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Digital Quality Control System—A Tool for Reliable On-Site Inspection and Documentation

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Abstract: The construction industry has seen an increase in its complexity. This has meant an increased need for time-consuming and costly quality control. Moreover, the construction industry continues to perform detection-based quality controls with little to no focus on prevention. Quality control documentation is a source of information and data that can support the development of construction processes toward prevention. However, current documentations are ambiguous and subjective, so they remain ineffectual. A case study was performed to explore the causes of the ambiguity and subjectivity of traditional quality control documentation, and to analyze the identified project-variable procedure’s transformation into standardized or even automated documentation. Evaluating the traditional quality control’s preparation, inspection, and documentation phases highlighted unique challenges requiring tailored solutions. This study identifies the challenges of inaccurate data creation and data entry, unusable documentation, and inefficient documentation. Therefore, the usefulness of data structuring and process standardization became apparent. Hence, the study explores two solutions: a digitalized quality control system (DQCS) that ensures one accurate structured data entry method, and a centralized unit that prepares the necessary data for quality control inspections, instead of the unique preparation for each project. The results show the benefits of increased accuracy, usability, and efficiency for reliable on-site inspection and documentation.

Keywords: quality control; centralization; standardization; automation; digitalization

1. Introduction

All projects, irrespective of scale, are subject to cost, time, and quality constraints. These three constraints are often referred to as the “Triple Constraints of Project Management”, and completing projects while satisfying these constraints is a central challenge in project management [1]. Dale et al. [2] argue that the three constraints are interdependent, rather than separate objectives, and that failure to recognize this interdependence can cause defects that significantly hinder the realization of satisfactory quality. ISO 9000 defines a defect as a non-conformity related to the failure to meet the specified or intended requirements [3]. Rework or repair to resolve a defect is described by Koskela [4] as a non-value-adding activity that construction sites must avoid to maximize productivity. Moreover, detection-based approaches to non-conformity contain the issues within the process but do not remove them, suggesting that they eventually will reoccur [2].

Quality management is critical to ensure the satisfactory quality of a product or service [5]. Dale et al. [2] describe quality management as a system with four discrete hierarchical stages: inspection, quality control, quality assurance, and total quality management. Inspection and quality control can be categorized as detection-type systems [2], i.e., systems that focus on searching for and finding defects. Conversely, quality assurance and total quality management focus on preventing defects from occurring in the first place. At present, the construction industry mainly relies on detection-based systems, and much research has focused on inspection and quality control [6–9]. Only a few studies...
have highlighted the importance of integrating prevention-based systems into construction processes [10–13].

Detection-based quality control at a construction site is inefficient and error-prone because it is labor-intensive and involves unstructured work [14]. Quality control documentation can help transform a detection-based system into one based on prevention, but is hindered by the ambiguous documentation caused by a lack of accurate and usable structured data [12]. Furthermore, construction site managers typically favor quick problem-solving [15]. Therefore, supervisors and their co-workers may regard quality control as merely a time-consuming administrative task, despite its usefulness in detecting errors. Hence, the value and importance of documentation are downplayed. These challenges are consistent with the perception that detection-based systems focus only on the task at hand, with little effort being made to learn from mistakes [2].

Some studies on detection-based systems [6–9,16,17] have examined the use of digitalization to automate and standardize data entry when documenting inspection outcomes. The benefits of these approaches include increased documentation efficiency and accuracy due to simplified and standardized documentation processes and data structuring. However, the value of preparation in quality control before creating digitalized checklists has not yet been evaluated. It could be argued that digital documentation tools alone are not sufficient to meet the needs of a prevention-based system. The construction industry will also need to learn how to utilize documentation effectively and develop standardized processes for defining project-variable requirements [12]. In this work, the term “project-variable” refers to factors that may differ between projects.

In this work, the study aims to explore how the construction industry could be helped in shifting from using detection-based systems to the use of prevention-based systems. To this end, this study analyses the ambiguity and subjectivity of quality control, as well as the use of a digital quality control system (DQCS) to facilitate communication, collaboration, and supportive work.

2. Theory

2.1. Quality Control at Construction Sites

In accordance with ISO 9000:2015 [3], the term ‘quality’ is defined in this work as “fulfilling the needs and expectations of customers and relevant interested parties”, meaning that customer satisfaction determines the quality of a product or service. Quality control aims to check whether a product or service fulfills the quality requirements and specifications demanded by the customer and regulatory agencies to ensure their satisfaction and the absence of defects [2]. In the literature, a defect is often associated with carelessness and a lack of knowledge, information, data, or motivation [18]. In addition, work performed at construction sites is often interconnected, meaning that one delay can cause additional delays. It is therefore highly desirable to prevent delays by identifying defects at the earliest possible stage [19]. Put another way, frequent quality control is essential [20].

Quality control at construction sites is primarily performed by site managers [16] and may be seen as a laborious task that requires extensive preparation, including meetings and analysis of drawings and sheets [21]. The preparative work is followed by on-site inspections of each task performed at the construction site to search for defects and deviations [17]. Finally, the inspection is documented on paper. Its results are often subsequently transferred to a computer, either by manual data entry into a spreadsheet or by scanning paper documents. In either case, the documentation process is often inefficient and error-prone [12,14].

Documentation generated as described above has proven difficult to use for any purpose other than demonstrating that some quality control work was conducted. This is largely due to the absence of standardized data entry and documentation procedures [22], which can support the comparability between the built projects and the planning [12]. While traditional quality control documentation can be analyzed in a beneficial manner, this requires laborious post-processing that is often avoided [12,23]. As a result of neglect-
ing the analysis, it becomes difficult to detect root causes [12]. This implies that traditional quality control systems are detection-based because of a lack of standardized documentation procedures. Furthermore, traditional quality control procedures at construction sites are subjective and heavily reliant on the experience of the management personnel. Consequently, they are inconsistent and error-prone [24,25]. The resulting ambiguity and subjectivity cause difficulties when evaluating progress [24,26], suggesting that quality control processes and the data they generate are project-specific [22,27]. While standardization can increase documentation accuracy [28], the information within the documentation is often unretrievable because it is unstructured and rarely digitalized [29], leading to redundancy and inefficiency [30].

2.2. Standardization and Automation of Documentation Procedures

Differences between projects have led to the emergence of different working procedures for quality control. These are often based on the experience of the individuals conducting the quality control work and have the potential to become new practices [31]. In addition, incorrect performance of the procedure may result in inaccurate inspection and documentation [32].

In a study on process standardization at factory and construction sites, Meiling et al. [15] observed that it can be difficult to drive managers to focus on process development, rather than being satisfied with approval from the customer. This may be due to the limited standardization of construction sites, which made it challenging to identify the root causes of defects, implying a need to increase standardization in order to facilitate the recognition of issues and opportunities for development. However, it is insufficient to standardize work procedures by introducing standard operating procedures because of problems including low worker adherence, subjectivity, and potential ambiguity [33]. Solutions have therefore been developed to visualize procedures [34–36] and streamline their implementation [14,37,38].

After prototyping studies, Zhang et al. [14] and Abdullah and Thai [37] developed and evaluated mobile web-based systems for automating project-variable documentation at construction sites. Their results indicated that such systems could increase documentation standardization and accuracy while also facilitating communication and increasing efficiency. Moreover, Park et al. [17] argued that, in addition to these benefits, data collected using digital tools could be more usable for defect reduction than conventional quality control data and could thus facilitate a shift from traditional detection-based approaches to prevention-based alternatives.

2.3. Standardization of Data

Data can be either structured or unstructured [39]. A large proportion of the information and data associated with construction projects is recorded in unstructured text documents, which means that it is not easily used in planning inspections or when comparing projects [40]. It is also common for data in documentation to be missing and/or contain inconsistencies in structure and terminology [12]. Standardizing data using tools such as classification systems [41] is one way to establish a structure that can facilitate communication between actors based on mutually agreed terminology and formats. Shared concepts of this type are essential to human communication and interoperability [42], which can enhance data transparency and traceability [43].

It should be noted that introducing new digital tools to a construction site and using them alongside traditional methods may lead to the generation of data with a high degree of diversity, also known as heterogeneity [44]. Nevertheless, there is a clear need for a way to facilitate the exchange of data more efficiently and effectively. This can be achieved by using predefined data structures, which enable the efficient utilization and matching of data across multiple digital tools [45]. Data structures organize data (which are often initially embedded in linguistic utterances) into a structured, rule- and constraint-based hierarchy, making it machine-understandable [39]. This provides a foundation to facilitate the transfer.
of information between digital tools [44]. Control over the structure of exchanged data is essential for any level of automation [46].

3. Research Method

An exploratory single-case study approach was used to develop an in-depth understanding of the studied phenomenon [47]. The objective was to identify causes of ambiguity in quality control data and ways of mitigating it. The single-case study approach enables a detailed analysis of context at the expense of generalizability [48]. The results obtained in the case study examining the DQCS were compared and analyzed in relation to existing theories, in accordance with what Yin [47] describes as significant for successful case study research. An industrialized house builder was chosen as the case company due to its use of a standardized quality management system. Despite using this standardized system in its offsite work, the case company has experienced quality control problems at construction sites similar to those experienced by traditional housebuilders.

Data were collected through a literature study, semi-structured interviews, and the analysis of archived documents. The literature study was performed to understand how traditional and state-of-the-art quality management is performed at construction sites and in other industries. One digitalization manager (interviewed on three occasions), five supervisors, and one solution developer (interviewed on two occasions) were interviewed. The digitalization manager was interviewed to gain knowledge on the company’s use of quality control documentation, the interoperability of the DQCS with existing IT systems, performance metrics, and the reasons that led to the development of the central unit. Next, supervisors were interviewed to gain an understanding of both traditional and digital quality control procedures, including the use of documentation and collaboration with the company and central unit. Finally, the solution developer was interviewed to gain insight into the decision that led to the development of the DQCS and to provide a comprehensive understanding of the technical solution. On average, the semi-structured interviews lasted just under an hour (58 min). The semi-structured approach made it possible to map the case company’s traditional and developed quality control systems while capturing the interviewees’ thoughts on the associated processes and individual procedures. The interview questions were tailored to gather information regarding the processes and procedures in place for the company’s digital and traditional quality control system’s preparation, inspection, and documentation. For the traditional preparation, interview questions were designed to assess the necessity of the preparation phase and map the requirements and procedures of the data gathering, data analysis, and documentation creation. Moreover, the interview questions addressed the supervisors’ collaboration with the case company, the construction site, and other relevant actors. For the digital preparation, along with that regarding the traditional preparation, the questions addressed the central unit’s collaboration with supervisors, the case company, and other relevant actors. For the digital and traditional inspection, interview questions primarily addressed the procedures of planning for the inspection, performing the inspection, and conformity with inspection instructions. For the traditional digital and traditional documentation, interview questions were designed to assess the utilization of documentation and map the procedures for data entry, data re-entry, data redundancy, and documentation frequency. All interviews were recorded and transcribed, which is essential for comprehending vital data [47].

The unit of analysis for the study was the quality control system, where the company’s standard operating procedures, quality control templates, and inspection templates were analyzed, both according to traditional procedures and the DQCS. This was conducted according to transformations regarding the standardization and automation of documentation procedures and structuring of data. In addition, documentation ambiguity and procedure subjectivity were evaluated regarding documentation accuracy, usability, and efficiency.
4. Case Company

The case company is a Swedish industrialized house builder specializing in the design–build of modularized timber residential buildings of two to eight floors. The company has a factory that produces one module every 50 min. These modules are then delivered to a construction site, where they are assembled and completed by conducting supplementary work, including inspections (of fire seals, ventilation systems, cables, and so on), kitchen assembly, and the closing of shafts (fire sealing). The company has optimized the efficiency and predictability of its processes through a combination of practices including standardization, modularization, and centralization. Although the case company has increased the efficiency and quality of its construction work, it recognizes that the quality and reliability of the work conducted at its construction sites could be increased. The existing quality control system at the company’s construction sites has many procedures that have generated inaccurate and underutilized data documentation (see Figure 1), making it impossible to take advantage of data that could reveal areas requiring further development and issues to address.

Figure 1. Two examples of project-based variation within construction sites’ quality control processes.

The inaccurate documentation of quality data was attributed to the ambiguous, subjective, and tedious quality control systems used at the construction sites. This ambiguity and subjectivity were readily apparent from the observation that the supervisors were required to gather and analyze quality control requirements to create inspection checklists. On the basis of their understanding and valuation of these requirements, the supervisors then prepared checklists, associated inspection instructions, and work instructions. Requirements were gathered from several sources, including inspection managers, the company’s standard operating procedures, floor plans, deviation data from the factory, building regulations, municipal authorities, and diverse experts. Depending on the source type, data could be gathered through a combination of meetings, presentations, and document reading. The case company had standard operating procedures to ensure the consistency and reliability of supervisors’ data gathering and analysis processes. However, the interviews revealed low adherence to these standard operating procedures, resulting in incompatible checklists and, thus, incompatible documentation. This was the case even when the created checklists were made from spreadsheet templates prepared by the company. Consequently, checklists from different projects had similar designs and appearances. However, their contents differed widely; among other things, there were differences in naming conventions (Inspection ID) and the structure of the location structuring of the inspection instances. More importantly, the inspection instructions differed because of the supervisors’ differing understandings of the requirements.
The utilization of the existing quality control documentation was problematic for the supervisors and the case company. Firstly, the supervisors had to manually examine the documentation to establish an up-to-date understanding of the progress of the construction work in order to plan for forthcoming inspections. This procedure had to be performed several times over the course of a construction project, but supervisors chose to perform it as rarely as possible because it was time-consuming and full of uncertainties. The uncertainty was attributed to the difficulty of ensuring accurate, up-to-date documentation and error-free examination.

Inaccuracies also arose within the documentation process, particularly during data entry and re-entry. Data entry was performed after the physical on-site inspections, during which the supervisors filled in the paper-based checklists and photographed critical aspects of the inspection. Then, upon returning to the office, the supervisors would transfer the documented inspection data from the paper checklists to a spreadsheet. In addition, they would transfer the photographs to the computer and manually organize them by renaming and categorizing them. The repetitive and subjective data entry and re-entry, combined with the ease of making mistakes, gave rise to inaccurate data. To avoid data re-entry, some supervisors preferred to memorize the data, rather than complete the paper-based checklists, creating a risk of inaccuracies that would be very difficult to track. Finally, there was considerable variation in the terminology and data formats used by different supervisors, such as in the reporting of inspection times, inspectors’ names, and descriptions of deviations.

Near the end of each construction project, the site management signed a certificate confirming that all inspections had been conducted in accordance with the relevant requirements. This required the manual inspection of the documentation by a site manager. Therefore, like planning, certification became a process that was considered to be time-consuming and full of uncertainties.

From the case company’s perspective, the documentation could be used to establish an improved understanding of its construction site processes and the impact of potential changes. However, the existing documentation would need post-processing to be used in this way because differences in data structure between construction sites would otherwise make it very difficult to compare sites and understand the content of the data. This issue is exacerbated by the inconsistent use of terminology within the existing data and by its inaccuracies, which caused the case company to second-guess the value of the documentation and create uncertainty about whether the data could be trusted.

5. Development of the Digitalized Quality Control System

This chapter describes how the case company developed a digitalized quality control system (DQCS) to support standardization and automation. To increase the system’s usability, two frontends were developed: a web application primarily used to prepare and create checklists and a mobile application primarily used during inspection and documentation (see Figure 2).
Figure 2. Central preparation utilizing DQCS to support construction sites’ work of inspection and documentation.

5.1. Preparation through Centralized Data Gathering and Analysis

The case company implemented a centralized approach to its preparation processes by forming a dedicated unit that was separate from the project-variable site supervisors and was responsible for gathering and analyzing quality control requirements. The work of this centralized unit focused primarily on the preparation stage.

The DQCS simplified the creation of inspection checklists in several ways. First, it eliminated the need to structure and define location data by drawing on data already present in the company’s production system. Second, it ensured that inspection instances were structured consistently across projects. Additionally, data entries and revisions were uploaded in real-time, ensuring that supervisors and the central unit had access to the same data at the same time. Finally, instead of the central unit having to keep track of revisions to paper-based inspection instructions, the instructions became interactive lists containing the latest revisions for each discipline. Moreover, each discipline was automatically linked to the relevant inspection instructions and the associated work instructions. As a bonus, it became possible for the central unit to organize the users of older revisions. Consequently, significant revisions were communicated immediately to the construction site. However, it was decided that non-significant revisions would be communicated only at the start of a project.

Once the centralized unit had obtained a comprehensive understanding of the company’s construction sites, its second task was to ensure the use of relevant and up-to-date inspection instructions. It also served as a point of contact for support in the event of
uncertainties, questions, or suggestions. As a result, the case company estimated that the centralized unit reduced preparation time by up to 70%.

5.2. Digitalized Planning and Inspection Support

The DQCS gave site supervisors and the central unit access to up-to-date documentation data and automatically generated statistics. As a result, compared with the company’s traditional quality control planning, supervisors could efficiently utilize the documentation and its statistics to obtain an improved holistic understanding of the project’s progress, thus enabling better planning for upcoming inspections. Additionally, the mobile application allowed supervisors to access the inspection instructions and work instructions by selecting the specific inspection moment, eliminating the need to search through papers and sheet-based documents.

5.3. Structured Inspection Data Documentation

The first step a supervisor takes when documenting quality control work using the mobile application is to select the location being inspected and the inspection instance. The supervisor then photographs critical elements of the object being inspected as specified in the inspection instructions. The captured photographs are then automatically sorted based on their metadata (time of photography), linked to the selected inspection ID, and uploaded to the company’s database. Concurrently, the data of the inspection time and inspector are also automatically added to the database in the appropriate format. In addition, the status is automatically converted depending on whether the inspection is still yet to be performed or completed. If a non-conformity is discovered, the supervisors write a description of the deviation; doing so automatically converts the status of the inspection to “deviant”. The standardization and automation incorporated into the mobile application resulted in a simplified documentation procedure that reduced supervisors’ quality control workloads by 80–90%. Moreover, the up-to-date documentation and automated generation of statistical data simplified the site managers’ task of verifying the required documentation’s existence, accuracy, and relevance. Finally, the system’s standardized structure streamlined the process of reviewing the documentation and photographs.

6. Analysis

The transition to a digitalized system incorporating structured data and standardized procedures enabled the firm’s quality control system to provide more reliable documentation that can support a shift into prevention-based systems. This transformation can be visualized in two dimensions, with the first dimension representing the extent of the transition from project-variable to standardized, automated procedures, and the second dimension representing the extent of the transition from unstructured to structured data (see Figure 3). Standardized processes for the accurate collection, communication, and use of data are needed to minimize the risk of inaccurate data entry and documentation [32].

The standardization of data entry enforced by the DQCS caused a diagonal shift of formerly unstructured project-variable data, such as the inspector’s name, inspection time, and photograph metadata, leading to their automated collection in a structured format. Similarly, inspection instructions and the recording of deviations were transformed from project-variable procedures into standardized procedures. No effort was made to change the data structure for this information; however, because this task was allocated to the central unit, its consistency increased between projects.
Figure 3. Transformation of data creation and data entry structures and procedures.

6.1. Transformation of Project-Variable Procedures

The structuring of quality control data to facilitate the implementation of a digitalized quality control system proved to be a practical first step toward improving data accuracy, usability, and efficiency.

The increased data accuracy of document creation and documentation could primarily be attributed to the standardization introduced by the DQCS, where data conformity is ensured without omission [28] by enforcing a single data entry procedure and structure [38]. The DQCS standardized previously project-variable procedures, such as creating inspection ID, inspection instruction, and deviation documentation. This means that workers now follow the same procedures, enabling a shift towards company-specific procedures. In addition, standardized data creation and data entry increased the documentation’s objectivity and reliability by reducing the subjectivity and ambiguity [4] of the data structures, interpretations, and reporting frequency. Furthermore, the automation within the DQCS helped to improve the accuracy of the documentation data by eliminating the error-prone procedure of data re-entry [29,49]. DQCS, as reported by the interviewed supervisors and solution developer, automatically collects, structures, and uploads data to the company’s database, which includes the inspector’s name, inspection time, inspection status, and photo metadata. This eliminates the tedious process of categorizing and sorting data and photographs, processes which could reduce accuracy over time [32].

The automatically provided accurate and up-to-date statistics regarding inspection completion, scheduled inspection, and identified deviations improved the usability of the collected data, which could be of use for frequent quality control planning [22]. Consequently, the interviewed supervisors stated that the DQCS enabled more regular construction project monitoring, leading to a better overall understanding of progression. Moreover, the supervisors stated that this relieved their worries about overlooking something important during their work, indicating increased confidence in the documented data. The structured and digitalized DQCS is expected to increase data usability for the case company by facilitating comparisons between projects regardless of their type, size, or site managers. The digitalization manager described the DQCS documentation as an easy-to-use and reliable data source which can be used to analyze the consequences of the company’s decisions accurately.
The increased documentation efficiency following the introduction of the DQCS can be primarily attributed to automation. It was previously established that automation could accelerate inspection processes by reducing the time spent on time-consuming or error-prone tasks [32]. For the case company, according to the interviewed digitalization manager, the tool’s introduction reduced the time spent on documentation by up to 80%. The increased documentation efficiency is secondly attributed to reduced redundancy, by not containing data re-entry procedures [14,38].

6.2. Creating a More Controlled Environment through Centralization

During the initial efforts to structure as much quality control data as possible, it quickly became apparent that a significant portion of the gathered data was unstructured and that much of the data gathered during the preparation phase was project-specific and subjective. In an exploratory study on the impact and uniqueness of project requirements from the design perspective, Eriksson et al. [50] showed that project-specific requirements can be complex because they could originate from many sources, including the building’s design, soil conditions, municipal authorities, client, residents, and other stakeholders. Furthermore, preparatory work results exhibited high variation even after standardizing the data gathering processes, because of differences in the management’s experiences and preferences [51]. Accordingly, there was considerable project variation in the preparatory work regarding the case company, even when the inspections were planned using a common data structure. This variation makes it difficult to develop efficient management practices [31]. A centralized preparation unit was set up to perform the preparation of quality control, instead of being set up by supervisors, increasing the consistency of the preparation [15]. Additionally, the central unit could efficiently work with process development and problem identification [12]. Observing the preparation of quality controls after centralization, increased preparation and terminology usage consistency were noted. According to the digitalization manager and solution developer, it simplified the identification of nonconformities and the implementation of changes to the quality control system, which made it easier to assess the impacts of changes. In a study comparing centralization to decentralization from a manufacturing perspective, Boccella et al. [52] found that, although centralization is not always suitable due to its low flexibility, it still has a notable advantage over decentralization when increased conformity and consistency are desired. Their conclusions are consistent with the increased conformity and consistency observed in this work. However, flexibility was not found by the digitalization manager to be reduced in this case, possibly because the work being conducted was already intended to be standardized. The greatest benefit of centralization was that it allowed certain individuals (i.e., the members of the central unit) to focus on and specialize in specific tasks previously handled inconsistently by a diverse group of non-specialists (i.e., site managers).

7. Discussion

Within the case firm, the standardization of inspection instruction processes alone was insufficient to ensure the reliability of the documentation. However, combining data structuring with process standardization and automation led to a clear increase in documentation accuracy, usability, and efficiency. This, in turn, allowed the firm to better understand the challenges at each stage of the documentation process that gave rise to ambiguity. Structuring the data also enabled effective traceability, which previously required manual work that did not ensure that all of the data had been correctly discovered or interpreted. This both simplified and encouraged the utilization of the documentation data.

Centralization gave the case company deeper insights into how its quality control work is performed. In particular, it gave a clear picture of how preparation was conducted, which was previously difficult to monitor. Orton and Weick [53] previously noted that decentralization complicates data sharing between projects and the company. Over time, this might lead to the emergence of deviations in performance and documentation. However, centralization by itself does not eliminate the issue of tedious and repetitive quality control
processes. A data structure is needed to automate such processes in a way that allows reliable conclusions to be drawn [12]. Therefore, the DQCS enforces well-defined data structures that enable filtering and efficient analysis with the support of automated statistics generation. Unified location structuring is used to link inspection instances to locations that can be identified by both machines and people, allowing both of their capabilities to be used in the process. Automation also gives supervisors access to real-time statistics, allowing them to accurately evaluate a project’s progress and giving them a stronger holistic understanding of the construction work [22]. Howell [54] states that not having access to real-time statistics leads to uncertainty about the actual progress of construction. The use of structured data was enforced in the digital tool to enable standardized communication, particularly between the central unit and site managers. Moreover, the data structure was designed to be comprehensible by people, making it possible for workers at different locations to communicate in a standardized way that minimizes misunderstandings. The digital tool ensures that information entered into the company’s database is standardized between projects and individuals. In addition, offloading planning work from site supervisors to the central unit and automating time-consuming processes reduced the time that supervisors had to spend on quality control work, enabling them to spend more time collaborating with the central unit on process development and implementing quality assurance plans. For this reason, DQCS’s documentation, which supports process development, has the potential to move closer to a prevention-based system, specifically, quality assurance. This is because DQCS enabled better control, perception of mistakes, development possibilities, development verification, and cost impacts.

The case company’s factory has an established quality management system that must communicate with construction sites if additional site-level quality controls are needed because of factory-related non-conformities. This necessitated a manual interface that has now been digitalized to automatically share information and requirements between the factory and the construction sites, allowing the firm and site staff to understand the impact of factory deviations better.

The majority of the construction in IHB takes place offsite, which minimizes the need for quality control measures at its construction sites in comparison to traditional construction sites. The increased need for quality control in traditional construction sites places greater responsibility and workload on supervisors, further increasing the need for an efficient quality control system. That being said, the construction sites of the IHB company have been found to have similar problems as traditional construction sites’ quality control systems, particularly in terms of poor communication, inefficiency, ambiguity, and subjectivity. Compared to traditional construction companies, a potential benefit of a central unit within the IHB company is the decreased reliance on subcontractors, as subcontractors may increase demand for supervisors and the central unit regarding coordination and communication. In addition, subcontractors are often practiced with traditional systems rather than with the developed system, leading to the possibility of it becoming a source for data loss or re-entry. Despite this, subcontractors’ regularity at IHB and traditional construction sites can vary depending on the type of project and the construction company. It is important to realize that a traditional construction company can rely less on subcontractors than IHB. Furthermore, traditional construction companies often require a higher degree of flexibility, which is an additional obstacle to integrating a central unit. For the most part, a centralized unit may be less adaptable to the unique needs of a flexible traditional construction than a decentralized system. Therefore, traditional construction companies that desire to integrate a central unit may need to increase the standardization of their construction sites and thus reduce their flexibility. Alternatively, they could develop a central unit with flexibility in mind. This may indicate the need for a central unit that efficiently processes incoming inputs and feedback while resisting disturbances.
8. Conclusions

This paper presents a study of a digitalized quality control system for the performance optimization of quality control at construction sites. The system effectively and systematically communicates and documents quality control data and exploits centralization to support the development of controlled preparation. The key lessons from the study are summarized below:

- Managing structured and unstructured data was vital when managing quality work in construction.
- To overcome challenges caused by unreliable quality control documentation and to improve documentation efficiency, as well as the accuracy and usability of documentation data, a DQCS was used to provide a company-specific standardization of the documentation procedures performed by site supervisors, enabling the automation of error-prone and tedious data sorting and uploading processes.
- To overcome the challenges resulting from deviations in quality control preparation at construction sites and improve their conformity, a centralized preparation unit was established to perform this work instead of supervisors. The centralized unit shared its work with supervisors using the developed digital tool. This centralization also made it easier for the company to identify and address suboptimal elements and errors that occurred during preparation because preparative work was conducted in a more controlled environment by a smaller group of dedicated personnel.

The application of DQCS was assessed by performing a case study on a Swedish industrialized house builder who has implemented such a system. The digital tool and centralization reduced the time that site supervisors spent on documentation by 80–90%. Moreover, automating the documentation improved searchability and reduced search times by up to 80%.

Limitations

The study’s scope was limited to quality control processes performed by the employees of the case company at construction sites, excluding processes conducted at the factory. Additionally, DQCS was assessed only in a single firm, so the above conclusions are limited in terms of generalizability; further case studies will be needed to draw more generalizable conclusions about the benefits of centralization and the DQCS.

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