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DEVISING VISUAL SYSTEMS FOR QUALITY MANAGEMENT IN CONSTRUCTION

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ABSTRACT

Construction projects face common challenges, including poor communication, distrust between managers and workforce, ineffective decision-making, and unfulfillment of quality requirements, often related to information management. To address these issues, this study explores the design and first run study of the implementation of Visual Management (VM) systems as a strategy to enhance process transparency and influence quality management practices in 2 building constructions in Peru.

The VM systems implemented followed the underlying principle of process transparency and consisted of three levels: facilitation, discipline and engagement. First, enhancing process transparency facilitated early defect detection, as well as reducing hidden defects and common errors. Second, it focused on fostering discipline among craftworkers to engage in correct procedures. Third, it promoted ownership of delivered work from craftworkers, as well as trust and communication between project staff and craftworkers. The VM systems implemented presented an initial supportive strategy for quality management with low process control but enhanced integration and collaboration.

VM systems require iterative refinement to address site-specific conditions and quality challenges. Recommendations for future research include the assessment of the effectiveness of the implementation of VM systems on quality management, as well as quantitative studies with causation analysis to evidence positive impact on quality.

KEYWORDS

Lean Construction, Visual Management, process transparency, quality, information systems.

INTRODUCTION

Construction projects are inherently unique with specific work conditions, constraints, and requirements. Such singularities lead to common problems among projects, such as ineffective communication and coordination (Galsworth, 2017), distrust between frontline workers and managerial staff (Formoso et al., 2002), ineffective decision-making (Eppler & Mengis, 2004), lack of integration between different construction processes (Demirkesen & Ozorhon, 2017), and unfulfillment of quality requirements (Love et al., 2004; Abdallah et al., 2023).

Some of the common issues of construction projects are related to the amount of information generated prior to, during and post on-site construction (Craig & Sommerville, 2006). On-site

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construction presents conditions that lead to the development of managerial systems for site management, e.g., safety management (Levitt & Samelson, 1987), production management (Koskela, 2000), quality management (Howarth & Greenwood, 2018). However, these systems may not address the goal of information management without a supporting strategy.

Information management aims to provide all project stakeholders with up-to-date, accurate, accessible, understandable, and relevant information (Reinbold et al., 2020). In light of the presence of barriers that may delay, restrict, intricate, or render obsolete information in construction sites, the units of production in those sites (i.e., construction processes) should follow the principle of process transparency. Process transparency is defined as "the ability of a production process (or its parts) to communicate with people" (Dos Santos et al., 1998). This principle is promoted through a sensory strategy for information management called Visual Management (Tezel et al., 2016). VM aims to improve performance through aligning organization objectives with management systems, work processes, workplace elements, and stakeholders, by means of stimuli (Tezel et al., 2009a) and holds a positive effect on reducing process wastes, production costs, quality problems and safety issues (Tezel et al. 2016). Although several papers have been published on the purpose, requirements and impacts of VM (Brandalise et al., 2022; Tezel et al., 2009a), the number of studies on how to implement it in construction sites, as part of a continuous improvement initiative, is still scarce.

The purpose of this paper is to present a study on the design and implementation of a Visual Management system for quality management in construction sites, based on existing taxonomies. The scope of the paper is limited to presenting the analysis of the first run study of the implementation of VM systems on 2 building constructions in Peru.

LITERATURE REVIEW

LEAN CONSTRUCTION

Lean Construction (LC) involves adopting the principles of the Toyota Production System (TPS) into the construction industry, treating construction as a value-driven system (Koskela, 1992) based on respect for people and continuous improvement. On the operational level, TPS addressed operations through a waste elimination approach proposed by Ohno (1988). From a management perspective, the core principles of TPS were translated into Lean principles such as generating value, creating flow, and continuous improvement (Womack & Jones, 1996).

Ohno (1988) describes seven production wastes as impediments to achieving efficient operations: overproduction, waiting, transportation, overprocessing, inventory, movements, and defects. Table 1 presents a description of the wastes that are relevant to quality based on the original seven identified by Ohno (1988).

Table 1: Quality wastes in construction (Adapted from Ohno, 1988)

Quality waste	Description
Waiting	Interruption of activities that have a waiting time limit
Over-processing	Delivery of work with more features than required
Under-processing	Delivery of work with less features than required
Defects	Undesired features or undesired procedures
Rework	Activities conducted to correct defects

Flow in Construction

One of the main ways to characterize construction in the field is through the concept of flow. Previous literature has discussed its meaning and implications (Ohno, 1988; Koskela, 2000;

Sacks, 2016). Kalsaas and Bølviken (2010) indicated that flow can be represented through four interpretations: a chain of events (i.e., a sequence of steps towards an end), continuous movement (i.e., incremental progress), moving freely (i.e., advancing without restrictions), and adding value (i.e., rejection of waste).

Koskela (1999) introduced 7 types of flow: construction design (information), materials, workers, equipment, space, previous work and external conditions. In addition to these enabler flows, Tommelein et al. (2022) described trade, operation, process, and product flows. Among them, product flow has the greatest potential for improvement (Sacks, 2016). Koskela (2000) defined six principles for improving flows: reduce waste, reduce cycle time, reduce variability, minimize the number of steps, maximize flexibility, and provide transparency. The principle of providing processes with enhanced visualization of their hidden elements and flows (operations, materials, resources, information) is called process transparency.

PROCESS TRANSPARENCY

Process transparency is achieved by making the main flows visible and comprehensible from start to finish, through organizational and physical means, measurements, and public display of information (Koskela, 1992). If it is successfully implemented, most problems, abnormalities, and types of waste can be easily recognized to allow remedial measures to be taken (Igarashi, 1991).

Koskela (1992) argues that improving transparency requires several changes carried out together to observe desired results: (1) reducing interdependence between production units, (2) using visual artifacts that allow immediate recognition of process status, (3) making the process directly observable, (4) incorporating information into the process, (5) maintaining a clean and orderly work site, and (6) representing invisible attributes through measurements.

VISUAL MANAGEMENT

Visual management is a managerial strategy that emphasizes short-range sensory communication (Tezel et al., 2016). VM provides a way to achieve continuous product and information flows through work control and information management (Tezel et al., 2018). Some VM taxonomies have been developed according to their degree of control (Galsworth, 1997), function (Tezel et al., 2009b), visual expression (Bititci et al., 2016), and specific purpose (Tezel et al., 2015). By integrating VM taxonomies, Brandalise et al. (2022) proposed a typology that classifies visual elements in 3 levels and 7 attributes (Figure 1). That typology offers a way to analyze, improve and standardize visual elements.

Level 1: Device	A visual display designed to achieve a certain degree of control by its visual appeal only for a certain period (e.g. permanent safety signals).
(1) Degree of control (Galsworth, 1997)	*Visual indicator,* which shares information with voluntary compliance. *Visual signal,* which catches attention and generates a reaction. *Visual control,* which impacts behaviors by limiting physical quantities. *Visual guarantee,* which ensures desired outcomes by mistake-proofing.
(2) Visual expression	Static (immutable) or dynamic (updated over time).
Level 2: Practice	A visual device designed to fulfill a specific function with a communication, collaboration, or managerial integration role (e.g. Kanban, Andon, 5S).
(3) Main purpose	Control artifact, execution procedure, target specification, material delivery, prototype, or others (specified in Tezel et al. (2015)).
(4) Communication role	One-to-one, one-to-many, many-to-one, or many-to-many.
(5) Collaboration role	Collaborative (stimulating interactions) or non-collaborative.
(6) Integration role to management routines	Integrated or not integrated.
Level 3: System	Two or more integrated visual practices with greater impact on the project.
(7) Integration of practices forming a system	Integrated or not integrated.

Figure 1: Typology of Visual Elements (Adapted from Brandalise et al., 2022).

Among the existing VM taxonomies, the taxonomy of functions provides a way to structure the design and implementation of visual elements according to their motivation and degree of interaction with construction operations (repetitiveness of use, proximity to operations, people involved, etc.). Tezel et al. (2009b) identified 9 functions in this taxonomy:

- *Transparency*: Ability of a production process (or its parts) to communicate with people.
- *Discipline*: Making a habit of properly maintaining correct procedures.
- *Continuous improvement*: Process of focused and sustained incremental innovation.
- *Job facilitation*: Conscious attempt to ease people's efforts physically and/or mentally on routine, already known tasks by offering various visual aids.
- *On-the-job training:* Learning from experience or integrating working with learning.
- *Creating shared ownership:* Feeling of possessiveness and being psychologically tied to an object (material or immaterial).
- *Management by facts:* Use of facts and data based on statistics.
- *Simplification:* Constant efforts on monitoring, processing, visualizing, and distributing system wide information for individuals and teams.
- *Unification:* Partially breaking organizational boundaries (vertical, horizontal, external, geographic) and fostering empathy through effective information sharing.

Visual Systems in the Field

At the beginning of its adoption in construction, VM was mostly applied to support managerial decisions in site offices and to support safety management in the field (Tezel & Aziz, 2017). The following stage of adoption involved the application of visual practices in the field to support specific operations. Some VM practices, such as Andon, prototyping, prefabrication and mistake-proofing, were applied as methods to efficiently detect, prevent or avoid mistakes (Tezel et al., 2015). However, most implementations reported in the literature so far lack integration and could not address site management strategies (other than safety) as a whole. To address the need to systematically support a management strategy through VM, Valente et al. (2019) proposed a 4-step model to conceive VM systems:

1. *Analyze the process:* gather data of problems, potential causes, and participants through direct observation, document analysis, and interviews.
2. *Analyze user needs:* identify relevant information to be displayed and the function of each element (Tezel et al., 2009b).
3. *Integrate visual elements to the process:* coordinate tasks, communication details, and promote collaboration.
4. *Define visual attributes:* establish the content, coding, location, and elements of attraction.

Neyra et al. (2024) indicated that in the field of quality management, VM practices and devices often served the functions of transparency and job facilitation. Therefore, those two functions were considered as a starting point to devise a VM system (Brandalise et al., 2022) for quality. Furthermore, starting points in terms of degree of control as part of the system would be visual indicators and signals (Galsworth, 1997) to fulfil purposes of early mistake detection, standard verification procedures and fulfilment of requirements.

QUALITY IN CONSTRUCTION SITES

One of the most accepted definitions of quality in construction is "meeting the requirements of the designer, constructor and regulatory agencies, as well as the owner" (Arditi & Gunaydin, 1997). Quality control in construction sites is a detection system of regular inspections of work that complies with agreed features and tolerances (Hussamadin et al., 2023). Typically, quality control is primarily carried out by site managers (Kim et al., 2008) and favors quick problem-solving over prevention-based systems (Meiling et al., 2014).

Quality control documentation is often performed in protocols based on procedures from quality plans (elaborated by constructors) which in turn are based on specifications (elaborated by designers based on owners and regulatory agencies requirements). However, quality documentation is frequently based on simple conformity and lacks from accurate and usable data for learning and improvement (Lundkvist et al., 2014).

There are issues regarding the perception of quality on construction sites. From the perspective of frontline workers, some misconceptions about quality could lead to the dismissal of undocumented standards, underestimation of valuable insights, avoidance of responsibility on quality control and compliance to low standards (Trivedi et al., 2024).

METHODOLOGY

Two case studies were conducted in building construction projects under shell construction, both located in Peru. Three sources of evidence were used: participant observation, document analysis, and unstructured discussions (Yin, 1994). Participant observation was selected as one of the authors acting as facilitator of the VM implementation. The unstructured interviews involved meetings with 2 quality engineers and 2 workforce leaders per project to capture their perspective on process details, information availability, quality and VM. The documentation consulted included handover documents, quality protocols, blueprints, and schedules.

The research took place between November 11th, 2024, and January 18th, 2025. The first case study was conducted for 4 weeks on Building A project, which was part of a condominium construction project. Meanwhile, the one on Building B project, which was a university building project, lasted for 5 weeks. They were selected for their interest on VM implementation.

PROCESS SCOPE DESCRIPTION

Two processes for each building project were observed, given the constraints related to time and number of observers (one pair per process observed). The selection criteria were based on the analysis of handover documents and quality protocols. Each one of the processes selected are presented in Table 2 and codified as PXX.

Table 2: Scope Selected from Each Work Area

Building A	Building B
P01: Steel rebar installation in pilasters	P03: Steel rebar installation in columns
P02: Concrete repair inside apartments	P04: Formwork for vertical elements

OBSERVATION INSTRUMENTS

In order to structure the observations made on the field to identify of quality issues, improvement opportunities and the status of VM and process transparency, four observational instruments were developed. First, INS-01 was a work sampling sheet that included a map of the building sectors and spaces to identify the sequence of activities of the process during the period of observation and wastes associated with quality issues. Second, INS-02 was a process mapping sheet that included a guiding legend to build the flow of activities and resources of the whole process. Third and fourth, INS-03 and INS-04 were the improved versions of the process transparency and visual management protocols from Neyra et al. (2024), respectively, and served the purpose of assessing the existing transparency approaches and features of the identified VM devices based on the literature.

INTERVIEWS AND FACILITATION

Two types of unstructured interviews were carried out. First, staff engineers were asked to describe the quality control of the project, as well as their agreements with frontline workers on quality requirements. Second, workforce leaders were asked to describe their perception on the use, benefits and challenges of the visual devices implemented. The facilitation role on the implementation stage involved answering doubts about how to use the devices and addressing observations during meetings around the sector control sheet on Building B.

RESEARCH FINDINGS

PROCESS MAPPING

To understand the product flow and identify improvement opportunities, process maps were produced. Each map contains aspects of location, operations, materials, resources, and information flow. Process maps were elaborated from INS-02 (see Figure 2).

PRODUCTION WASTES RELATED TO QUALITY

Activity sampling was conducted through INS-01, and some wastes associated with quality were identified. Based on 5 quality wastes (see Table 1), Table 3 presents the description of the following detected wastes: defects (D), rework (R) and under-processing (UP).

Table 3: Waste Identification

Process	Waste Code	Description
P01	UP	The quantity of steel ties of some elements was less than required.
P02	D	Wall portions that need treatment remain unseen due to visual barriers.
P03	R	Repetitive markings for steel tie positions on each vertical element.
	D	Difficulty to verify the correct position of the steel rebar in the field.
P04	D	Some formwork walls yield more than two millimetres after pouring.

PROCESS TRANSPARENCY AND VISUAL MANAGEMENT STATUS

The most relevant aspects of process transparency (Koskela, 1992) observed are detailed in Table 4. Similarly, Figure 3 presents the classification of the visual elements identified. Among the existing visual elements, biweekly sheets and steel bar markings exhibited great potential to be improved and standardized into a VM system for Buildings A and B, respectively.

Table 4: Summary of process transparency features

Process	Feature	Description
P01	Visual elements that incorporate information into the process	Displayed structural blueprints Markings on steel bars for tie position
P02	Visual elements that incorporate information into the process	Observation marks on the wall as repair instructions
	Visual element for status recognition	Biweekly sheet on apartment entrance
P03	Visual barriers	Scaffolding and element height (3.7 m)
	Visual elements that incorporate information into the process	Markings on steel bars for tie position Column type identification mark on the floor
P04	Measurement of invisible attributes	Random record of plumbing values

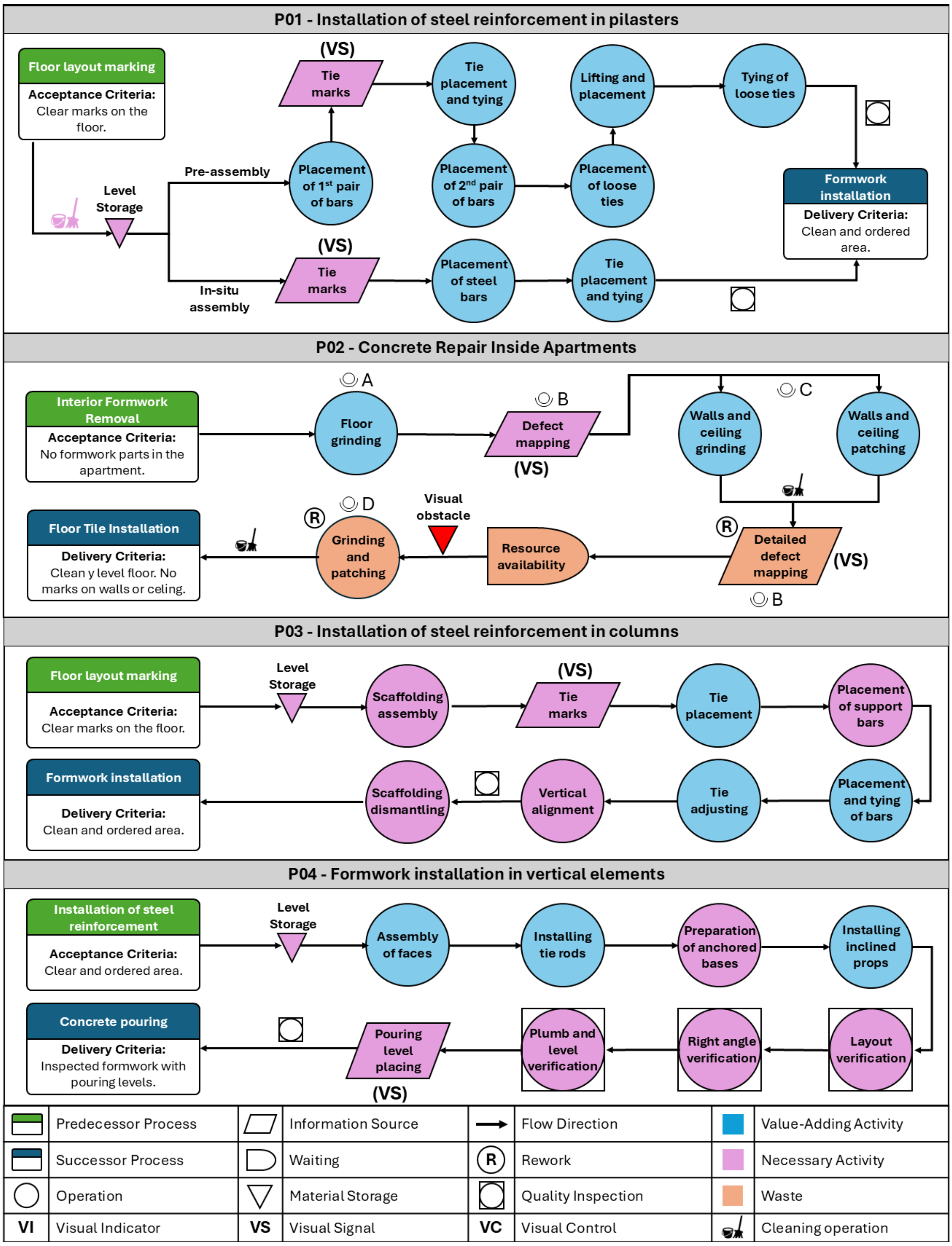


Figure 2: Process Maps with Elements and Flows Identified

Element	Degree of control	Visual expression	Role of communication	Role of collaboration	Role in managerial routines integration
Structural blueprints	Visual indicator	Static	One-to-many	Non-collaborative	Not integrated
Biweekly sheet	Visual indicator	Static	One-to-many	Non-collaborative	Integrated
Steel bar markings	Visual signal	Static	One-to-one	Non-collaborative	Not integrated
Column ID marks	Visual control	Static	One-to-one	Non-collaborative	Not integrated

Figure 3: Classification of Visual Elements Identified

Design and Implementation of Visual Systems

To design visual systems to support quality management, we followed the 4-step model proposed by Valente et al. (2019). First, we gathered data from the processes, identified problems and participants involved. Second, we proposed three levels of implementation motivated by 4 VM functions (Tezel et al., 2009b): facilitation level (work facilitation), discipline level (discipline), and engagement level (ownership and unification). The transparency factors (Koskela, 1992) were considered, as well as the information to be transmitted. Third, we defined the coordinators in charge of updating or displaying the visual elements. Finally, we designed their content and selected a suitable location.

Three of the elements of the first VM system were implemented (see Figure 4) and studied for 1 week due to resource and time constraints. In contrast, all elements of the second system were implemented (see Figure 5) for 2 weeks. Both implementations were supported by a researcher in the role of facilitator.

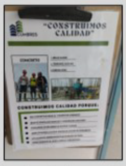
	Building A – Visual System for Quality				
	Facilitation Level	Discipline Level		Engagement Level	
Element	 Standard defect mapping	 Work instructions in biweekly sheets	 Daily commitment sheet	 "We build quality" sheets	 "We are all quality" signs
Problem	P02 presented visual obstacles, unclear instructions, and undefined coding.	Procedures and controls were not documented, limiting analysis and improvement.	Progress and location of the activities of each floor are not easily identified.	Unclear quality practices in each process.	The purpose of quality management was not clear enough.
Participants	Foreman (defect mapping) Site engineer (instructions) Journeyman (reads marks)	Site engineer (instructions) Workforce (experience)	Foremen (report progress and inspection) Site engineer (analyze data)	Site engineer and workforce	Site engineer and workforce
Information	Remaining obs. Arrows for hidden marks Grind (0-5mm) Chip (5-10mm) Patch (0-10mm)	Materials, procedures, and standard practices	Progress on work sector Reporting inspection of completed work	Identification of each crew Best quality practices from the team	Quality quotes based on error identification, suggestions, and improvements
Transparency	1. Process visibility 2. Incorporating information 3. Measurement of invisible attributes	1. Recognition of process status 2. Incorporating information	1. Recognition of process status 2. Measurement of invisible attributes	1. Process visibility (indirect effect)	1. Incorporating information (indirect effect)
Coord.	Foreman	Site engineer	Not implemented	Quality engineer (lead sheet design)	Not implemented
Content	Colored marks in walls of activity and thickness. Red mark of the number of remaining observations.	QR code attached to biweekly sheet and paper copy displayed on apartment entrance.	Map of work sectors for location. Table for assigning progress and verification signature.	Identify each crew (names and photo), process they perform and agreed quality practices.	Design with colors of the company logo and a QR code for reporting errors, suggestions or comments.

Figure 4: Visual System for Quality in Building A

	Building B – Visual System for Quality				
	Facilitation Level	Discipline Level		Engagement Level	
Element	 Color legend for column bar	 Steel distribution sheet	 Column verification sheet	 Sector control sheet	 "We are all quality" signs
Problem	Current visual elements of P03 were almost invisible for external viewers.	Verification of P03 was sporadic and always required blueprints.	Verification of P04 was sporadic and lacked documentation.	Construction sequence (P03 and P04) was disordered and lacked clear verification.	The purpose of quality management was not clear enough.
Participants	Foreman (instructions) Workforce (use element)	Quality engineer and journeymen (collaborative verification)	Quality engineer and journeymen (collaborative verification)	General foreman, foremen, and site engineer (collaboration)	Site engineer and workforce
Information	Tie spacing: 20cm (blue) 15cm (green) Bar splicing (orange)	Reinforcement type, diameter, quantity, and position	Plumbing, right angle, stiffness and alignment to be verified	Sector map (elements), subsectors (to define) and pouring date	Quality quotes based on quality control and work verification
Transparency	1. Process visibility 2. Incorporating information	1. Recognition of process status 2. Incorporating information	1. Recognition of process status 2. Measurement of invisible attributes	1. Process visibility 2. Clean and orderly site	1. Incorporating information (indirect effect)
Coord.	Foreman	Foreman and quality engineer	Foreman and quality engineer	Site engineer and general foreman	Quality engineer (support message in daily huddles)
Content	Diagram of colored bar following a legend.	Visible column type, location, space to verify reinforcement and indicate verifier.	Three instances of plumbing control (work finished, before pouring, after pouring) and verification space.	Table to indicate start and end dates of P03 and P04 (progress and verification).	Design with colors of the company logo.

Figure 5: Visual System for Quality in Building B

DISCUSSION

VISUAL MANAGEMENT AND PROCESS TRANSPARENCY

In both construction projects, VM was implemented by incorporating information into the process, recognizing process status, enhancing visibility, and representing invisible attributes (Koskela, 1992). In contrast to Building A, Building B presented more elements (3 out of 5) with dynamic expression and collaboration fostering. The reason for this difference was related to takt planning; Building B had longer work sectors, while Building A had a daily takt plan. Therefore, implementing changes and coordinating was easier in Building B.

Both VM systems exhibited low degree of control (only visual indicators and signals) given that the first run study did not aim to change construction processes significantly but attempted to increase the understanding of the influence of VM systems in quality management.

QUALITY AND PROCESS TRANSPARENCY

Enhancing process transparency exhibited some quality related benefits, as stated by some of the frontline workers interviewed. Incorporating information in the process fostered correct procedures, “It’s like a guide to do my work,” and improved work verification, “it’s easier to be sure that what someone is doing is correct.” Additionally, representing invisible attributes contributed to transparent quality control, so that “anyone can be aware of the steps carried out to verify this element.”

From the perspective of the analysis of waste, defects were intended to be prevented through information incorporated into the process, as exemplified by a journeyman: “Oh! I missed five [ties], let's correct that.” These early detecting and prevention of defects aims at (1) avoiding hidden defects, (2) reducing common errors, and (3) avoiding propagation of variability.

At a higher level of implementation, process transparency aimed at fostering trust between managerial staff and frontline workers. However, some crucial conversations were necessary to ensure that the influence of transparency was not considered to be a way to exert more control over people. After that clarification, some craftworkers expressed their satisfaction: “with this [the visual element] we can be on the same page when discussing quality or progress”.

QUALITY AND VM FUNCTIONS

VM functions, as suggested by Tezel et al. (2009b), were key to guiding the development and integration between elements. First, job facilitation was selected as the function of the first level due to its practical nature and its direct relationship with processes. Second, discipline was considered to be an adequate way to connect different job facilitation practices along with existing quality practices by fostering correct procedures. Third, by creating shared ownership the implementation of the VM system would be properly connected to the people instead of to an object. Finally, through unification the system would be seen as collaborative (staff and workforce) and better integrated with quality management.

In both projects, the VM systems implemented proposed a shift from either a protocol-oriented or experience-oriented quality management system to a visually meaningful quality system supported by Visual Management. However, to sustain that change the systems require constant revision, registration, and improvement to adapt to site conditions and quality issues.

CONCLUSIONS

The present study highlights the role of VM systems as support strategies for quality management. Devising such systems required three implementation levels (facilitation, discipline, and engagement) addressing different functions along with the core principle of process transparency to bridge the gap between current and desired quality practices.

Enhanced process transparency aimed at facilitating promoting correct procedures, improving work verification, and increasing visibility of defects and common errors. Additionally, transparency started a path to foster trust and collaboration among project managerial staff and frontline workers, ensuring shared understanding and alignment in quality objectives.

Despite its apparent benefits, VM systems require iterative refinement and provision of autonomy to fully address site-specific conditions and quality challenges. Future research could use iterative cycles to assess the effectiveness of implementing VM systems on quality management, as well as a quantitative approach along with causation analysis to evidence the impact of VM systems on quality.

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