Uusitalo, Petteri; Lappalainen, Eelon; Seppänen, Olli; Pikas, Ergo; Peltokorpi, Antti; Menzhinskii, Nikolai; Piitulainen, Mikko

To trust or not to trust: Is trust a prerequisite for solving design quality problems?

Published in:
Construction Management and Economics

DOI:
10.1080/01446193.2020.1865553

Published: 03/04/2021

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Uusitalo, P., Lappalainen, E., Seppänen, O., Pikas, E., Peltokorpi, A., Menzhinskii, N., & Piitulainen, M. (2021). To trust or not to trust: Is trust a prerequisite for solving design quality problems? *Construction Management and Economics*, *39*(4), 279-297. https://doi.org/10.1080/01446193.2020.1865553

Construction Management and Economics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

To trust or not to trust: is trust a prerequisite for solving design quality problems?

Petteri Uusitalo, Eelon Lappalainen, Olli Seppänen, Ergo Pikas, Antti Peltokorpi, Nikolai Menzhinskii & Mikko Piitulainen

CONSTRUCTION MANAGEMENT AND ECONOMICS
2021, VOL. 39, NO. 4, 279–297
https://doi.org/10.1080/01446193.2020.1865553

To trust or not to trust: is trust a prerequisite for solving design quality problems?

Petteri Uusitalo[a], Eelon Lappalainen[a], Olli Seppänen[a], Ergo Pikas[a], Antti Peltokorpi[a], Nikolai Menzhinskii[a] and Mikko Piitulainen[b]

[a]Department of Civil Engineering, Aalto University, Espoo, Finland; [b]Infrastructure Department, Sweco PM Ltd., Helsinki, Finland

ABSTRACT
Low trust levels among project parties are generally believed to harm construction project performance, but the role of trust in the context of information flow and solving design quality problems (DQP) remains understudied. Whereas lean design management research highlights the importance of managing information flow, few studies have investigated the association between trust, information flow and DQP (or any combination thereof). This exploratory study investigates the association between trust and information flow in design projects and how these factors influence design quality. The paper presents a conceptual framework based on existing research on building design management and trust in a project context. The framework is elaborated on and validated using a single case study approach with multiple sites. The results indicate that even though the trust trend in the project is somewhat negatively connected to the overall amount of work and work in progress of DQP, increasing trust is not a prerequisite for solving DQP and that owners and contractors can have opposite opinions on the trust level. This study contributes to ongoing discussions about trust, information flow and design management and suggests that teams should focus on improving communication and collaboration to compensate for low trust levels.

ARTICLE HISTORY
Received 1 July 2020
Accepted 13 December 2020

KEYWORDS
Trust; lean; design management; information flow; design quality

Introduction

In construction projects, designs containing errors and omissions decrease productivity at construction sites (Kärnä and Junnonen 2017) and negatively affect the life cycle value of built assets (Chong and Low 2006). Variations in design processes because of late design changes and fixes, for example, often lead to increases in contract prices and delayed project schedules (Arain *et al.* 2004). For these reasons, disputes in the construction industry are often directly or indirectly related to problems with design information, design processes and design management practices (Love *et al.* 2010). Prior research has thus established design quality as an essential aspect for the successful delivery of construction projects. The reduction of errors, omissions and delays in design information and documentation is now a key approach to improve the delivery of construction projects (Fleischer and Liker 1992, Chan and Kumaraswamy 1997, Lee *et al.* 2003, Tilley 2005, O'Connor and Woo 2017).

Tilley *et al.* (1997) and McGeorge (1988) defined "design quality" as the effective and timely delivery of design information to contractors as well as the cost-efficiency and constructability of designs. The effective delivery of design information requires the management of design processes and related design quality problems (henceforth "DQP"). Koskela *et al.* (2002), who have argued that traditional design management based on the transformation view has failed, proposed various lean approaches where flow and value are also considered.

Lean construction, which includes lean design management (LDM), evolved alongside traditional construction project management (Tilley 2005). The use of LDM supports design managers in creating a structured approach to improve value generation and information flow while minimizing waste (El Reifi and Emmitt 2013). Using LDM, design managers and project teams apply various methods and tools to collaboratively address design issues (Tribelsky and Sacks

CONTACT Petteri Uusitalo petteri.uusitalo@aalto.fi Department of Civil Engineering, Aalto University, P.O. Box FIN-11000, Rakentajanaukio 4, Espoo 00076, Finland

2011, Zimina *et al.* 2012, Fosse and Ballard 2016), improve information flow (Tilley 2005, Tribelsky and Sacks 2011, Aasrum *et al.* 2016, Al Hattab and Hamzeh 2017) and increase process transparency (Aasrum *et al.* 2016, Tauriainen *et al.* 2016).

LDM researchers acknowledge that design management involves the management of the technical and social aspects of design processes (Ballard and Koskela 2013). Trust among team members is an essential element of managing the social aspects of design processes, and such trust plays an important role in project success. In particular, it serves as a social lubricant by helping to reduce conflicts (Lindskold 1978) and enhancing information exchange between project parties (Wong *et al.* 2008). According to some studies, a low level of trust is a primary factor in the failed delivery of design projects (Akintoye and Main 2007).

Although one study has investigated the connection between LDM methods and trust when solving design management problems (Uusitalo *et al.* 2019), none to date have elaborated on the association between low trust levels and DQP. In addition, little discussion has occurred on the effects of trust on information flow, perhaps because trust involves complex relationships, and how trust and other project aspects interact remains unclear (Butler 1999). This study aims to reveal the association between trust and information flow in design projects and to determine how these factors, either independently or in combination, influence design quality. An empirical case study approach was selected to do so.

This paper is divided into five sections. The following section covers the theoretical background for DQP, information flow, characteristics of LDM, trust and project performance. The theory is summarised in the proposed conceptual framework on the connections between LDM, trust and information flow in solving design management problems. The next section describes the research methods used to empirically investigate the connections and then summarises the results. In the discussion section, the findings are synthesized and evaluated in light of previous research. The final section presents various conclusions.

This study, which contributes to the Festschrift in Construction Management and Economics project prepared in honour of Dr. Glenn Ballard, continues the work of Dr. Ballard and his colleagues in the field of LDM. Dr Ballard is highly regarded and recognized for his trademarked Last Planner System (LPS), but his research has also addressed solutions for design problems and related phenomena, such as the social side of projects and information flow (Ballard 2000, Ballard and Zabelle 2000, Ballard and Koskela 2013, Fosse and Ballard 2016).

Theoretical background

Design quality problems

A variety of problems, ranging from technical to social, have been reported in the building design and design management literature. These design problems often co-exist and can have a compounding effect on the delivery of construction projects. For example, Kärnä and Junnonen (2017) collected data from general contractors, construction management consultants and clients and found that the main points that contractors and project managers criticized were related to DQP. For these reasons, the authors argued that poor designs and design processes reduce construction productivity.

Design problems commonly cause variations in construction projects. Variations in the design process and of design products negatively influence projects' key performance indicators (KPIs). Mansoor and Pheng (2005), who addressed design variations in the context of construction contracts, defined a "design variation" as a deviation from the agreement in the design's scope, schedule and quality, or any combination thereof. Design variations typically result in increased contract prices and scheduling delays. Love *et al.* (2010) found that many construction disputes were attributable to design deficiencies and that the resulting project variations were often caused by poor-quality design.

Researchers who have focussed on design quality (Chan and Kumaraswamy 1997, Lee *et al.* 2003, Tilley 2005) have highlighted that the reduction of errors, omissions and delays in the delivery of design information is the most important strategy for improving the delivery of construction projects. An operating model has thus been developed in the construction industry in which, as Love and Li (2000) have described, the contractor acts as a gatekeeper to ensure sufficient design quality. Ensuring adequate design quality by inspecting the design information and documents before beginning construction and by avoiding problems when hiring subcontractors is in the contractor's interest.

As Lee *et al.* (2003) have argued, however, not all issues within designers' drawings and changes are discovered. The late discovery of errors in drawings often leads to "last-minute syndrome" and then requires improvisation. Higgin and Jessop (2001) argued that drawings are key elements that construction project parties utilize when passing on information to other parties. Similarly, Chan and Kumaraswamy (1997) found in their study on contractors that the three most significant factors leading to on-site delays were those in the delivery of design information as well as mistakes and discrepancies in design documentation.

O'Connor and Woo (2017), who studied quality assurance processes and the proportion of DQP during the first round of design reviews, compared these DQP with those in later design reviews. Their aim was to quantify the number of problems in drawings that pass the first round of reviews by studying "request for information" (RFI) cases. Problems pass the first round of review partly because of the large amounts of complex data in the design process, which is often inadequately managed (Nielsen and Sayar 2001). As McGeorge (1988) argued, the lack of formal techniques and procedures to manage the design process hinders the achievement of high-quality designs.

The role of information flow in design management

According to Tribelsky and Sacks (2011), although unstable information flow cannot be used to predict a project's outcomes, the measurement of flow can be used as an indicator of possible upcoming problems. That is, understanding the principles and processes of information flow and the factors hindering the information flow in production is essential in design management (Baldwin *et al.* 1999, Ballard 2000, Tribelsky and Sacks 2011). For example, allowing design decisions to be made based on improvisation diminishes the reliability of information flow (Koskela *et al.* 2002).

In addition to reliability, the existence of stable and rapid information flow helps design teams solve design problems more efficiently and effectively (Bar-Yam 2004). Sacks (2016) stated that product and design information flow plays a key role in construction project production. To improve transparency, design information flow also needs to be visualized (Sacks *et al.* 2010, Seppänen *et al.* 2010, Uusitalo *et al.* 2017). Another method for improving information flow is to transfer design information in smaller batches, which reduces the effort required to share information and change it if necessary (Ballard and Zabelle 2000, Kpamma and Adjei-Kumi 2011, Tribelsky and Sacks 2011).

But many barriers to good information flow exist in the design. According to Song *et al.* (2009), RFIs and drawing revisions both hinder the effectiveness of information flow in design projects. Hicks (2007) emphasized a lack of complete information and information duplication as being among the fundamental barriers to improved information flow. That is, poorly managed RFIs and the existence of drawing revisions may generate multiple instances of what seems to be the same information, thus making the identification of up-to-date and accurate information a challenge. Hicks (2007) explained that large batch sizes and a significant amount of work in progress (WIP) are also barriers to improved information flow.

Characteristics of lean design management

The implementation of LDM processes, methods and tools supports the improvement of information flow in design processes (Tilley 2005, Tribelsky and Sacks 2011, Aasrum *et al.* 2016, Al Hattab and Hamzeh 2017). El Reifi and Emmitt (2013) argued that in addition to information flow, the usage of LDM supports design managers in creating value for the customer. The use of LDM methods and tools also assists design managers in promoting collaboration to effectively solve design problems (Tribelsky and Sacks 2011, Zimina *et al.* 2012, Fosse and Ballard 2016) and to increase the transparency of design processes (Aasrum *et al.* 2016, Tauriainen *et al.* 2016).

LDM processes, methods and tools may be broadly divided into different categories based on the design and design management activities they support (Seppänen *et al.* 2010, Uusitalo *et al.* 2017, Uusitalo *et al.* 2019). One way to categorize these processes, methods and tools is to consider whether they primarily support either the social or the technical aspects of design processes. Several methods and tools, such as the LPS, support both social and technical aspects (Ballard 2000).

The function of social interaction in the LPS is to build and ensure trust within design teams (Pishdad-Bozorgi and Beliveau 2016). LPS also involves technical aspects, such as the usage of different metrics. The most commonly used metric is the percent plan complete (PPC), which measures the reliability of a planning process (Ballard 2000), although other metrics to support the implementation of LPS in the design context have also been proposed. El Samad *et al.* (2017) argued for the need to complement PPC with, for example, the *required level* and *completed uncommitted* metrics for planning and controlling workloads.

LDM practitioners have adopted and adapted Scrum, which originated in software engineering but has goals similar to those of LPS, for the construction context. In Scrum (a term borrowed from rugby to stress teamwork), the focus is on improved workflow and the achievement of predictable design project outcomes. Important principles in Scrum include the incremental and iterative organization of processes, the transparent communication of progress, the limitation of the number of WIP projects and the stabilization of processes (Owen and Koskela 2006, Abbas *et al.* 2008).

Because of Scrum's focus, previous researchers have categorized its methodology as a technical design and design management practice (Uusitalo *et al.* 2017). This may be an incorrect interpretation of the Scrum methodology, however. Similar to LPS, Scrum involves social aspects related to delivering projects. In the building design context, implementing Scrum together with a co-location (e.g. "Big Room") and daily huddles benefits project teams (Streule *et al.* 2016). A Big Room refers to the co-location of a project team in a large space to support collaboration and to reduce communication pathways. With these methods, some of the critical issues associated with decision-making, communication, planning and trust between the parties can be eliminated (Dave *et al.* 2015). Social interactions between project parties in the Big Room are necessary to improve information flow and to reduce latency in communication when making decisions (Tauriainen *et al.* 2016).

Trust and project performance

Because building-design projects are temporary organizations (Akintoye and Main 2007), creating a project identity/culture is vital for successful project delivery (Franz *et al.* 2017). In particular, team integration plays a significant role in achieving project performance (Franz *et al.* 2017). A well-fostered team culture contributes to the development of more trust within a team (Kumaraswamy *et al.* 2005), improves communication and information flow (Evbuomwan and Anumba 1998), and supports the establishment of a shared understanding of project goals (Moore and Dainty 2001).

Trust has two functions in the context of construction projects: (1) as a social lubricant, trust can help to reduce and mitigate conflicts in project organizations (Lindskold 1978); (2) trust also promotes open and transparent information exchange between project parties (Wong *et al.* 2008). Trust contributes to the development of better collaboration and innovation and can reduce project buffers (Uusitalo *et al.* 2019). In contrast, a low trust level can contribute to the failure of design projects (Akintoye and Main 2007).

Trust in project teams is influenced by the psychological safety of the team members. According to Edmondson's (1999) study, psychological safety affects a team's performance, and trust has qualities that promote psychological safety. With psychological safety, workers are more motivated, open-minded, willing to share information and open to learning (Edmondson 1999), all of which are prerequisites for divergent thinking and problem-solving in design processes (Fredrickson 2013).

Previous researchers have measured and used trust in different ways. The majority of prior research has measured trust with a single survey serving as a snapshot of the project timeline at either the industry level (Cheung *et al.* 2013) or the design project team level (Smyth 2005). Some scholars have developed team integration indexes (Che Ibrahim *et al.* 2013). Chiocchio *et al.* (2011) conducted a study on graduate students in which they formed five integrated design teams and measured how trust, conflict and collaboration affected team performance. To the present authors' knowledge, previous researchers have not used measurements of trust, collaboration and communication together over a long period of time in a real-life project setting within the design management context.

Conceptual framework

In this study, we created a conceptual framework for trust in design management based on existing research. In the formulation of the framework, we mainly referred to two previous publications. Pikas (2019) developed a new design model that integrates the technical and social aspects of design based on the different proportions of causality and interpretation in design activities. Uusitalo *et al.* (2019), who adopted a view of design management that involves both technical and social aspects, proposed a conceptual framework for solving design management problems by implementing LDM processes, methods and tools. In particular, Uusitalo *et al.* (2019) focussed on how the distinct but interconnected social and technical aspects present in LDM processes, methods and tools influence the resolution of design management problems. Figure 1 depicts the conceptual framework used in the present study, which was inspired by the work of Pikas (2019) and Uusitalo *et al.* (2019) and their work's connections to our research questions.

In the framework, the technical and social domains are influenced by LDM processes, methods and tools. Trust is included as a proxy for the efficiency and effectiveness of design management when handling the social aspects of design processes. Information flow

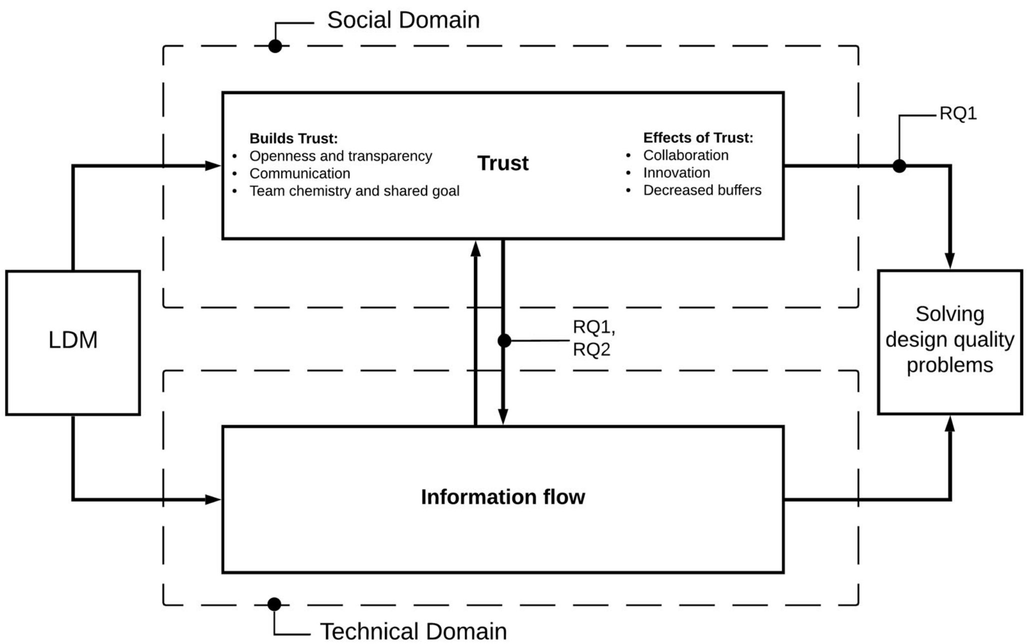

Figure 1. Illustration of the research design and conceptual LDM framework.

belongs to the technical domain. Although previous research has suggested an interconnection between trust and information flow, the connection has not been thoroughly, empirically verified in the construction project context, and while trust does have multiple positive effects, whether the trust is a prerequisite for solving DQP has not been empirically justified.

With the proposed conceptual framework, the present study answers Uusitalo *et al.*'s (2019) call for future research to focus on the interplay between the social and technical domains (i.e. the association between trust and information flow) based on empirical data. To the best of our knowledge, previous studies have not addressed this topic. In particular, no previous research has used a mixed-method approach (i.e. both qualitative and quantitative methods) to study trust and information flow in the context of design management and DQP, nor have any studies focussed on understanding the association between the level of trust and information flow in building projects. Based on knowledge gaps in existing research we have identified, this study aims to answer two research questions:

RQ1: What is the connection between the level of trust and design quality?

RQ2: What is the connection between the level of trust and information flow?

Research approach and methods

A single case study approach with multiple sites belonging to the same project was used to investigate the association between trust, information flow and DQP. This study combines quantitative and qualitative data collection and analysis methods to answer the research questions (Love *et al.* 2002). A combination of document analysis and interviews was used to triangulate data sources and seek convergence in the data (Flick 2007, Bowen 2009).

Table 1 presents each component of the LDM framework, the research question to which each component is linked, how each data source connects to different components of the LDM framework, and what types of analyses are applied to each dataset. For example, RFI resolution time and revision data are used to answer the questions related to DQP and information flow. The following sections describe the case, which includes seven project sites, the datasets, and data collection and analysis methods.

Case description

The case project was selected based on the project size, the number of similar sites, the use of LDM tools, collaborative practices, co-operation metrics, and the extensive and obtainable datasets. The case project is located in southern Finland and has been under construction since 2014. The research data for this study were collected between 2017 and 2019. The case project is an owner-driven infrastructure project with seven large and equally complex construction sites contracted out to different design and construction organizations. Six of the seven sites were assigned to project management contractors, and one (site C) was

Table 1. Connections of the research methods and data sources to components of the LDM framework and related research questions.

Connection to LDM Framework	RQ	Data sources	Types of analyses
Trust	RQ1	8 Interviews, trust; Trust index metrics	Descriptive analysis; Content analysis
Solving design quality problems	RQ1	8 Interviews, Revision data, RFI Resolution time; Meeting memo data	Descriptive analysis; Content analysis
Collaboration	RQ1	8 Interviews, collaboration; Collaboration index metrics	Descriptive analysis; Content analysis
Communication	RQ1-2	8 Interviews, communication; Communication index metrics	Descriptive analysis; Content analysis
Information flow	RQ2	Revision data, RFI-WIP, RFI Resolving time	Content analysis

designed and built by a consortium of contractors and designers. The contract values ranged from €60 to 80 million. The contract at each site had identical attributes: risk allocation, contractual obligations, arrangements and project delivery. The only difference between the sites was that for site C, the design responsibility was allocated to the consortium in site C. The owner chose to emphasize the collaborative aspects of the project management contract when choosing the delivery type. At the time of this research, all seven sites had entered the mechanical, electrical and plumbing installation and finishing phases. This research focussed on the structural design phase and the construction of load-bearing structures.

The owner established an integrated project organization to bind all parties involved in the seven sites, all of which operate according to Big Room principles. Each site was assigned a dedicated design manager who worked under the design director's authority, as well as head designers, users, owners and experts at the local rescue department. In addition, a coordinating manager for each technical system was assigned to each site.

The design managers used the Scrum methodology to manage and organize the structural design phase for load-bearing structures. The structural engineering work was planned in 2-week "sprints". The design work's progress was monitored using Jira software; in total, 2771 design tasks were recorded and managed in the system.

The Scrum methodology was augmented with LPS elements, including phase and make-ready planning, pull principles and commitment management. Three LPS phase planning sessions for sites A, B and D and 47 bi-weekly sprint meetings for all the sites were organized. The LPS sessions included different design disciplines and the owner representatives at different sites, not just the structural engineers. The sessions took place during the final quarter of the implementation design phase and included components related to phase scheduling, make-ready planning and commitment management. Root cause analysis of unfinished or delayed tasks was performed for only one of the seven sites.

After the implementation design phase, the responsibility for design management shifted to the project management contractors. The use and implementation of LPS greatly varied between contractors and thus was no longer systematic. Similarly, the use of the Scrum methodology waned, and contractors applied their own practices.

Because the owner had decided to use the Big Room at an early stage of the project, the owner decided to develop a co-operation measurement for the construction phase to ensure that the trust, communication and collaboration within the Big Room remained adequate. The owner used a private consulting company that applied a method wherein the Big Room members were repeatedly asked questions related to trust, communication and collaboration. As an indicator of trust, the Big Room members were asked to rate the statement "I can easily raise even difficult issues at our construction site". Changes in co-operation trends were monitored and used as indicators of potential problems in the project's social domain.

Data sources and collection

Several sources and methods were used for data collection. First, document analysis was performed with three kinds of documents: (1) design meeting minutes (e.g. memos), (2) structural design drawings and (3) reports of co-operation measurements, which also contained information on collaboration.

The design meeting memos contained issues that had to be processed by all project parties, including the owner, designers and contractor. Before every design review meeting, the design coordinator prepared a draft memo and shared it with all parties. As a rule, any matters that had not been planned and announced were postponed to the next meeting. The meetings addressed design issues related to scheduling, drawings (including delivery) and design-related safety issues. They were also used as a forum for project management contractors to demonstrate that they had generated and studied the design alternatives to be discussed with other project parties. Contract-related issues were discussed at the separate construction site meetings.

Table 2. Overview of the interview arrangements for sites A–G.

Interview number	Number of informants	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Role
1	1			X					Contractor's design manager
2	1	X							Contractor's design manager
3	2	X^A	X^B	X^A	X^B	X^A	X^B	X^B	Head of structural design, person A (X^A), Head of Structural design, person B (X^B)
4	1					X	X		Owner's design manager
5	1				X			X	Owner's design manager
6	1		X						Owner's design manager
7	1	X							Owner's design manager
8	1			X					Owner's design manager

Any issues identified in the meeting minutes were documented in a spreadsheet and grouped into the following six categories: (1) errors in drawings, (2) RFIs, (3) missing drawings, (4) issues with the schedule for drawings and delays, (5) issues with the feasibility or constructability of drawings, and (6) other. Some issues fell into several categories. After issues were grouped and counted for each construction site, they were summarised in a table to provide an overview of all seven sites' issues. The research team used this initial data in the following two stages for the numerical analysis of the changes in the structural drawings and interviews with key site personnel.

A quantitative content analysis (Riffe *et al*. 1998, White and Marsh 2006) of the drawing revision block information was conducted for all structural drawings from the seven sites. Quantitative content analysis, in this context, refers to a systematic examination of text (e.g. revision notes) and the forming of a classification based on the content as well as counting the appearances based on those classified categories. White and Marsh (2006) have called these steps establishing data collection units and coding the data. All the drawings were in PDF format and were the last valid versions of the drawings. The content and changes of the drawings were examined based on the revision notes. If no sufficient information could be obtained, the drawings were reviewed in detail, and a researcher interpreted the category of the change based on the visual investigation. All drawings' revisions were categorized into 11 types, based on the content of the change and the revision dates, as follows:

1. Drawings without revisions
2. Drawings with mistakes
3. Reinforcement, rebars, etc.
4. Openings and holes
5. Addition, change or deletion of sections and details
6. Textual changes
7. Changes by the owner or architect
8. Changes by contractors
9. Changes in references and links
10. Changes in geometry or the addition/deletion of objects
11. Other (mostly related to changes in the calculation)

A total of eight semi-structured exploratory interviews were conducted to gain a deeper understanding of the context and to triangulate the data sources. The purpose of the interviews was to enrich the data sources and to collect feedback from the seven sites to better understand the interplay between trust, information flow and DQP in the design management context. The interview questions were related to four categories, focussed on the social aspects of the project: (1) communication, (2) collaboration, (3) trust and (4) solving DQP. The connection of each category to the research questions is presented in Table 1. The duration of the interview sessions was 36–58 min, with an average of 48 min. In total, nine construction professionals were interviewed from the seven sites. The number of interviewees per site and their roles are presented in Table 2.

All the interviewees worked in design management roles, with their experience ranging from 4 to 25 years. Before each interview, the informants were briefed about the purpose of the research and how their data would be anonymized, stored and handled. Each audio-recorded interview was transcribed verbatim, and the data were imported into the qualitative research analysis software ATLAS.ti 8.4.4.

An iterative technique for analysis was then used. During the first iteration, text quotes/extracts were coded into the four main categories of communication, collaboration, trust and DQP. All quotes were marked as either positive or negative in the second iteration, based on their context and meaning. Illustrative extracts from the transcribed text were then used to justify the positive and negative categorizations.

In the final step of compiling the research material, the co-operation measurements provided by the owner and the numerical estimates were combined into time series. During the construction phase, the co-operation index was measured quarterly in the Big

Room by the consulting company that had been hired by administering a survey. Responses could be sent via a mobile phone or a web application. The respondents were key personnel from the project parties. Responses were divided into two groups: those from administrative personnel and those from on-site personnel. For this research, a site-based focus was chosen to reduce complexity and to reveal the on-site relationship dynamics. Based on the responses, an index value ranging from 0–100 was calculated to indicate each construction site's co-operation level. These values were then shared among the researchers, but respondents' personal feedback in the interviews was not transferred for anonymity reasons.

The aim of measuring trust by monitoring trends was to assess the health of the project during execution. The trust trends were visualized for all parties in the Big Room. People were able to reflect on their own experience of the development of trust relative to previous measurements. When trust declined too rapidly or too significantly, managers took corrective actions.

Data analysis

After collection, the data were stored, sorted and filtered in Microsoft Excel and Minitab version 19.0. In the Microsoft Excel master table, data were grouped into categories such as data type, construction site and connection to the LDM framework. Data on the RFI resolution time and unresolved RFIs (RFI-WIP) were collected from the design review meeting memos and represented in a time series. The average co-operation measurements, expressed as a time series, were collected and normalized for comparison with the RFI and RFI-WIP measurements.

Results

This section presents the results based on source triangulation and data analysis. We first present the clustering of project sites based on their trust trends as well as the categorization of the independent and dependent variables. We then address the key metrics before presenting the results of the exploratory interviews.

Project site clustering and variables categorization

For the comparison of results across different project sites, data were grouped into six categories: (1) project characteristics, (2) trust trend, (3) collaboration trend, (4) communication trend, (5) LDM methods and tools, and (6) DQP. All the variables that describe the seven sites were categorized as either dependent or independent variables.

Based on whether the trust was decreasing, stable or increasing over time, the projects were clustered into four groups: (1) low-trending cluster, (2) stable cluster, (3) high-trending cluster or (4) special case. These clusters and the variables are presented in Table 3. For example, sites A, B and F belong to the low-trending cluster. Site C is a special case because it differs from other sites in terms of design responsibility. The contractor was responsible for the planning and control of both the implementation and detailed design phases at this site, which meant that the contractor dictated the development of design solutions. At other sites, the owner and contractors shared the responsibility for design planning and control.

Measurements of key metrics

As Table 3 shows, in the low-trending cluster (sites A, B and F), the mean RFI resolution times did not differ from those in the high-trending cluster (sites E and G) or the special case (site C). In the low-trending cluster, the mean RFI resolution time was 1.13 months; in the high-trending cluster, the figure was 1.10 months. The standard deviation (SD) of RFI resolution times was marginally lower in the high-trending cluster and the special case than in the low-trending cluster. In the low-trending cluster, the mean SD of RFI resolution time was 0.33 months; in the high-trending cluster, the SD was 0.29 months. These findings suggest that minor differences could be identified in RFI resolution times between the low-trending, stable and high-trending clusters.

RFI-WIP trends increased in the low-trending cluster but somewhat shifted towards smaller RFI backlogs in the high-trending cluster. Site D, which is in the stable cluster, showed higher RFI resolution time (mean: 1.36 months) and an increasing RFI-WIP trend compared with the low- and high-trending clusters.

The total number of DQP and the total amount of revised drawings were considerably higher in the low-trending cluster than in the high-trending cluster. In the low-trending and high-trending clusters, the mean numbers of DQP were 395 and 271, respectively, while the mean numbers of revised drawings were 620 and 480, respectively.

Site C (a special case) had a substantially lower number of DQP and drawing revisions. This lower number is visible in the percentage of drawing revisions compared with the total number of drawings: for site C, the percentage of revisions was 55.3%; for the low-trending, stable and high-trending clusters,

Table 3. Clustering of site data based on trends in contractors' trust.

Metric	Variable dependency	Low trending cluster Site A	Site B	Site F	Stable Site D	High trending cluster Site E	Site G	"Special case" Site C
Project characteristics								
Facility purpose	Independent	Under-ground public spaces, technical rooms	Under-ground public spaces, technical rooms	Under-ground public spaces, technical rooms	Under-ground public spaces, technical rooms	Under-ground public spaces, technical rooms	Under-ground technical spaces, tunnels, no public spaces	Under-ground maintenance spaces, no public spaces
Design responsibility, basic design	Independent	Owner	Owner	Owner	Owner	Owner	Owner	Contractor
Design responsibility, detail design	Independent	Contractor	Contractor	Contractor	Contractor	Contractor	Contractor	Contractor
Trust trend								
Trust trend – all (mean)	Independent	Slightly decreasing (84)	Decreasing (81)	Slightly decreasing (81)	Stable (81)	Increasing (71)	Slightly increasing (87)	Increasing (68)
		–	– –	–	0	+ +	+	+ +
Trust trend – owner – site (mean)	Independent	Slightly increasing (90)	Slightly decreasing (84)	Slightly increasing (89)	Stable (91)	Increasing (79)	Slightly decreasing (89)	Increasing (68)
		+	–	+	0	+ +	–	+ +
Trust trend – contractor – site (mean)	Independent	Decreasing (81)	Decreasing (81)	Decreasing (76)	Stable (80)	Increasing (65)	Increasing (88)	Increasing (72)
		– –	– –	– –	0	+ +	+ +	+ +
Trust trend – design team (mean)	Independent	Stable (87)	NA	NA	NA	Slightly decreasing (79)	Stable (90)	(72) one measurement
		0	NA	NA	NA	–	0	NA
Collaboration trend								
Collaboration trend – all (mean)	Independent	Slightly decreasing (82)	Slightly decreasing (79)	Slightly decreasing (78)	Stable (82)	Stable (70)	Slightly increasing (86)	Slightly increasing (65)
		–	–	–	0	0	+	+
Collaboration – owner – site (mean)	Independent	Increasing (86)	Decreasing (78)	Slightly decreasing (88)	Stable (91)	Increasing (81)	Slightly decreasing (89)	Slightly increasing (68)
		+ +	– –	–	0	+ +	–	+
Collaboration trend – Contractor – site (mean)	Independent	Decreasing (79)	Slightly increasing (81)	Decreasing (69)	Stable (78)	Increasing (64)	Increasing (88)	Increasing (65)
		– –	+	– –	0	+ +	+ +	+ +
Collaboration trend – design team (mean)	Independent	Stable (84)	NA	NA	NA	Decreasing (76)	Slightly decreasing (83)	(53) one measurement
		0	NA	NA	NA	+ +	–	NA
Communication trend								
Communication trend – all (mean)	Independent	Slightly increasing (78)	Slightly increasing (75)	Slightly increasing (75)	Increasing (71)	Slightly increasing (69)	Increasing (80)	Increasing (59)
		+	+	+	+ +	+	+ +	+ +
Communication trend – owner – site (mean)	Independent	Increasing (81)	Increasing (75)	Increasing (90)	Increasing (78)	Slightly increasing (84)	Stable (84)	Slightly increasing (63)
		+ +	+ +	+ +	+ +	+	0	+
Communication trend – contractor – site (mean)	Independent	Decreasing (75)	Slightly decreasing (74)	Stable (64)	Increasing (67)	Increasing (64)	Increasing (81)	Increasing (53)
		– –	–	0	+ +	+ +	+ +	+ +
Communication trend – design team (mean)	Independent	Slightly increasing (79)	NA	NA	NA	Decreasing (65)	Slightly decreasing (77)	(42) one measurement
		+	NA	NA	NA	– –	–	NA
LDM tools used								

(*continued*)

Table 3. Continued.

Metric	Variable dependency	Low trending cluster			Stable	High trending cluster		"Special case"
		Site A	Site B	Site F	Site D	Site E	Site G	Site C
Big room	Independent	Used	Used	Used	Used	Used	Used	Used
Scrum in implementation design phase	Independent	Used	Used	Used	Used	Used	Used	Not used
Scrum in the construction phase	Independent	Not used	Partially used	Partially used	Partially used	Partially used	Partially used	Not used
LPS in implementation design phase	Independent	Used	Used	Not used	Used	Not used	Not used	Not used
LPS in construction phase	Independent	Not used	Not used	Not used	Not used	Not used	Not used	Not used
BIM	Independent	Used	Used	Used	Used	Used	Partially used	Not used
Collaborative weekly meetings	Independent	Used	Used	Used	Used	Used	Used	Not used
Indicators of information flow and design quality problems								
RFI resolution time	Dependent	Stable	Stable	Stable	Fluctuating	Stable	Fluctuating	Stable
RFI resolution time – mean (months)	Dependent	1.17	1.05	1.17	1.36	1.11	1.18	1.00[a]
RFI resolution time – standard deviation	Dependent	0.37	0.21	0.42	0.85	0.31	0.55	0.00[a]
RFI WIP (trend)	Dependent	Increasing	Increasing	Increasing	Increasing	Increasing	Stable	Decreasing
Total amount of design quality problems in meeting memo's	Dependent	306	498	382	347	387	268	158
Total amount of revisions/ number of drawings (%)	Dependent	577/352 (163.9%)	873/840 (103,9%).	411/536 (76.7%)	350/402 (87.1%)	595/573 (103.8%)	542/461 (117.6%)	303/548 (55.3%)

[a]No more than 1-month old RFI's in the design meeting memo's.

the percentages were 114.8%, 87.1% and 110.7%, respectively. The potential reasons for this situation are addressed in the discussion section.

The researchers also made general observations related to trust, collaboration and communication. Site D showed a stable collaboration trend and an improving communication trend. One surprising finding was that in the low-trending cluster, the owner and contractor communication trends seemed to diverge, with the owner and contractors having slightly opposing trust and collaboration trends. In contrast, in the high-trending cluster and the special case, the trust, communication and collaboration trends increased from both the owner's and contractors' perspectives.

When measuring the trust index, no noticeable differences in LDM tools were observed between the clusters. Although the design responsibility shifted towards contractors, none of the sites decided to use LPS in a design management context. Sites B, D, E, F and G partially used the Scrum methodology during the construction phase, while sites A and C did not use the Scrum methodology at all in the construction phase. Except for the special case, all sites implemented the Big Room, building information modelling (BIM) and weekly collaborative meetings.

Design managers' perspective on performance

Eight interviews were conducted to deepen the contextual understanding of the seven sites. Figure 2 summarizes the exploratory interviews' main results, which were categorized based on the polarity of the coded interview extracts. In other words, the informants' responses and opinions related to the specific

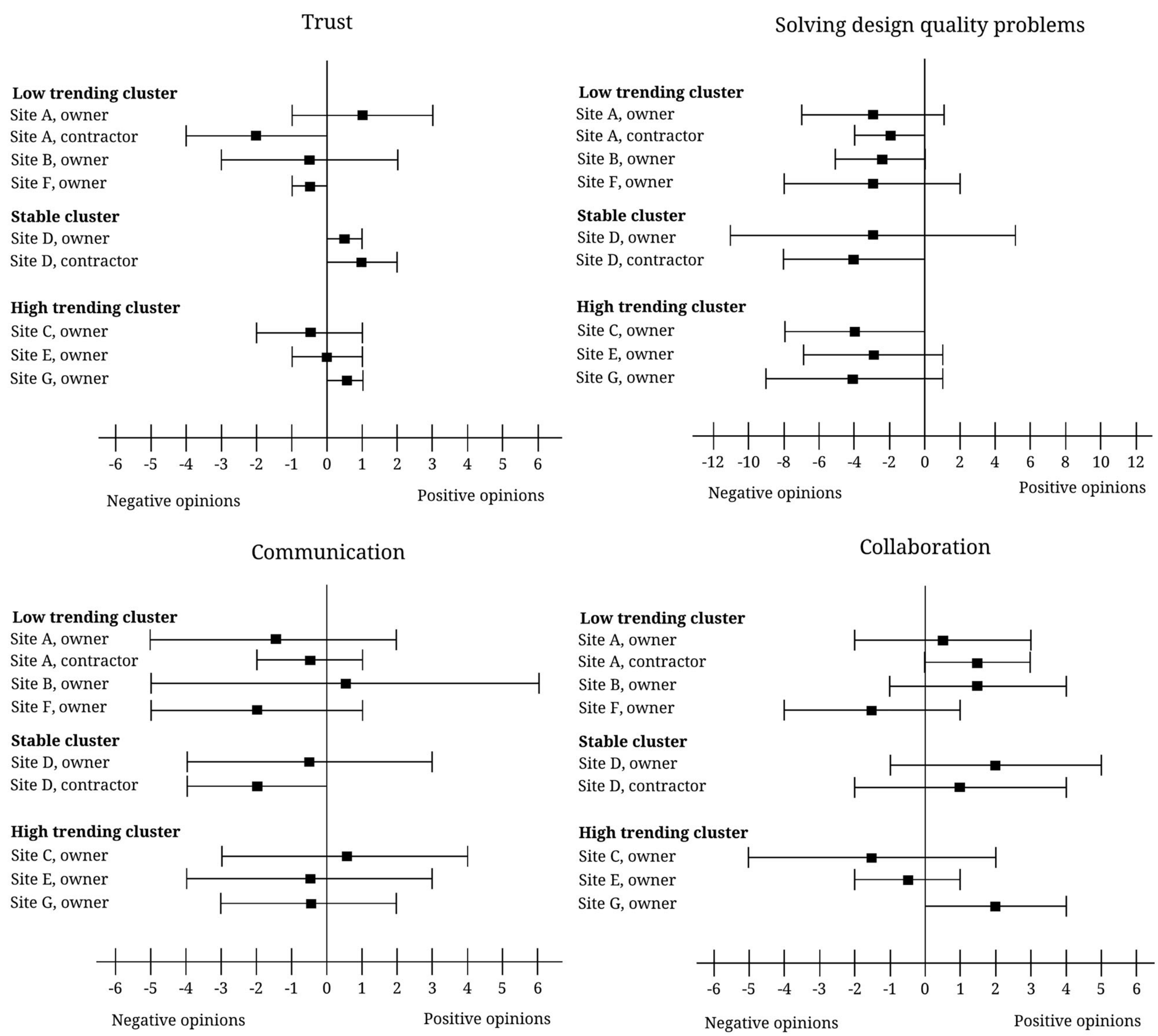

Figure 2. Project participants' opinions on the performance by each cluster.

Table 4. Illustrative extracts from exploratory interviews that provide positive and negative examples of each LDM category; the number of extracts are also presented by each site.

LDM theme	Polarity	Site	Number of mentions	Illustrative extract from interviews
Communication	Positive	A	3	"And then, if there is some bigger separate design issue, we will then organise either face to face meeting or then just with Skype".
		B	6	
		C	1	
		D	3	
		E	4	
		F	3	
		G	2	
	Negative	A	7	"It's two different things, weather I receive the information or do I keep up. I'm receiving the information rather well, but the problem is almost the sheer volume of information, so that at this moment, the daily emails are between 70 to 100 and genuinely keeping up with it all is way too much".
		B	5	
		C	5	
		D	8	
		E	3	
		F	4	
		G	3	
Collaboration	Positive	A	6	"It's feasibility. In, both Site D and Site G have had a lot of meetings where, and they are mainly structural but also architectural, we also had designer, contractor and owner present and possibly even subcontractor who is going to do the work. And then we would all run this through, that in what way would it be best to actually do".
		B	4	
		C	1	
		D	9	
		E	2	
		F	1	
		G	4	
	Negative	A	2	"They [contractor] started way too unprepared, without single own design discipline or own … if we talk about structural design, in there, we've given them opportunities to relatively freely communicate with designer and owners designer, so pretty easily they go like 'where can I find this and that drawing?'. It's been somewhat soft and lazy how they familiarised to those drawings".
		B	1	
		C	4	
		D	3	
		E	5	
		F	2	
		G	0	
Trust	Positive	A	4	"Quite reliable, [structural engineers promise's], like they all don't happen or not meeting schedule, but specially this project manager of structural design has kept everything under control".
		B	2	
		C	0	
		D	3	
		E	1	
		F	1	
		G	1	
	Negative	A	1	"Perhaps then if I reflect on the fact that, I was not around form the early beginning of design, but what I have gathered it [trust] is not so good, and that collaboration hasn't been working and promises haven't been kept and schedules haven't been met, so it would require actions to it to improve".
		B	3	
		C	1	
		D	0	
		E	2	
		F	1	
		G	0	
Design management problems	Positive	A	1	"And the contractor proposed that could they be like slab on grade, … And now when we will do them with slab on grade, we can do the work anytime and the amount of groundwork is much less than predicted and that the proposed solution is much more feasible".
		B	0	
		C	2	
		D	5	
		E	0	
		F	1	
		G	1	
	Negative	A	11	"We might have, like those material errors that they aren't suitable for their purpose. And then … what did we fix last? Perhaps just these measure errors".
		B	5	
		C	8	
		D	19	
		E	8	
		F	7	
		G	9	

categories were coded as either negative or positive. The numbers of negative and positive extracts were calculated, and the means and ranges were then placed on a graph. Figure 2 is a visualization of the polarities for the different categories, while Table 4 presents sample quote extracts from each category (one positive and one negative), which represent polarities of the responses (i.e. one extract was counted as one response).

The main findings from the interviews related to trust, DQP, communication and collaboration are presented in the following part of this section. Across all sites, positive quotes on trust were generally associated with the predictable delivery of drawings by engineers and consistent and respectful behaviour towards other project parties in collaborative meetings. Negative quotes about trust were mostly related to structural engineers and their inability to consistently deliver drawings on time.

Positive quotes about DQP were related to constructor-led design change proposals and management activity at sites C, D and G, which people saw as less bureaucratic and more dynamic than the proposals and activities at some of the other sites. Some respondents stated that the contractors' innovations for alternative design solutions were a positive factor. Negative quotes on DQP were typically related to design errors, omissions in drawings, missing drawings or delays in the design schedule.

Positive communication-related responses indicated good meeting practices, proper usage of information channels and regular weekly collaborative meetings that enabled face-to-face interaction among the project parties. Negative communication-related responses indicated inadequate management of drawing revisions and mark-ups, information overload in emails, and designers not informing others about design changes.

Positive opinions about collaboration were mostly associated with site-based collaborative meeting practices and contractors' problem-solving efforts in those meetings. Opposing views were typically related to inefficient coordination and bureaucratic processes for inspecting design quality.

We made several general observations during the interview analysis. Although the design management roles and responsibilities were contractually assigned to specific parties at each site, the interviews revealed that the boundaries of responsibility between the owner and contractors were often the main reason for conflicting views. At sites A and D, where contractors were interviewed, both the owner and the contractors stated that the other party was not taking enough responsibility to manage the design and improve the information flow and that design changes were not clearly communicated. Except for site C, where the contractor considered design management responsibility to be transparent and well managed, unmanaged responsibilities seemed to be common across the other six sites.

All interviewees, regardless of whether they were affiliated with the owner or contractors, agreed that the weekly collaborative meetings helped to improve the overall information flow and interaction between parties, thus positively affecting collaboration. All interviewees also agreed that the processes by which contractors designed development proposal–related documents and drawing approval were slow and too bureaucratic for minor or swift changes.

Regarding the mistakes in drawings, the owner's and contractors' perceptions differed. The owner considered drawing revisions to be a regular part of the process for producing design information. For the contractor, however, revisions meant that the drawings lacked the necessary information to construct the facility. In other words, the contractors considered the drawings erroneous, which led them to initiate design changes. Design changes were not only considered to be a negative factor, however: all the interviewees saw some benefits of the changes the contractors had presented. Although the changes may have delayed the project schedule, they often improved the project's productivity. The interviewees noted, however, that sometimes the processes for approving design changes were too bureaucratic for small drawing changes and updates, such as corrections of minor mistakes found in drawings.

Discussion

This empirical study of seven sites was conducted to understand the association between trust and information flow and these factors' independent and combined impact on design quality. From a social collaboration perspective, teams are typically expected to produce high-performance results. Previous research has noted that the importance of shared values and trust among project parties generally increases over time when they strive to meet project goals (Chinowsky *et al.* 2008).

Regarding the first research question, the level of trust and the DQP were found to be associated with each other. In the low-trending cluster, indicators of DQP were higher on average than in the high-trending cluster. The speed with which those DQP were resolved, however, was almost the same in both the low- and high-trending clusters. Previous research has highlighted the importance of trust in utilizing LDM tools and enhancing collaboration when solving design management problems (Uusitalo *et al.* 2019).

Howell et al. (2004) and Tilley (2005) have emphasized the importance of trust to successfully reach project goals, while Zaheer *et al.* (1998) revealed a direct link between inter-organizational trust and performance. The current study results indicate that the association between trust and DQP is not as strong as previous researchers have assumed. This finding is somewhat in line with Zaheer *et al.*'s (1998) findings, where they did not find a link between interpersonal trust and design performance. For the trust-related measures, we do not know in which context (inter-organizational or interpersonal) the respondents perceived the trust-related questions, although the results of the interview analysis suggest that they understood trust as meeting commitments (predictable delivery of drawings) and as respectful behaviour. Furthermore, in the conceptual framework, the indicators of DQP were assumed to be trust-dependent variables, but the results of the interview analysis suggest that trust was negatively affected by the inability to deliver a high-quality design. This study found a correlation, but the research design we selected did not allow us to infer the direction of causality.

The findings also indicate that contractors' early involvement could play a significant role in avoiding and solving DQP. If we focus on the special case (site C), which outperformed all the other sites in terms of design quality and information flow indicators, the key difference was the contractor's responsibility for managing the design process in the basic design phase. Having extended time for team-building also seems to pay dividends when solving DQP in the later phases of a design project. Wong *et al.* (2005) suggested that when contractors effectively perform and communicate, they act as the project's trust initiators. Zhang *et al.* (2020) pointed out that complex contracts are effective safeguard mechanisms to enhance trust between project parties. Contracts can also be used as governance mechanisms to facilitate co-operative relationships (Yan and Zhang 2020, Zhang *et al.* 2020).

Lindblad and Guerrero (2020) presented the association between clients' roles and different construction innovation types. Interaction, such as that found in weekly collaborative meetings, is one driver for construction innovation. Again, innovation aids when solving DQP (Uusitalo *et al*. 2019), as indicated by the positive mentions of innovations when interviewees were asked about such problems. A competitive environment promotes supplier-led innovation (Lindblad and Guerrero 2020), which might have affected the performance of site C.

The second research question focussed on the connection between trust and information flow. Song *et al.* (2009) stated that because RFIs and drawing revisions both hinder effective information flow, poorly managed RFIs and drawing revisions could generate multiple instances of the same information, thus presenting a challenge for the contractor to identify the latest correct information. Lindhard and Larsen (2016) showed that both parties (owners and contractors) consider that consistent and correct project documents are the most important factor in high-performance projects. The results of the present study show that sites in the low-trending cluster did not perform significantly worse or better in terms of information flow than sites in the high-trending cluster. This result slightly contradicts those of previous studies, which identified trust as a component that enables the sharing of information (Uusitalo *et al.* 2019) and the achievement of performance (Kotter 1996). Uusitalo *et al.* (2019) proposed that both trust and information flow are necessary for efficiently solving design management problems, including DQP. Butler (1999) advocated for a trustful climate as a prerequisite for effective communication and found that, from a project actor (owner or contractor) viewpoint, trust and communication showed similar trends. In terms of the current study, this finding means that contractors in the low-trending cluster experienced a decreasing communication trend, while contractors in the high-trending cluster experienced an increasing communication trend. A similar pattern was observed for the owner's trust and communication trends in both clusters.

We also found a positive connection between trust and collaboration trends. The contractor must manoeuvre on site with the constructability issues caused by DQP. Thus, from a project progression perspective, contractors' perception of collaboration should have a vital role. Contractors' collaboration trends and trust trends had a strong connection. This connection has been highlighted by Uusitalo *et al.* (2019), who argued that trust has a significant positive effect on improving collaboration in projects. Scholars have also shown that trust and communication have a symbiotic connection (Aapaoja *et al.* 2013, Cheung *et al.* 2013, Cerić 2015, Uusitalo *et al*. 2019): communication builds trust, and trust enhances communication. The current study confirms this symbiotic connection and reveals the close relationship of trust and communication with collaboration.

Previous researchers have found that owners have a lower level of trust in other project parties than consultants and contractors do (Lindhard and Larsen 2016). This study contradicts that finding. The owner's trust trends on every site were either as positive as, or more favourable than, contractors' trust trends. One unanticipated finding was that we noted differences between the contractors' and owner's views on trust, collaboration and communication. An apparent difference was observed in the trust and communication trends, which moved in opposite directions in the low-trending cluster; whereas the contractors' trust trends decreased at these sites, the owner's trust trends increased. The owner's communication trends also increased, while the contractors' communication trends decreased, slightly decreased or remained stable. This finding could be explained by Ning et al.'s

(2019) argument that when clients experience discomfort that results in variations in contractors' performance and quality, such discomfort could lead the clients to re-balance their levels of trust and distrust.

Another explanation for contractors' lower trust trends could be the various control mechanisms or "open-book" requirements applied by the owner. Badenfelt (2010) argued that various control actions affect trust. Lumineau (2017) argued that contracts could have both beneficial and detrimental effects on trust and distrust; the effects are independent of one another, and both trust and distrust have positive as well as negative outcomes. For example, positive outcomes of distrust include encouraging constructive scepticism and supporting alertness, while negative outcomes of trust include a supported lack of objectivity and reduced numbers of constructive discussions. In the present study, because we applied measures of trust levels and did not measure the impacts of distrust levels, the effect of contracts remained partly unclear.

Differences between owner and contractor views might have stemmed from contractual effects on distrust. Lau and Rowlinson (2011) presented the idea that trust is multi-faceted and might be influenced by the other party's perception of technical and scheduling-related matters. The owner's more extensive experience from the project's technical and scheduling-related issues compared with the contractors' less extensive experience might explain the owner's more positive trust, communication and collaboration trends than the contractors' trends in the low-trending cluster.

The results of the interview analysis also highlighted how differently the contractors and owner understood design management responsibilities. One possible reason for these discrepancies may have been the teams' different experiences (McDermott *et al.* 2005). The data from the case project did not contain information about factors related to the teams' experiences, but the qualities of these experiences may be relevant in situations where DQP arise and trust is under pressure. When significant DQP, delays and dysfunctions exist in information flow, an experienced team working together can manage challenges better than an inexperienced team working together for the first time can. The literature has also described a positive relationship between a team's previous collaboration and trust (Laan *et al.* 2012).

Returning to the first research question, the results show that sites in the low-trending cluster managed to solve DQP at the same rate as sites in the high-trending cluster. Uusitalo *et al.* (2019) argued that trust could be a requirement for the effective implementation of the social domains of LDM. Even though our findings support this argument, trust could potentially not be a prerequisite when solving DQP, since such problems can also be effectively solved in projects with low levels of trust.

Conclusions

The current study is the first to establish the association between trust trends and information flow in a design management context and to explore how these factors independently or together influence design quality. Qualitative and quantitative data were obtained from multiple sites in a single project to establish the association. This study's most apparent finding is that higher trust trends are associated with a lower number of design quality problems (DQP) but are not associated with information flow metrics, such as a request for information (RFI) resolution times. The interview findings led to the hypothesis that DQP may affect trust levels but not vice versa, although the study's design did not enable us to determine the direction or existence of causality.

In summary, this study indicates that trust is positively correlated with the final design quality, but no correlation was found between trust and the speed of solving DQP. Trust is thus not a prerequisite for solving DQP: design issues can also be efficiently solved in projects with decreasing trust levels. The study results also underline that owners and contractors may have opposing perceptions of trust that seem to stem from unclear contractual responsibilities and different views on design changes in the project.

This study has two significant implications for managers. First, we suggest that in addition to measuring the trust level among the project team, project managers should pay at least equal attention to the operative design management metrics and to the level of collaboration and communication in the project, because trust may be a trailing indicator, and these operational measurements could affect trust measurements. Second, to fully benefit from relational contracts and management, managers should strive to increase the shared understanding of both project goals and individual goals. When a relationship requires repairing, an intervention to increase trust and communication could pay dividends in solving DQP. The contract models seem to influence contractors' perceptions of trust as well as the trust trends in projects. The owner plays a critical role in establishing good communication in the more traditional division of responsibilities, but early involvement in (and a stronger commitment to) contractors' design management will positively affect both trust trends and design quality.

Limitations

A significant limitation of this research is related to its cultural context. The case project and all the sites are located in Finland, which has one of the highest interpersonal trust ratings globally and is one of the least corrupt countries (Andreasson 2017). Stronger trust lowers all transaction costs in such an environment, and society functions better (Holmberg and Rothstein 2020). As Gehbauer *et al.* (2017) have argued, even in corrupt countries with low levels of trust, where lean construction principles (for example) cannot be applied, construction work still continues. We thus call on other researchers to collect more data and to study this phenomenon in culturally varied environments and for different project types to fully explore the effects and importance of trust when solving project-related problems.

Another significant limitation of this study is that co-operation was not measured at the design implementation phase based on the owner's decision, so site-specific differences were not obtainable for the period before the start of construction. A further limitation was that contractors from some sites did not participate in the interviews. The interviews were voluntary, and the researchers did not receive an explanation or reason for the contractors' refusal to participate in the interviews. Because we noted apparent differences between sites, site-specific differences in co-operation could have existed before the contractors joined the team. Another limitation is that the contractors' design management during the transition to the construction phase mainly involved traditional design management methods, such as meetings, memos and critical path scheduling; the only lean design management (LDM) design control methods were the Big Room, weekly co-operative group meetings and building information modelling (BIM). Because design management included a significant number of traditional control methods during the construction phase and the implementation of LDM methods, any conclusions we can draw about the effectiveness of LDM will be limited. Finally, the authors recognize that several other information flow metrics exist than what we have used in this study, including action rate, information package size and batch size (Tribelsky and Sacks 2010), although those metrics were not available in the case project.

Future research

The importance of previous experience and collaboration should not be underestimated and should be thoroughly explored in research to further develop the LDM framework. LDM developers should also consider the present study's findings on the effect of trust trends on solving DQP and should measure trust trends in the social domain. The sample includes seven sites, and thus the results are exploratory; these results offer excellent opportunities for further research. Researchers should also study the impact of teams' previous experience on project performance in a design management context.

Acknowledgements

The authors would like to thank the Owner for the case project as well as for providing access to data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data are available from the authors upon request.

References

Aapaoja, A., *et al.*, 2013. The characteristics of and cornerstones for creating integrated teams. *International journal of managing projects in business*, 6 (4), 695–713.

Abbas, N., Gravell, A. W., and Wills, G. B, 2008. Historical roots of agile methods: where did "agile thinking" come from?, Agile Processes in Software Engineering and Extreme Programming, Lecture Notes in Business Information Processing, Springer Berlin, Heidelberg, Vol. 9, pp. 94–103.

Andreasson, U., 2017. *Trust – the Nordic Gold*. Copenhagen, Denmark: Nordic Council of Ministers.

Aasrum, J., *et al.*, 2016. Communication in building design management: a comparative study of Norway and Germany. *In*: T. Kim and Y.-W. Kim, eds. *Proceedings of the 24th annual conference of the International Group for Lean Construction*, 19 July 2016, Boston. Boston, MA: IGLC, 43–52.

Akintoye, A. and Main, J., 2007. Collaborative relationships in construction: the UK contractors' perception. *Engineering, construction and architectural management*, 14 (6), 597–617.

Al Hattab, M. and Hamzeh, F., 2017. A process-social perspective for understanding design information flow. *Lean construction journal*, 11, 1–11.

Arain, F. M., Sadi, A., and Low, S. P, 2004. Causes of discrepancies between design and construction. *Architectural Science Review* 47 (3): 237–249.

Badenfelt, U., 2010. I trust you, I trust you not: a longitudinal study of control mechanisms in incentive contracts. *Construction management and economics*, 28 (3), 301–310.

Baldwin, A.N., *et al.*, 1999. Modelling information flow during the conceptual and schematic stages of building design. *Construction management & economics*, 17 (2), 155–167.

Ballard, G. and Zabelle, T., 2000. *Lean design: process, tools & techniques*. London, UK: Lean Construction Institute, White Paper No. 10.

Ballard, G. and Koskela, L., 2013. Rhetoric and design. *In*: U. Lindemann, *et al.*, eds. *The 19th International Conference on Engineering Design*, 19–22 August 2013, Seoul. Seoul, Korea: Design Society.

Ballard, H.G., 2000. *The last planner system of production control*. Thesis (PhD). The University of Birmingham.

Bar-Yam, Y., 2004. *Making things work: solving complex problems in a complex world*. Cambridge, MA: NECSI/Knowledge Press.

Bowen, G.A., 2009. Document analysis as a qualitative research method. *Qualitative research journal*, 9 (2), 27–40.

Butler, J.K., Jr, 1999. Trust expectations, information sharing, climate of trust, and negotiation effectiveness and efficiency. *Group & organization management*, 24 (2), 217–238.

Cerić, A., 2015. *Trust in construction projects*. Exeter, UK: Routledge.

Chan, D.W., and Kumaraswamy, M.M., 1997. A comparative study of causes of time overruns in Hong Kong construction projects. *International journal of project management*, 15 (1), 55–63.

Che Ibrahim, C.K.I., Costello, S.B., and Wilkinson, S., 2013. Development of a conceptual team integration performance index for alliance projects. *Construction management and economics*, 31 (11), 1128–1143.

Cheung, S.O., Yiu, T.W., and Lam, M.C., 2013. Interweaving trust and communication with project performance. *Journal of construction engineering and management*, 139 (8), 941–950.

Chinowsky, P., Diekmann, J., and Galotti, V., 2008. Social network model of construction. *Journal of construction engineering and management*, 134 (10), 804–812.

Chiocchio, F., *et al.*, 2011. Teamwork in integrated design projects: understanding the effects of trust, conflict, and collaboration on performance. *Project management journal*, 42 (6), 78–91.

Chong, W. K., and Low, S. P, 2006. Latent building defects: causes and design strategies to prevent them. *Journal of performance of constructed facilities* 20 (3): 213–221.

Dave, B., *et al.*, 2015. ViBR–conceptualising a virtual big room through the framework of people, processes and technology. *Procedia economics and finance*, 21, 586–593.

Edmondson, A., 1999. Psychological safety and learning behavior in work teams. *Administrative science quarterly*, 44 (2), 350–383.

El Reifi, M.H. and Emmitt, S., 2013. Perceptions of lean design management. *Architectural engineering and design management*, 9 (3), 195–208.

El Samad, G., Hamzeh, F.R., and Emdanat, S., 2017. Last planner system–the need for new metrics. *In*: K. Walsh, I. Brilakis, and R. Sacks, eds. *Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 9–12 July 2017, Heraklion. Heraklion, Greece: IGLC, 637–644.

Evbuomwan, N.F. and Anumba, C.J., 1998. An integrated framework for concurrent life-cycle design and construction. *Advances in engineering software*, 29 (7–9), 587–597.

Fleischer, M., and Liker, J.K., 1992. The hidden professionals: product designers and their impact on design quality. *IEEE transactions on engineering management*, 39 (3), 254–264.

Flick, U., 2007. Concepts of triangulation. *In*: U. Flick, ed. *Qualitative research kit: managing quality in qualitative research*. London, UK: SAGE Publications, Ltd., 38–54.

Fosse, R. and Ballard, G. 2016. Lean design management in practice with the last planner system. *In*: T. Kim and Y.-W. Kim, eds. *Proceedings of the 24th Annual Conference of the International Group for Lean Construction*, 19 July 2016, Boston. Boston, MA: IGLC, 33–42.

Franz, B., *et al.*, 2017. Impact of team integration and group cohesion on project delivery performance. *Journal of construction engineering and management*, 143 (1), 1–12.

Fredrickson, B.L., 2013. Positive emotions broaden and build. *Advances in experimental social psychology*, 47 (1), 1–53.

Gehbauer, F., Ballard, G., and Leonova, M., 2017. How research can help transform the construction industry. *In*: K. Walsh, I. Brilakis, and R. Sacks, eds. *Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 9–12 July 2017, Heraklion. Heraklion, Greece: IGLC, 293–300.

Higgin, G. and Jessop, N., 2001. *Communication in the building industry: the report of a pilot study*. London, UK: Routledge.

Hicks, B.J., 2007. Lean information management: understanding and eliminating waste. *International journal of information management*, 27 (4), 233–249.

Holmberg, S., and Rothstein, B., 2020. Social trust – the Nordic Gold? *QoG working paper series*, 2020 (1), 1.

Howell, G.A., *et al.*, 2004. Leadership and project management: time for a shift from fayol to flores. *In*: S. Bertelsen and C.T. Formoso, eds. *12th Annual Conference of the International Group for Lean Construction*, 3–5 August 2004, Helsingør. Helsingør, Denmark: IGLC.

Kärnä, S. and Junnonen, J.M., 2017. Designers' performance evaluation in construction projects. *Engineering, construction and architectural management*, 24 (1), 154–169.

Koskela, L., Huovila, P., and Leinonen, J., 2002. Design management in building construction: from theory to practice. *Journal of construction research*, 3 (1), 1–16.

Kotter, J.P., 1996. *Leading change*. Boston, MA: Harvard Business School Press.

Kumaraswamy, M.M., *et al.*, 2005. Constructing relationally integrated teams. *Journal of construction engineering and management*, 131 (10), 1076–1086.

Kpamma, E.Z. and Adjei-Kumi, T., 2011. Management of waste in the building design process: the Ghanaian consultants' perspective. *Architectural engineering and design management*, 7 (2), 102–112.

Laan, A., *et al.*, 2012. Levels of interorganizational trust in construction projects: empirical evidence. *Journal of construction engineering and management*, 138 (7), 821–831.

Lau, E. and Rowlinson, S., 2011. The implications of trust in relationships in managing construction projects.

International journal of managing projects in business, 4 (4), 633–659.

Lee, S.H., Pena-Mora, F., and Park, M., 2003. Reliability and stability buffering approach in concurrent design and construction projects. *In*: J.C. Martinez and C.T. Formosa, eds. *Proceedings of the 11th Annual Conference of the International Group for Lean Construction*, 22–24 July 2003, Blacksburg. Blacksburg, VA: IGLC.

Lindblad, H. and Guerrero, J.R., 2020. Client's role in promoting BIM implementation and innovation in construction. *Construction management and economics*, 38 (5), 468–482.

Lindhard, S. and Larsen, J.K., 2016. Identifying the key process factors affecting project performance. *Engineering, construction and architectural management*, 23 (5), 657–673.

Lindskold, S., 1978. Trust development, the GRIT proposal, and the effects of conciliatory acts on conflict and cooperation. *Psychological bulletin*, 85 (4), 772–793.

Love, P.E., Holt, G.D., and Li, H., 2002. Triangulation in construction management research. *Engineering construction and architectural management*, 9 (4), 294–303.

Love, P.E., Davis, P., and Ellis, J., 2010. Dispute causation: identification of pathogenic influences in construction. *Engineering, construction and architectural management*, 17 (4), 404–423.

Love, P.E. and Li, H., 2000. Quantifying the causes and costs of rework in construction. *Construction management & economics*, 18 (4), 479–490.

Lumineau, F., 2017. How contracts influence trust and distrust. *Journal of management*, 43 (5), 1553–1577.

McDermott, P., Khalfan, M., and Swan, W., 2005. Trust in construction projects. *Journal of financial management of property and construction*, 10 (1), 19–31.

McGeorge, J.F., 1988. Design productivity: a quality problem. *Journal of management in engineering*, 4 (4), 350–362.

Moore, D.R. and Dainty, A.R., 2001. Intra-team boundaries as inhibitors of performance improvement in UK design and build projects: a call for change. *Construction management & economics*, 19 (6), 559–562.

Nielsen, Y. and Sayar, T., 2001. Web-based information flow modelling in construction. *In*: A. Akintoye, ed. *17th Annual ARCOM Conference*, 5–7 September 2001, Salford. Salford, UK: University of Salford, 1–10.

Ning, Y., *et al.*, 2019. Understanding clients' experience of trust and distrust in dwelling fit-out projects. *Engineering, construction and architectural management*, 26 (3), 444–461.

O'Connor, J.T. and Woo, J., 2017. Proactive approach to engineering and design deliverables quality enhancement. *Journal of management in engineering*, 33 (4), 1–11.

Owen, R.L. and Koskela, L., 2006. Agile construction project management. *In*: R.D.G. Amaratunga, ed. *6th International Postgraduate Research Conference in the Built and Human Environment*, 6–7 April 2006, Salford. Salford, UK: University of Salford.

Pikas, E., 2019. *Causality and interpretation: integrating the technical and social aspects of design*. Thesis (Doctoral). Aalto University.

Pishdad-Bozorgi, P. and Beliveau, Y.J., 2016. A schema of trust building attributes and their corresponding integrated project delivery traits. *International journal of construction education and research*, 12 (2), 142–160.

Riffe, D., Lacy, S., and Fico, F., 1998. *Analyzing media messages. Using quantitative content analysis in research*. London, UK: Mahwah.

Sacks, R., 2016. What constitutes good production flow in construction? *Construction management and economics*, 34 (9), 641–656.

Sacks, R., Koskela, L., Dave, B. A., and Owen, R., 2010. Interaction of lean and building information modeling in construction. *Journal of construction engineering and management*, 136 (9), 968–980.

Seppänen, O., Ballard, G., and Pesonen, S., 2010. The combination of last planner system and location-based management system. *Lean Construction Journal*, 6 (1), 43–54.

Smyth, H. J., 2005. Trust in the design team. *Architectural Engineering and Design Management*, 3 (1), 193–205.

Song, L., Mohamed, Y., and AbouRizk, S.M., 2009. Early contractor involvement in design and its impact on construction schedule performance. *Journal of management in engineering*, 25 (1), 12–20.

Streule, T., *et al.*, 2016. Implementation of scrum in the construction industry. *Procedia engineering*, 164, 269–276.

Tauriainen, M., *et al.*, 2016. The effects of BIM and lean construction on design management practices. *Procedia engineering*, 164, 567–574.

Tilley, P.A., 2005. Lean design management: a new paradigm for managing the design and documentation process to improve quality? *In*: K. Russell, ed. *Proceedings of the 13th International Group for Lean Construction Conference*, July 19–21 2005, Sydney. Sydney, Australia: IGLC, 283–295.

Tilley, P., Wyatt, A., and Mohamed, S., 1997. Indicators of design and documentation deficiency. *In*: S.N. Tucker, ed. *5th Annual Conference of the International Group for Lean Construction, International Group for Lean Construction*, 16–17 July 1997, Gold Coast. Gold Coast, Australia: Griffith University, 137–148.

Tribelsky, E. and Sacks, R., 2010. Measuring information flow in the detailed design of construction projects. *Research in engineering design*, 21 (3), 189–206.

Tribelsky, E. and Sacks, R., 2011. An empirical study of information flows in multidisciplinary civil engineering design teams using lean measures. *Architectural engineering and design management*, 7 (2), 85–101.

Uusitalo, P., *et al.*, 2017. Review of lean design management: processes, methods and technologies. *In*: K. Walsh, I. Brilakis, and R. Sacks, eds. *Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 9–12 July 2017, Heraklion. Heraklion, Greece: IGLC, 571–578.

Uusitalo, P., *et al.*, 2019. Solving design management problems using lean design management: the role of trust. *Engineering, construction and architectural management*, 26 (7), 1387–1405.

White, M.D. and Marsh, E.E., 2006. Content analysis: a flexible methodology. *Library trends*, 55 (1), 22–45.

Wong, P.S., Cheung, S.O., and Ho, P.K., 2005. Contractor as trust initiator in construction partnering—prisoner's dilemma perspective. *Journal of construction engineering and management*, 131 (10), 1045–1053.

Wong, W.K., *et al.*, 2008. A framework for trust in construction contracting. *International journal of project management*, 26 (8), 821–829.

Yan, L. and Zhang, L., 2020. Interplay of contractual governance and trust in improving construction project performance: dynamic perspective. *Journal of management in engineering*, 36 (4), 1–12.

Zaheer, A., McEvily, B., and Perrone, V., 1998. Does trust matter? Exploring the effects of interorganizational and interpersonal trust on performance. *Organization science*, 9 (2), 141–159.

Zhang, S.B., Chen, J., and Fu, Y., 2020. Contract complexity and trust in construction project subcontracting. *Engineering, construction and architectural management*, 27 (9), 2477–2500.

Zimina, D., Ballard, G., and Pasquire, C., 2012. Target value design: using collaboration and a lean approach to reduce construction cost. *Construction management and economics*, 30 (5), 393–398.