Received: 10 February 2017 | Revised: 9 November 2017 | Accepted: 28 December 2017
DOI: 10.1002/sys.21425

RESEARCH PAPER

WILEY

Successful verification of subcontracted work in the construction industry

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Abstract

Due to the introduction of new types of contracts, such as Design, Build, Finance, & Maintain (DBFM), a major shift in tasks and responsibilities from client to contractor can be seen in the construction industry. To manage these new contracts and corresponding shifts in responsibilities, systems engineering (SE) is seen as a relevant instrument and applied increasingly in this industry. When these new, integrated contracts are applied in combination with SE, the contractor becomes responsible for verification. The contractor, however, is not the only organization that executes verification tasks as contractors regularly subcontract work to suppliers. Although the main contractor bears the final responsibility toward the client, it may be expected that the supplier verifies its own work. This requires verification to be carried out further down the supply chain. However, many problems are experienced when allocating these verification responsibilities to the suppliers. This paper explores which verification problems are faced in construction work that is subcontracted to suppliers. A conceptual framework is applied to categorize these problems and to analyze the solutions applied in the construction industry. The major finding of this study is that causes of verification problems can be found at both the contractor and the supplier side. Improvements are suggested for both these sides.

KEYWORDS

civil engineering, construction industry, subcontracting, supply chain, verification

1 | INTRODUCTION

In the construction industry, clients increasingly focus on their core business and pay more attention to exploiting specific knowledge and skills available on the market. This has resulted in a shift in tasks and responsibilities from the client to the contractor in the past decade. To accommodate this shift, new types of contracts are used increasingly and these new contracts integrate a larger part of the project life cycle and are known as integrated contracts, for example, Engineering & Construct (E&C), Design & Construct (D&C), and Design, Build, Finance, Maintain, & Operate (DBFMO) and similar types.[1,2] Although being responsible for a smaller part of the project life cycle in these contracts, clients still want to keep control over their construction projects. Systems engineering (SE) is therefore applied increasingly and is seen as a way to outsource a larger part of the project life cycle, for example, design, engineering, and construction, while still being in control.

That the attention for SE in the construction industry is rising becomes clear by an increasing number of publications about the method in academic journals, conference proceedings, magazines, and in guidelines and handbooks. For example, in a position paper, Aslaksen[3] specifically addresses the use of SE in the construction industry, and together with Brouwer and Schreinemakers, Aslaksen further elaborates on tailoring SE principles to the construction industry.[4] Also professional magazines address the use of SE in the construction and civil engineering industry more prominently. For example, the magazine "INSIGHT" has published a special issue on infrastructure SE, including articles on the civil engineering industry.[5–7] Handbooks and guidelines have also appeared in the past 15 years, such as the "Guide for the Application of SE in Large Infrastructure Projects,"[8] the guidebook on SE in the civil engineering industry in The Netherlands,[9] and the "Systems Engineering Guidebook for Intelligent Transportation Systems."[10] Moreover, articles have been published in which the use of SE in specific civil engineering projects is

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discussed.[11–14] Finally, SE in the civil engineering industry is considered in relation to education and training[15] and procurement.[16] In general, literature demonstrates that the attention for SE in the civil engineering industry and the construction industry is increasing and vice versa. Not only can civil and construction engineers learn from systems engineers, but systems engineers can also learn from this specific industry.[17]

Important elements of SE are the iterative requirements specification, functional analysis, and design processes, and hierarchically structuring the requirements, system, and activities.[18] The iterative nature of these activities allows the distinction of different levels of detail, as they are carried out on an abstract level in the first iteration, and in more detail in subsequent iterations. This enables the client to choose a certain level of detail, or several levels of detail for different parts of the system, for the contract that is tendered, possibly leaving out the prescription of (technical) solutions and thus maximizing the opportunities for the contractor to use its knowledge and optimize solutions. This also enables the client to procure a larger part of the project life cycle and to focus on its core business, while still maintaining control over the design process.

Two important elements of SE are verification and validation, often considered in close relationship with one another. Verification is the confirmation, through the provision of objective evidence, that specified requirements have been fulfilled. It is a set of activities that compares a system or system element against the required characteristics. This may include, but is not limited to specified requirements, design description, and the system itself.[18] Validation is defined as confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled. Validation is the set of activities ensuring and gaining confidence that the system is able to accomplish its intended use, goals, and objectives (i.e., meet stakeholder requirements) in the intended operational environment.[18,19]

As a consequence of the use of integrated contracts and the application of SE, there is a shift in responsibility for verification and validation in the construction industry. In the case of traditional contracts, in which the client prescribes in detail what has to be done by the contractor, verification and validation are the responsibility of the client, but in the integrated contracts, this responsibility shifts to the contractor.

Due to this major shift in tasks and responsibilities from client to contractor, most research focuses on the client–contractor relation.[20,21] The contractor, however, is not the only organization that executes design or construction tasks. Since contractors sometimes subcontract up to 90% of the total project turnover, suppliers (or subcontractors) have a large impact on project performance too.[22] Due to this large part of the work being subcontracted, the suppliers play an important role in the verification and validation process. These interrelations are shown in Figure 1. Although the contractor bears the final responsibility toward the client, it may be expected that, similar to the shift in responsibilities from client to contractor, also a shift takes place from contractor to supplier, meaning that the supplier also verifies its own work.

This requires the application of SE further down the supply chain. However, many problems are experienced when allocating verification and validation responsibilities of subcontracted work to the suppliers. In practice, for example, contractors experience problems such as the verification and/or validation not being executed by the supplier, not being complete, or not being executed at the desired level of detail. Along the same line, other problems are discussions about responsibilities and interfaces, design problems in late phases of the project when changes are expensive and difficult, a lack of coercive instruments to stimulate the supplier to execute the verification and validation, and finally extra costs to solve the aforementioned problems.

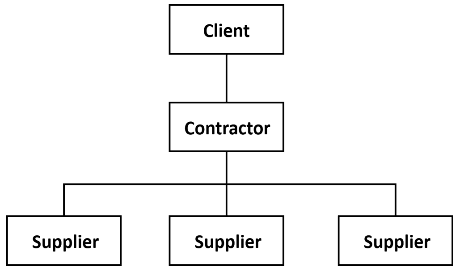

FIGURE 1 Project interrelations and hierarchy

Besides, a specific, but crucial characteristic of the construction industry is the culture that suppliers are mostly not allowed to contact the client directly. Sometimes, the contract prohibits this contact, but even if the contract allows it, the client can be unwilling to communicate with suppliers as it only wants to deal with the main contractor, even if direct communication between client and supplier might be in the best interest of the client. Also, the main contractor may restrict communication between supplier and client, because the contractor wants to be in full control, wants to prevent the communication of possible contracting information, does not trust the supplier, or wants to prevent commitments from the suppliers.

Therefore, in many cases in the construction industry, contact between supplier and client has to run through the main contractor. This makes it difficult, or almost impossible, for the supplier to validate its work. This is reinforced by the fact that validation of the system as a whole is not always possible because of the limited scope of the supplier. Consequently, this lack of direct communication between client and supplier puts enormous pressure on the verification process as, in this specific context, verification then becomes the only process to ensure that the system is in keeping with stakeholder expectations. Verification in this setting gets the function of validation too. In several SE handbooks, articles, and guidelines, it is said that verification is the process to ensure that the system in built right, and that validation is the process to ensure that the right system is built. However, in the construction industry, the verification process has to ensure both: that the system is built right and that the right system is built.

Among others, the context and problems mentioned result in tension in the client–contractor relation and the contractor not being able to prove to the client that all specified requirements are met. This can lead to the client withholding payments and finally causes adverse financial consequences for the contractor.

Based on the situation described above, the specific research question answered in this paper is therefore as follows: *Which verification problems do contractors face when subcontracting work to suppliers and how are these problems solved?*

This paper contributes to practice by presenting recommendations to contractors to develop their procurement strategy. Among others, this prevents problems with the verification of subcontracted work and may increase project performance. This paper contributes to theory by combining concepts from construction supply chain management, SE, and verification and validation, a combination not addressed in research before. Most research addresses verification and validation, but does not include verification and validation further down the supply chain.[23–26] There are some notable exceptions, but these do not focus on the construction industry.[27,28] More specifically, this paper contributes to knowledge about the role of verification in a context where validation is not allowed.

This study introduces a conceptual framework based on the System and Requirements Classification Model (SRCM) of Terry Bahill and Henderson[26] to categorize verification problems and possible solutions. This conceptual framework functions as a set of a priori constructs to direct the content analysis of a case study conducted among 17 contractor–supplier relations of a medium-sized Dutch contractor.

The paper continues in Section 2 with describing the verification process, the verification problems experienced, and introduces a conceptual framework to categorize verification problems and possible solutions. Section 3 describes the methodology followed. Section 4 presents the results of a case study and links these results to the conceptual framework. After the discussion of the results, Section 5 presents the conclusion and provides improvements for the subcontracting of work in order to prevent verification problems.

2 | VERIFICATION PROBLEMS AND SOLUTIONS

To categorize the verification problems that contractors experience when they subcontract work to suppliers, we used the framework of Terry Bahill and Henderson.[26] To categorize system failures, Terry Bahill and Henderson developed the SRCM. This model juxtaposes two important and interrelated concepts from the SE theory: "system verification and validation" and "requirements development" (i.e., determining stakeholder expectations, demands, and needs and process these into a [functional] requirement set). Based on these two concepts, the model categorizes system failures and provides a means of categorizing systems in terms of design conformity and requirements satisfaction. It also provides a way to study requirements not yet satisfied by any system. The SRCM can provide a framework to categorize problems and find solutions for the verification of suppliers' work.

The SRCM is, however, not directly applicable to verification problems in work that is subcontracted to suppliers. In our study, we excluded validation, but validation is an integral part of the SRCM, as system verification and validation are considered together. Simply leaving out the validation part, would cripple the model, as a large part of the model would no longer be relevant. Directly applying the SRCM to this study is therefore not possible.

The axes of the SRCM on which failures or problems are categorized are, however, relevant within the scope of verification of subcontracted work. Therefore, an adapted framework using these axes has been developed for categorizing verification problems that occur in subcontracted work further down the supply chain. The framework is based on two axes: (1) supplier compliance to the contracted verification obligations and (2) the validity of the contracted requirement set.

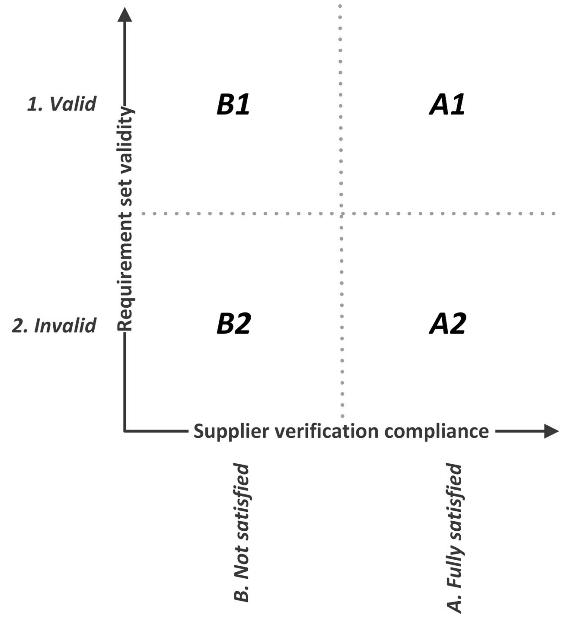

FIGURE 2 Framework for categorizing supplier verification problems (based on Terry Bahill and Henderson[26])

Figure 2 shows the framework for categorizing supplier verification problems. Given the two axes, the following four groups can be distinguished:

- Group A1 describes the contractor–supplier relations in which a valid requirement set was contracted and the supplier fully satisfied its contractual verification obligations, which means that the supplier has proved, to the level its contract requires, that the system fulfills the specified requirements. Also, the requirement set is considered valid for the scope of the supplier's work. In fact, group A1 describes the cases in which no verification problems occurred.
- Group B1 also describes relations in which a valid requirement set was contracted. However, the supplier did not satisfy its verification obligations. Although the requirements were valid, the supplier could not prove that the specified requirements were met. In this group, the verification problems originate from the supplier's verification process. It can, for example, be caused by a lack of verification competence. Additional verification could prove that the system satisfies the specified requirements.
- Group A2 describes the relations in which the supplier satisfied its verification obligations. However, the contracted requirement set is considered invalid. This means, for example, the requirements set is incomplete, inconsistent, or does not match the type of work of the supplier. Although the supplier has satisfied its verification obligations and there is no contractual problem between contractor and supplier, the requirements not included in the contract, remain unverified. This may lead to verification problems for the system as a whole.

- Finally, in group B2, the contractor provided an invalid set of requirements, and the supplier did not satisfy its verification obligations, causing a contractual problem between contractor and supplier. Problems, however, can also be traced back to the contractor as the requirements set is invalid, making it difficult or impossible to prove that the system meets all requirements. This may lead to verification problems later on.

2.1 | Solutions for verification problems

To solve or prevent verification problems of work that is contracted to suppliers, four possible solutions have been identified based on literature. These solutions can be divided in two precontract solutions (I, II) that can be applied during the contractor's procurement process before the contract with the supplier is signed, and two postcontract solutions (III, IV) that can be applied after the contract with the supplier is signed. Combinations of solutions are also possible.

2.1.1 | Precontract solutions

There are two precontract solutions that the contractor can apply to prevent or solve verification problems. The first solution (solution I) is for the contractor to carefully consider the level of detail of the work to be subcontracted to a supplier in relation to the choice for a specific supplier. The contract level of detail determines which part of the tasks and responsibilities are allocated to the supplier and which are not. The contractor has several options for contracting out based on a certain level of detail. The first option is that all design and engineering tasks, including verification, are performed by the contractor. Consequently, the supplier is only contracted for executing the work. The second option is that design and execution are carried out by the supplier, but verification is done by the contractor. The third option is that design, execution, and verification are done by the supplier, using a verification procedure prescribed and managed by the contractor. And finally, design, execution, and verification are all done by the supplier (i.e., "completely" subcontracted).[22,29]

It is important to consider the choice for the contract level of detail in relation to the skills of the supplier. Among others by taking into account the competences and experience of the supplier.[2,30–32] A mismatch between the level of detail contracted out and the competences of the supplier can cause verification problems, for example, because the supplier does not have the skills to successfully execute the verification process.

As a second precontract solution (II), the contractor could explicitly consider and describe the supplier's scope, responsibilities, and expectations, especially with regard to the verification process and results. This should be explicitly stated in the contract between contractor and supplier.[33]

2.1.2 | Postcontract solutions

Besides the precontract solutions, also postcontract solutions can be distinguished in literature to prevent or solve verification problems. As a postcontract solution (solution III), the contractor can heavily coordinate the requirement development, the verification process, and interfaces for the entire project, making sure that all requirements, further decomposed by the suppliers, are able to verify the top level requirements and that no gaps or contradictions between the decomposed requirements arise.[22,33,34] This solution means that the contractor remains responsible for the interfaces between the suppliers and should invest resources in coordination activities.

As the final postcontract solution (IV), the contractor can take over the verification tasks from the supplier and execute or finish them.[9,32] This is an emergency solution when the supplier is not able to meet its verification responsibilities. This solution requires the contractor to ad hoc invest in verification activities.

3 | RESEARCH METHODOLOGY

We analyzed 17 supplier relationships among three projects. The projects are contracted to a middle-sized construction contractor in the Netherlands. The projects were selected following procedures described by Yin.[35] Using the one-phase screening approach, a quick scan among nine different construction projects was conducted to determine the suitability of each for further analysis. Based on this quick scan, three projects were selected, including 17 suppliers in total. These projects were selected so that all projects were SE projects that all used integrated contracts. Moreover, the number of suppliers was equally distributed over the three projects and consisted of a diversity of suppliers with different levels of experience in verification and working with integrated contracts.

The first project is the design and construction of a highway exit, including a highway overpass, reconstruction of parts of the local road network, and landscaping. This project consisted of different types of work, ranging from relatively simple earthworks to the more complex parts of the highway overpass. The contract between client and contractor was specified in such a way that, especially for the overpass, the contractor still had to make important design decisions and was able to choose, for example, construction type, method, and phasing. This also created opportunities for the contractor, in its role of coordinating both the design and construction phases, to determine its subcontracting strategy. Although procured by a local municipality, Rijkswaterstaat* was also closely involved.

The second project is the design and construction of a large sash lock, which also has a water safety function, and includes a moveable bridge. Procured as an integrated contract, this project included a variety of work including earthworks, roadworks, civil works, and complex electro technical and mechanical installations. The main contractor was responsible for both the design and construction phase, but hired a specialized engineering firm for the design coordination. The water safety function of an existing lock at the same location created technical and phasing challenges for the contractor, since simply removing the old lock and replacing it, was not allowed. Especially the complex electro technical and mechanical installations, for controlling the bridge and lock, proved to be difficult as this was outside the field of expertise of the contractor, and thus subcontracted to several suppliers.

The third project is about the reconstruction of a train station, redevelopment of the train station's surrounding urban area, and the construction of two grade separated railway crossings. Procured as an integrated contract, a variety of different types of work and a combination of clients, including ProRail,[†] NS (Dutch railways), and a local municipality, resulted in a complex contract. This, however, also enabled the contractor to subcontract work at different levels of detail, for example, by subcontracting all steel-related works to a specialized supplier.

3.1 | Data collection and analysis

The data for this research are collected from semistructured interviews with key project members, and from a document's analysis. The interviewees were all closely involved in both the design and construction phase of the projects, for example, as project leader, design leader, or technical manager. In these roles, they had a good overview of the project, the SE challenges, and the subcontractors involved. In addition, desk research has been conducted in which contracts, scope descriptions, verification plans, and other relevant documents were inspected.

The data collection and analysis can be split in roughly three successive stages. First, a conceptual framework was developed to categorize different types of verification problems that occur in practice. This framework was built upon SE theory and allows for a clear analysis of each verification problem type and helps to identify solutions to these verification problem types. In the second stage, the framework is used to gather the data from the projects. The final stage is to analyze and explain the problems and solutions using the conceptual framework and the empirical results found.

3.2 | Enhancing reliability

To secure that the case study is valid, this research uses a combination of methodological, theoretical, investigator, and data triangulation. Methodological triangulation was applied by analyzing the three projects and 17 supplier relations using both interviews and document study. By using the conceptual framework for categorizing both verification problems and solutions, we achieve theoretical triangulation. During the research process, each case study research step as described by Yin, for example, the case study protocol, the data, and the analysis report, were discussed with senior researchers in the field of construction management research (investigator triangulation).

As suggested by Eisenhardt and Yin,[35,36] a case study protocol was developed and discussed before starting the actual study. Also, a case study database was developed, which was used to document the desk research and interviews, thus improving the reliability of our study.

Swanson and Holton[37] describe external validity as the extent to which a study's findings can be generalized to other populations or settings. In this research, we increased the external validity by using accepted constructs for categorizing the verification problems and solutions, by data source triangulation, and by the external control of the interview manuscripts and draft case study reports through the key informants. The external validity of the present multiple-case study is further enhanced by making use of 17 contractor–supplier relations resulting in a broad overview of SE verification problems and solutions occurring in civil engineering projects.

Our findings were compared to the existing literature (see Section 4). Similarities with existing literature enhanced the internal validity and generalizability of the findings. Conflicts between findings and existing literature provided a better understanding of the findings, and sharpened the conclusions.

3.3 | Scope of the research

This research focuses on identifying verification problems that a construction contractor faces when subcontracting work to suppliers in integrated construction contracts. The scope is limited to projects in which integrated contracts and SE are used, and only the relation between contractor and supplier is considered.

Another important scope limitation is the exclusion of validation. As explained in the Introduction, direct contact between client and supplier is often not allowed or wanted, despite the fact that the client can benefit from adequate validation by the supplier. Consequently, the supplier is, due to its limited scope, not always able or allowed to execute the validation process. In the construction industry, validation is done at the system level and carried out by the main contractor. The further down the supply chain, the more difficult it becomes to validate and the more reluctant organizations are to allow validation. Therefore, validation is not included in the scope of this study. Only the verification of the specified requirements is considered.

The final scope limitation is the context of the research. The context of this research is the Dutch construction industry, which has shown the major shift in tasks and responsibilities from the client to the contractor in the past decade. With the introduction of new legislation on integrated contracts, construction projects are tendered in earlier phases of their life cycle and for a larger part of their life cycle. This has resulted in the Dutch construction industry making a change from an owner controlled to a contractor controlled environment and the extensive use of SE.

4 | RESULTS

In this section, the results of the research are presented. First, an example of one contractor–supplier relationship is described to demonstrate how the data were analyzed. Then, the data of the other contractor–supplier relationships are presented in a table and further analyzed and explained.

4.1 | Analysis example

At the start of the analysis, each contractor–supplier relation is analyzed separately by categorizing the problem group and the applied solutions (see Table 1). As an example, the analysis of supplier relation 2-1, from the sash lock and moveable bridge case, is described. The indication “2-1” means case number 2 and supplier number 1. Supplier

TABLE 1 Overview of cases, suppliers, and corresponding verification problem groups, ordered to problem categories

Supplier	Type of work	Problem group	Applied solution
2-2	Integral design of both the civil constructions and road works, supplier reviews, risk management, and interface management	A1	I
3-2	All rail-related objects in the project, such as the tracks, sleepers, ballast, and electrical installations	A1	I
1-5	Engineering and realization of road markings, barriers, signage, and traffic measures	A1	I, II,[a]
1-6	Execution of earthworks	A1	I, II,[b]
3-4	Engineering and execution of all sheet piling, drainage, Cutter Soil Mix (CSM) walls, and ground works	A1	I, II
1-4	Design, realization, and maintenance of greening	A1	I, II, III,[c]
2-4	Execution of sheet piling, canal/lock floor protection, canal/lock bank construction, slackening structures, ground works, and some detailed design tasks	A1	I, II,[c]
1-1	Integral design	B1	III
3-1	Positioning of the railroad crossing's deck	B1	III,[d]
3-6	Design and adaptation of the station's steel roof structure, including the conservation and mounting	B1	IV
2-1	Integral design, engineering, production, testing, supplying, assembling, and completion of the steel structure of the movable bridge and the steel lock doors	B1	II, III, IV
3-3	Integral project design, excluding the design responsibilities of Supplier 3–5	B1	IV
3-5	Design, engineering, and execution of all installations (except the rail-related installations from Supplier 3-2) and lighting	B2	III, IV
1-2	Engineering, production, and supply of the overpass' girder work and pressure layer	B2	II, IV
2-5	Design, engineering, production, testing, supplying, mounting, and completion of all electrical installations (e.g., the bridge and lock door control systems)	B2	II, III, IV
1-3	Design and realization of vertical vegetation on the highway overpass, including the verification of the requirements	B2	IV,[e]
2-3	Integral design, engineering, production, testing, supplying, mounting, and completion of all mechanical installations for both the moveable bridge and the lock doors	B2	III, IV

[a]Payments only after completed verification.
[b]Matching contract level of detail to supplier competences.
[c]Explicitly describing expectations.
[d]Enforce verification by supplier.
[e]Formal notice of default.

2-1 was responsible for the integral design, engineering, production, testing, supplying, assembling, and completion of the steel structure of the movable bridge and the steel lock doors. A letter of intent was signed with Supplier 2-1 during the project's tendering phase.

Supplier 2-1 is categorized in verification problem group B1. In general, the verification executed by the supplier was incomplete and lacked the required detail. Therefore, the supplier did not comply with the verification obligations. The contracted requirement set is valid as there were no indications that requirements were lacking or incomplete.

The results show that the contractor applied several solutions for the verification problems in the relation with Supplier 2-1. The contractor decided to subcontract all steel structure–related work, including all levels of details, as the contractor did not possess the required competences and knowledge and the supplier did. The choice for Supplier 2-1 was, therefore, based on the supplier's expertise related to steel structures, a strategic and thoughtful selection. However, the level of detail of the work contracted out resulted in the supplier being responsible for the verification. Supplier 2-1 did not have all required skills and expertise regarding this verification responsibility. The contractor did not apply precontract solution I completely, as the supplier's verification skills and expertise were not considered in the selection procedure. Precontract solution II was applied as the contractor explicitly described the supplier's scope regarding verification in an appendix to the contract. Finally, the contractor coordinated the requirement development process and the interfaces between suppliers during the project, especially in the design phase. This is an example of postcontract solution III.

Despite the contractor's effort in applying the precontract solutions and the postcontract solutions, there were still verification problems in this contractor–supplier relation. The verification problems were mainly caused by a lack of effort and resources allocated by the supplier to verification, resulting in incomplete and inconsistent verification. The contractor, therefore, decided to complete the lacking verification parts, an example of postcontract solution IV.

Along a similar line of reasoning, also the other 16 contractor–supplier relationships were analyzed. Among 17 suppliers in three projects, seven supplier relations did not show verification problems and were thus categorized in group A1. Ten suppliers were categorized as having experienced verification problems (i.e., groups B1, B2). Category A2 is not present. A draft report including these findings is discussed with participants of the study, the contractor and with independent researchers to further increase the validity of the study.[35,37]

4.2 | Analysis results

In this section, the 17 contractor–supplier relations are presented in Table 1 and further explained in the text.

The A1 category is represented the most and consists of seven contractor–supplier relationships. This means that there are quite some situations without verification problems. Moreover, the A1 category is present in all cases, meaning that in all three projects there are contractor–supplier relationships without verification problems. Regarding the solutions used in this category, solutions I, II, and III are used. Obviously, solution IV, in which the contractor takes over verification tasks from the supplier, was not used as no verification problems occurred. Moreover, different kinds of combinations of solutions are present, but solution I is always present in this category, often in combination with solution II.

There are five suppliers in the B1 category. This means that the requirements set provided by the contractor is valid, but the suppliers did not comply with their verification responsibilities. This situation is present in all three projects. Regarding the solutions used in this category, the postcontract solutions III and/or IV are used in most supplier relations. Precontract solution II is used only once and solution I is not used at all.

There are five suppliers in the B2 category. This means that the contractor provided an invalid requirements set and the contractors did not comply with their verification responsibilities. Also this situation is present in all three projects. Regarding the solutions used in this category, a similar pattern as in the B1 category is visible. In all supplier relations, a postcontract solution (III and/or IV), was applied, while precontract solution II was applied in only two relations and solution I was not applied at all.

Summarized, the results show that in each project there are contractor–supplier relationships without any problems. Also, in each project, the contractor has provided invalid and valid requirement sets, and in each project there are suppliers that comply with their verification responsibilities. Situations in which suppliers fail to meet their verification responsibilities, are however also present. Moreover, there is no evidence that some cases did better than others with respect to verification. Case-specific patterns are thus absent. These findings were discussed with participants of the study, the contractor and researchers to increase the validity of the study.

4.3 | Overall patterns

With regard to the precontract solutions applied, two important patterns appear. First, solution I was applied in all category A1 supplier relations, but not applied in any of the B1 and B2 supplier relations. This indicates that the careful consideration of the level of detail of the work to be subcontracted to a supplier, in relation to the choice for a specific supplier, is crucial for preventing verification problems. This is strengthened by the fact that in most category B supplier relations, in retrospect, it appeared during the project that the supplier lacked the required competences. Thus, a match between the supplier's competences, especially regarding verification, with the level of detail of the subcontracted work is crucial.

Second, solution II (clearly defining scope) was present in most category A1 supplier relations (five out of seven) and absent in most category B1 and B2 supplier relations (absent in 7 out of 10), which indicates that a clear description of the scope, especially considering verification, can contribute to preventing verification problems. A clear description of the supplier's responsibilities regarding verification can prevent differences in the conception of the verification responsibility. Although a scope description was present in almost all supplier relations, for example, using a standardized purchase specification, detailed information regarding verification processes lacked in the category B supplier relations.

With regard to the postcontract solutions applied, some other patterns appear. Solution III (heavy coordination by the contractor) is applied three times in both the B1 and B2 categories. This solution is often used in combination with solution IV. Solution IV was applied in three out of five B1 relations and in all B2 relations, which indicates that the contractor often completes or takes over the suppliers' verification tasks. This resulted in extra costs for the contractor. In the case study interviews, it was often mentioned that project progress was considered more important than keeping the supplier to its contractual obligations. Also, the contractor's available contractual coercive measures were limited.

4.4 | Results summary

Precontract solution I, carefully considering the level of detail of the work to be subcontracted to a supplier in relation to the choice for a specific supplier, can be considered as a prerequisite for successful verification. Verification problems can be further prevented by explicitly describing the supplier's scope regarding verification (solution II). In most category B cases, this explicit description, including the contractor's actual expectations of the verification process and results, lacked. Finally, the contractor completed the supplier's verification in most category B cases, instead of keeping the supplier to its contractual obligations, and thus made extra costs.

The problems mentioned above, can be partly traced back to a lack of time spent to these potential solutions, for example, caused by a tight schedule or limited budgets. The tight schedule for the contractor can be caused by an already tight client schedule, an aspect outside the scope of this research. However, it can also be caused by the contractor paying too little attention to, or not recognizing the importance of, procurement and verification. The same applies to the budget for procurement and verification, which can be limited due to a tight overall project budget. It can also be caused by the contractor reserving insufficient budget for verification.

5 | CONCLUSION AND RECOMMENDATIONS

In this research, which verification problems contractors face when they subcontract work to suppliers is explored. A conceptual framework has been developed, based on the SRCM described by Terry Bahill and Henderson,[26] to categorize different types of verification problems that occur when subcontracting work to suppliers. Several conclusions stand out.

The first main conclusion is that verification problems are not always caused by the supplier, but can also originate from choices made by the contractor in early stages of the project. One should therefore not only focus on the verification process executed by the supplier, but also on how the contractor procures work to suppliers and the integration of the entire system, as also noted by Elich et al.[33] and Segerstedt and Olofsson.[38]

The second conclusion with regard to the verification of subcontracted work is the mismatch between the contract level of detail and the selected supplier's competences. The choice for the contract level of detail and the supplier choice are often made separately. This results in a mismatch between the required supplier competences and the actual competences, leading to verification problems. Although the contract level of detail[22,29] and the supplier choice[33] have been described separately, the explicit coupling of these choices in relation to the verification of work subcontracted to suppliers has not been described before.

The third and final conclusion is that there is a lack of time and budget reserved for procurement and verification processes. In all cases studied, it seemed that, in retrospect, the contractor neither recognized the importance of verification during procurement, nor after procurement. Therefore, too little time and budget was available for verification, causing several problems.

Based on this study, three improvements for preventing verification problems of subcontracted work to suppliers are recommended. First, a contractor should always consider the combination of contract level of detail and supplier selection as a whole. Considering these choices separately may result in a contract level of detail that does not match the supplier's competences, or vice versa. Second, contractors should explicitly describe the scope and expectations of each supplier involved, including the verification process and expected results, and adjust the information supplied with the contract accordingly. Third, continuous coordination of interfaces and monitoring of the integrity of the entire system during the entire project is needed. Contractors should consider that when allocating time and money to the verification process.

Compared to other available literature, this research contributes by integrating two important aspects of the construction industry: supply chain and verification. Since the specific characteristics of the supply chain play an important role in construction projects, due to fragmentation and a geographical focus, it is relevant to consider the supply chain effect on the verification process.

6 | LIMITATIONS AND FUTURE RESEARCH

In this section, we will indicate which parts of the research warrant caution. We also point out directions for future research. First, this research is based on a limited amount of supplier relations, and can therefore contribute primarily in a qualitative way. To further improve and test the framework and its applicability, more research is needed in other countries, or in cases using other types of contracts. That said, the relation and contracts between client and contractor determine the conditions within which the contractor subcontracts work. Further research on the effects of changes in the client–contractor relation on the contractor–supplier relation is therefore also suggested.

Second, this research deliberately focused on verification only and not on validation. The main reason for this is that in the construction industry, validation by suppliers is often not allowed or wanted and research into validation is therefore difficult. However, despite these difficulties, including validation in future research is still needed to further enhance our understanding regarding verification and validation further down the supply chain.

Third, the conceptual framework we used for categorizing verification problems proved to be helpful in the analysis, and can contribute to solving or preventing future problems. Further research, in which more solutions and improvements are described and linked to the framework's verification problem types, can further improve the framework.

Another relevant direction for further research is to analyze the economic losses or project delays as a result of the verification problems analyzed, for example, by determining indicators measuring the additional efforts required for solving verification problems.

Finally, it is important to note that an important part of the solutions require "soft skills" and trust between contractor and supplier, as Gundlach and Cannon[29] already stated. Such competences require specific personal characteristics of the project team members, but cannot always be studied straightforward. However, in our research, they appeared important, but as "soft skills" were not part of our framework of analysis, we did not really investigate this in depth. Nevertheless, we suggest to study this further.

ACKNOWLEDGMENTS

The authors would like to thank Djim Witjes and Niek van Bentheim for their support during this research.

ENDNOTES

* Rijkswaterstaat is the executive body of the Dutch Ministry of Infrastructure and Water Management, and is responsible for the safe and smooth flow of traffic on roads and waterways in The Netherlands, including development and maintenance.

† ProRail maintains and controls the Dutch railway network and the transfer related facilities at railway stations and is financed by the Dutch Ministry of Infrastructure and Water Management.

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How to cite this article: Makkinga R, De Graaf RS, Voordijk H. Successful verification of subcontracted work in the construction industry. *System Engineering*. 2018;21:131–140. https://doi.org/10.1002/sys.21425