the indication of proprietary selection criteria. This ensures that the collation of qualitative data could not be influenced by the collection of quantitative data. Statistical methods were used for evaluation.

3.5 Validation and Reliabililization of the findings

During the study, pre-selected criteria were examined in terms of market occurrence. Given the market dominating position of the companies that were examined, the years
these companies have survived in a competitive environment, and the inclusion of all functional levels that are involved in the formwork selection process, the sampling and, as such, the selection of interview partners and, ultimately, the findings, can be deemed to be quasi representative.

4. Findings from the study

The findings presented in this paper are based on the evaluation of the collected data, with focus on the statistical examination of the selection criteria and their weighting. The evaluation needed to take into account the fact that the interviews were conducted both with a supplier and clients. These players pursue differing economic goals – clients want to minimize overall costs, suppliers want to maximize sales – which is why qualitative content analysis [16] was used for the separate evaluation of each. In addition, the study reveals the extent to which the supplier recognizes the clients’ goals and can generate maximum client benefit in order to increase market shares and maximize profits. The weighted criteria will be evaluated statistically, whereas at the same time the empirically obtained material will be analyzed controlled methodically and split into the following four categories:

- There is no standard systematic approach to selecting formwork systems.

- Formwork systems are generally chosen intuitively.

- Formwork systems are generally chosen irrespective of any interfaces.

- Formwork systems are generally chosen with insufficient account being taken of any uncertainties.

4.1 Systematics

There is no standard systematic approach to selecting formwork systems. As such, the individual meetings revealed that neither the formwork manufacturers that were examined nor individual construction companies adopt a cross-corporate standard systematic approach to selecting formwork systems. Since only about 80% of the interviewees listed different selection criteria for the formwork selection procedure and even on inquiry only about 40% were able to describe the clear structure of the individual work steps and their sequence, it is still doubtful whether the procedure adopted by the individual engineers is based on a clear structure.
4.2 Subjectivity

Formwork systems are generally chosen intuitively. All interviewees – both supplier and clients – admitted that their decision-making process was based on personal experience and personal preferences. Only one third of the interview partners is aware that their intuitive handling prevents them from examining other, possibly better solutions.

The prioritization of the selection criteria varies from one agent to the next, on both the supply and client sides. This is demonstrated by the large standard deviations; as such, there is no guarantee that a different agent will repeat the decision making process. Therefore the reproducibility is not given.

![Figure 2. Comparison of selection criteria and their importance for selecting formwork in terms of suppliers and clients with indication of the mean values (standard deviation)](image)

The calculation of the correlation coefficient for measuring the agreement in terms of the weightings by the two groups revealed linear agreement with more than 90 percent certainty. As such, the various criteria are weighted similarly by both the supplier and clients, apart from a few exceptions.

The selection criterion “Staff management and quality” revealed the largest discrepancy between the supplier’s and clients’ mean values. The minor importance for the supplier in terms of formwork selection is mainly due to a lack of knowledge or insufficient information relating to the client’s planned deployment of manpower. In contrast, clients generally know which staff will be used even before the project begins and can therefore adapt the formwork system if necessary. Otherwise, the relatively large standard deviations of 1.04 and 1.16 indicate a large spread of the answers.
The criterion “Client requests” revealed a spread of answers that was nearly as large. Since the property developer as the construction company’s client (“client of the client”) is generally not terribly interested in a specific formwork system, this criterion was not further pursued in the interviews with staff members of construction companies. In contrast, the construction company, as the formwork manufacturer’s client, is very experienced and has clear ideas of which formwork system should be used for specific projects. The interviews with the supplier’s staff revealed that these client requests only represent a material or important factor in the formwork selection for about 22% of the interviewees, whereas some 20% classed this selection criterion as irrelevant.

The weighting of economic efficiency, on the other hand, revealed general consensus, both among the individual interview partners and among the formwork manufacturers and construction companies, as demonstrated by the low standard deviation values of 0.47 and 0.62 and the minor difference between the mean values. At the same time, all interviewees agreed that economic efficiency was one of the main criteria with the highest level of importance for the formwork selection, in addition to repeatability and, as such, the frequency of use of the formwork within the framework of the specific project.

An evaluation of the collected data, taking account of the various functional levels, is illustrated in Figure 3. Although the weighting by the supplier’s various functional levels is more or less identical, the findings reveal marked differences on the part of the clients. This is confirmed by a correlation coefficient test (62% clients, 93% supplier).

![Figure 3. Comparison of selection criteria and their importance for selecting formwork in terms of functional levels with indication of the mean values (standard deviation)](image)

On the client side, the largest differences occur in the evaluation of the building site structure and the importance of staff management and quality. Whereas the building site...
staff believes that the first factor is underestimated by the corporate administration, especially in terms of existing and requisite crane capacity, exactly the opposite is true for the second criterion.

However, it is the selection criteria indicated during the collection of the qualitative data that are more interesting for the evaluation. For example, the study found that the importance of a formwork system being flexible changed depending on the function of the interview partner. Whereas the clients’ corporate administration staff point to contractually agreed budget lead times and delivery schedules and, as such, weight flexibility as correspondingly less important, the construction managers who were interviewed classify the rapid adaptability to changing plans or constraints as a central aspect in the formwork selection process, based on their personal experience.

Further selection criteria that were listed by the interview partners during the collection of qualitative data and classified as relevant include the foreman’s preferences on the client side, whereas the supplier lists material availability, personal contacts and a basis of trust.

### 4.3 Inclusion of interfaces

Formwork systems are generally chosen irrespective of any interfaces. Nearly 80% of the interviewees admitted to taking no, or scarcely any account of internal (shell) and external (shell-finishing works) interfaces and the ensuing reciprocal impairments when selecting a formwork system (Fig. 4). About 17% address such issues as crane capacity and use these considerations as a basis for defining the formwork system requirements only for major projects (e.g. stadium building sites). In terms of “normal” standard projects, such as multi-story buildings with reinforced concrete frame constructions, the associated planning effort and time involved are deemed to be too large compared with the benefit that might be gained. According to 75% of the clients’ interview partners, the finishing activities are of lesser priority. Since, in addition, the finishing works are generally performed by subcontractors or independent companies, the interactions between shell and finishing works are not taken into account when selecting the formwork system. This should, however, be critically challenged in terms of the ensuing losses from non value adding activities [20].

![Figure 4. Illustration of the interview findings in terms of the inclusion of interfaces](image-url)
4.4 Inclusion of uncertainties

Assumptions relating to performance values must be made when preparing cycle plans, which then are used as the basis for calculation. These values are generally based on experience from similar projects and, consequently, represent specific mean values rather than being aligned to optimal processes. Since it is difficult to transfer values once they have been calculated, given the unique character of the construction industry, all parameters need to be analyzed within certain bandwidths when addressing the issue of the uncertainties associated with these values in the formwork selection process.

The collection of qualitative data revealed that these uncertainties are taken into account in practice in generally two ways:

- The interview partners totally ignore the aspect of uncertainties, some even assume optimal conditions and only intervene with corrective measures during the actual construction process. This approach is an unrealistic reproduction of reality and, as such, a poor basis for work preparation. It results in more work in the actual construction execution process, sub-optimal construction processes, increased manufacturing costs and a reduction in the calculated profit or margin.

- Other interview partners use buffer times and defensive performance assumptions to hedge against these uncertainties. The assumptions in question are based on experience. If these factors are already included in the bid calculation, the approach will scarcely culminate in orders being awarded, given the current competitive situation. Moreover, in terms of schedule planning, it is seldom possible to adhere to contractually agreed deadlines if such defensive performance assumptions are adopted.

Neither of the two alternatives seems to be ideal for guaranteeing low-friction construction works. Ideally, existing uncertainties should be identified, the impacts of the various constraints should be incorporated into the performance assumptions and, based on this, the optimal formwork system and stock volumes should be selected.

5. Conclusion

The project-specific and process-oriented selection of construction methods represents a core competency of a construction company and has a decisive impact on work efficiency and the related costs. Based on the evaluation of the qualitative and quantitative data collected, the study was able to prove that, generally speaking, neither theoretically existing knowledge nor a (standard) systematic approach are applied, nor are the interactions among the finishing works being performed, in part, in parallel
taken into account when it comes to choosing systems – even for complex construction projects.

In addition to selection criteria culled in advance from literature research, further criteria were identified during the collection of the qualitative data, which are material for the selection of formwork. The evaluation of the quantitative analysis revealed that economic efficiency, repeatability and the actual structure itself represent the main selection criteria. The study further revealed that any evaluation of economic efficiency to date has been restricted to an analysis of the requisite stock volumes and the costs immediately associated with the formwork. In addition, the study revealed that formwork manufacturers are largely aware of their clients’ criteria, and are able to adequately assess the clients’ weighting. So far, suppliers have underestimated the importance, both of performance and of client requests.

Since no signs of a holistic approach were found in practice, the next research work will focus on developing such a holistic approach. This must take into account the technical and economic impacts of individual system decisions on the overall process, and incorporate the associated internal and external interactions into the decision making process.

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