湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

第 50 卷 第 2 期
2 0 2 3 年 2 月

Available online at http://jonuns.com/index.php/journal/index

Vol. 50 No. 2
February 2023

Open Access Article https://doi.org/10.55463/issn.1674-2974.50.2.28

Systemic Quality Management Processes in Construction Projects

Kaoutar Ghafiki[1]*, Benaissa Kissi[1], Hassan Aaya[2]

[1] National High School for the Arts and Professions, University of Hassan II, Casablanca, Morocco

[2] International University of Casablanca, Morocco

* Corresponding author: Ghafiki.kaoutar@gmail.com

Received: December 6, 2022 ▪ Review: January 10, 2023 ▪ Accepted: February 8, 2023 ▪ Published: February 27, 2023

Abstract: This research is part of the quality approach of a construction company. It aims to make the assessment of quality management for a real construction project, this assessment will be done through the analysis of the database of the company and the documentation established during the realization of the site. Obtaining quality in construction will always remain problematic, in the absence of monitoring of construction work, defects in the execution may appear and affect the durability, stability, and aesthetic appearance of the built work. The non-quality can affect the project from the design and study phase, through the course of the work to the commissioning of the project. Hence, the need for quality control in the successive phases of design and construction, an analysis of the issues, and a description of the quality system can formalize the requirements of sustainable adequacy of works to ensure that the project requirements are constantly met according to the ISO 9001 and Moroccan standards of construction. A formalized risk management tool for non-conformities previously encountered on site is implemented to put into practice the theoretical and methodological approach proposed in several case studies. The current study develops an operational quality management process for the company, to identify non-conformities, qualify, and quantify them. This tool could become a powerful communication tool for all actors and a real decision support tool within the companies. Indeed, complex construction projects present enriching experiences to better master the economy, technique, design, construction, and maintenance. The future of this type of innovative projects depends on better collaboration between the parties to share responsibilities and risks.

Keywords: quality management, construction site, non-compliance, formalized process, ISO 9001.

建设项目的系统质量管理流程

摘要: 这项研究是建筑公司质量方法的一部分。它旨在对一个真实的建设项目进行质量管理评估，该评估将通过分析公司的数据库和现场实现过程中建立的文件来完成。施工质量始终存在问题，在施工过程中缺乏监督，施工过程中可能会出现缺陷，影响建筑的耐久性、稳定性和美观性。从设计和研究阶段，通过工作过程到项目调试，非质量都会影响项目。因此，需要在设计和施工的后续阶段进行质量控制，分析问题，描述质量体系，才能使工程的可持续充分性要求形式化，以确保项目要求不断满足国际标准化组织 9001 和摩洛哥建筑标准。针对以前在现场遇到的不合格情况，实施了正式的风险管理工具，以将几个案例研究中提出的理论和方法付诸实践。当前的研究为公司开发了一个运营质量管理流程，以识别不合格、限定和量化它们。该工具可以成为所有参与者的强大沟通工具和公司内部真正的决策支持

工具。事实上，复杂的建设项目为更好地掌握经济、技术、设计、施工和维护提供了丰富的经验。此类创新项目的未来取决于各方更好地协作以分担责任和风险。

关键词: 质量管理、建筑工地、不合规、正式流程、国际标准化组织 9001.

1. Introduction

The last decades have been marked by notable evolution in terms of civil works, but also by a recurrent loss of earnings and unfulfilled objectives during construction projects, which call into question the building and public works profession. If the margins of progress still seem present both in techniques and in processes, they seem to be constrained by compartmentalized knowledge and practices.

As a result, public work has entered the quality approach and have considerably improved the control of sites and customer satisfaction with ISO 9001. This standard represents a strong cultural evolution with the taking into account of users wishes, in particular the need to lighten and simplify the quality system, to adapt it to the work and to make it more efficient.

This work allows site managers, work supervisors, quality managers, and safety coordinators to understand the qualitative dimension of the processes related to their function and to implement them in an approach of research of quality by establishing a set of rules and approaches of organization and communication allowing the company to well control its site and to make it live.

A well-structured and formalized process of quality management for construction projects allows to identify and analyze the non-conformities met in the construction sites [1]. The formalized process adapts to the dynamic and evolving nature of the project and to the vision of an actor who manages the quality.

The objective of our study will thus consist in developing an operational process of quality management for the company, to identify the nonconformities, to qualify them, and to quantify them. The whole of the steps followed are nourished by feedback drawn from a real project.

2. State of the Art of Quality Management for Construction Projects

At the international level, the ISO 9001 standard defines quality as "The ability of a set of intrinsic characteristics to satisfy requirements", that is to say, a relative notion based on the satisfaction of the end-user's need.

Although each project has its own characteristics and specific requirements, the management of any project is based on the same quality approach that integrates technical, administrative, and financial requirements.

Each phase of a project (preparation, organization, technical coordination, execution of the work, acceptance of the work, completion of the project) requires an analysis of its follow-up and a structuring of its quality and safety management with simple and effective tools of piloting and analysis to keep its agility and reactivity.

The diversity of the quality approaches of the building site generally calls upon various competences of expertise of a construction company to know:

For the owner, it should:

- Respond in terms of time, reliability, and compliance to the needs of users relating to the work delivered.
- Adopt a precise specification allowing control from the beginning of the operation the costs and deadlines, including those due to the risks of non-quality or nonconformity.
- Minimize modifications during the execution of the project and reduce additional work.

For the project manager/site manager, it should:

- Define a project and reduce modifications after acceptance of the project.
- Have a control of the costs and deadlines by leaving the least possibilities of improvisation on site.
- Deliver a compliant construction, completed on time, without exceeding the budget, to the client.

For the company, this means:

- Presenting a well-estimated offer with a fair competition.
- Having enough time to prepare the construction site.
- Having a precise and complete definition of the work to be carried out.
- Optimizing production costs by a preventive approach.
- Working under an effective coordination of the tasks.

Fig. 1 The importance of quality in the construction process

The quality approach requires compliance with a process defined by the ISO 9001 standard. This one is articulated around 4 major stages, which follow one another with an aim of permanent improvement:

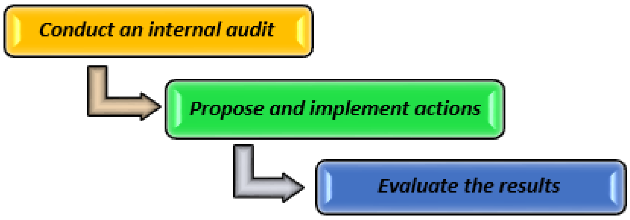

Fig. 2 Stage of the quality process according to the ISO 9001 standard

- *Conducting an internal audit*: analyzing operations, identifying customer needs and requirements;

- *Proposing actions: providing* target proposals for improvement;

- *Implementing:* managing the decided actions by mobilizing the necessary resources;

- *Evaluating the results:* bringing corrective actions to the action plan

Fig. 3 The quality management approach according to ISO 9001

3. Methods and Materials

3.1. Tools of Quality

Among the most used quality tools in the field of construction, we can mention the BRAINSTORMING, the 5W method, and the ISHIKAWA diagram.

3.1.1. Brainstorming

This is a participatory method that is based on the creativity of the participants. It must allow to find new and better ideas. The facilitator collects all the exchanges, without too much constraint so as not to limit the thinking process. Brainstorming is used in problem solving.

Procedure:

- Form a multidisciplinary group.

- Remind the group of the golden rules (say everything, plunder the ideas of others, do not comment on or criticize the ideas put forward, do not formulate ideas in the form of questions but as solutions).

- State the subject, the theme to be treated in the form of a question, explain it and post it on a board.

- Each participant gives ideas in turn and writes them down.

3.1.2. The 5W Method

This tool consists of asking yourself the 5 key questions to identify a situation: Who, What, Where, When, and Why the objective of this tool is to collect all the necessary information related to a situation, a system, or a problem. It allows to pose a problem in its completeness, it is not a question of looking for the causes of the problem, but it can be used when we want to understand a phenomenon, a behavior, and give meaning to an event.

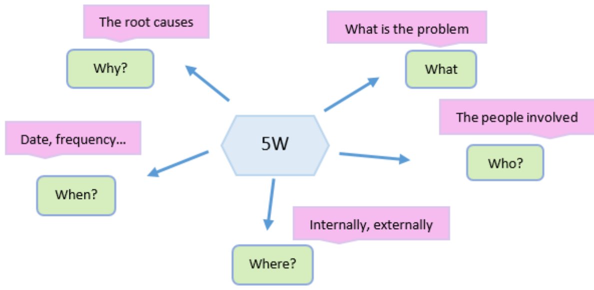

Fig. 4 The principle of the 5W method

3.1.3. ISHIKAWA Diagram

The objective of this tool is to analyze all possible causes of an effect. It is often used in problem solving to discover the root cause(s) of the problem.

This tool provides a structured representation of all causes that produce or could produce the observed effect

We will look for the causes by grouping them according to the five classes below:

Material: The raw materials, and more generally the inputs of the process.

Equipment: Includes equipment, machines, tools, hardware, software, and technology.

Method: Operating procedure and research and development

Manpower: Everything related to human resources

Environment: Environment, positioning, and context.

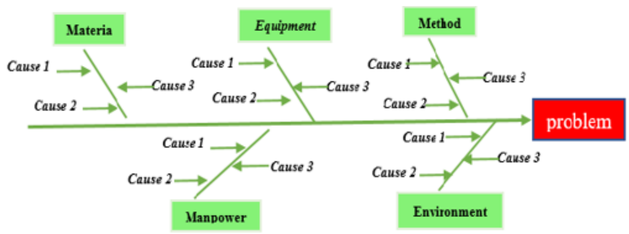

Fig. 5 The structure of an ISHIKAWA diagram

3.2. The Contribution of Quality Management to the Construction Sector

The quality approach in construction sites follows the quality management system as described in the ISO 9001 standard, which is based on the "process approach".

The process approach means the application of a system of processes within the organization, as well as the identification of interactions and management of these processes. The term "process" refers to any activity that uses resources and is managed in such a way as to allow the transformation of input elements into output elements, the output element most often being the input element of the following process.

The quality management system model is based on processes presented by the "Deming Wheel" concept designated as "Plan, Do, Check, Act". This concept is described as follows (Figure 6):

Plan: Establish the objectives and processes necessary to deliver results that meet customer requirements and organizational policies.

Do: Implement the processes.

Check: Monitor and measure processes and products against policies, objectives, and product requirements and report results.

Act: Take actions to continuously improve process performance.

Fig. 6 Model of a process-based quality management system

3.3. Non-Quality in Civil Engineering

Non-quality is characterized by a failure to meet the specified requirements; non-quality generates additional costs to the company (Figure 7).

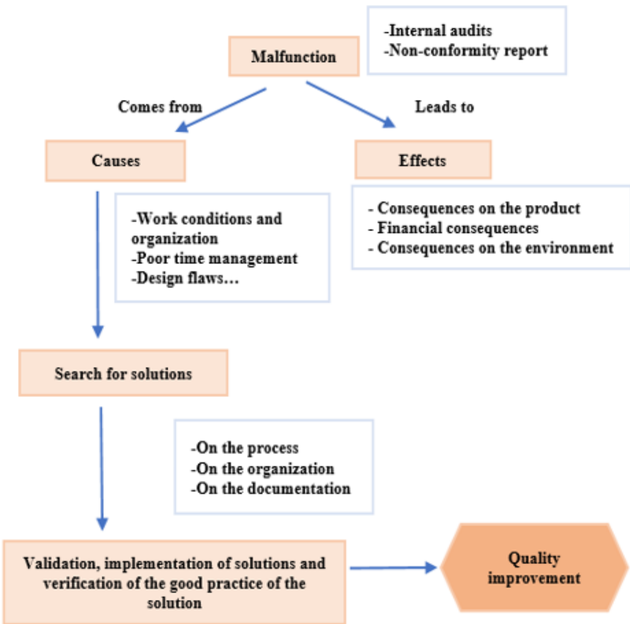

Fig. 7 Non-quality resolution methodology

Indeed, it is generally more expensive to correct defects or errors than to "do it right" from the start. On the other hand, the cost of non-quality is all the more important as it is detected late.

The quality tools mentioned in the previous paragraph allow:

- Express the problem in a measurable way;

- Analyze the causes: list the possible causes, determine the major causes;

- Find solutions, implement them, and verify their effectiveness.

3.3.1. Analysis of the Needs of a Construction Company for Quality Management

Our case study was conducted on a large project of a leading construction company called Jacobs Engineering, an international engineering and construction company created in partnership with the Office Chérifien from phosphate OCP. The Jacobs group (the 3rd largest engineering company in the world) and the Office Chérifien from Phosphate (leader in phosphate) have signed a partnership agreement in industrial engineering, which has allowed the creation of a joint engineering company that will provide project management and engineering services for projects included in the investment program of OCP [2].

This partnership has enabled Jacobs to demonstrate its ability to manage, execute, and deliver large projects, some examples of which are listed below:

- The 4 industrial fertilizer production units in Jorf Lasfar;

- The Slurry Pipeline, the first wind turbine plant in Africa for Siemens;

- The port of Jorf Lasfar;

- The Sheikh Khalifa Hospital in Casablanca.

Several case studies of real projects were proposed by the company we chose one of the above projects to analyze the quality approach. This project was in the closure phase, which allowed us to have feedback on the quality approach implemented during the project.

An inventory allowed us to identify and analyze the concerns, practices, and tools available or implemented within the company for quality management. The inventory was conducted from monthly reports and documentation proposed by the project leaders, working meetings, analysis, and synthesis of existing quality manuals in the company.

For the project studied and which exceeds 45 000 000 Dirhams a committee of quality control hygiene security was charged to validate and follow the project at several milestones: before issuing the application, before making the first offer, before making the final offer and before contracting.

This committee is composed of several people: directors, project managers, quality engineer, health, safety and environment managers, etc.

The position of quality manager within the company now has a decisive place in the growth strategy. This specialist accompanies the manager in the definition of a quality policy that must then be implemented through action plans and continuous improvement techniques.

Based on the current situation, we have identified the company's priority needs for quality management:

- To develop a common quality management methodology associated with a support tool. The proposed methodology will have to ensure the traceability of data and information and to set up the feedback.

- To develop a quality management approach to deal with nonconformity throughout the project life cycle.

The analyzed documentation of the company and its mastery:

The tasks carried out during this project were scheduled and recorded in the form of documentation. The recording of monitoring and control documents reflects the completion of tasks and compliance of tasks and works performed, and the supervision and monitoring must be sufficiently mastered to accomplish the tasks assigned to him to comply with the quality approach in construction sites according to ISO 9001.

The documentary aspect is of primary importance in the management of construction projects. The documents required for the quality management system must be controlled and managed by the company efficiently [3]. There are three types of documents:

1) Documents of organization, planning, and quality management: These are the documents of organizational order and quality management in the site, it is a document that is equivalent to the quality manual, it defines:

- The global organization in the management of the project,
- The quality policy committed by the company,
- The tasks and responsibilities of the personnel,
- The logistics dedicated to the site,
- The stopping points and critical points,
- The management of the nonconformity.

This document also contains:

- The health and safety plan: It is a document that takes as reference the ISO 9001 standard and the Moroccan standard of construction, it specifies the whole of the actions and instructions to adopt for the respect of the principles of hygiene and safety, and this by reference to the specificities of the building site.
- Quality assessment reports: These are generally monthly reports that summarize the positive and negative assessments of the
- Performance of controls to provide adequate solutions to the nonconformity detected during the control of work.

2) Procedural documents: These are the procedures for executing the work and its control, they describe the process of realization of each activity, and we find the quality of the personnel and the material necessary for the realization of the concerned activity.

3) Documents of record: These are documents that must be established and maintained to provide evidence of compliance with the requirements specified in the quality management system. These are the monitoring and control sheets that are established by the project managers and work leaders and validated by the quality managers. These sheets are the evidence of compliance or non-compliance of a given control service.

Table 1 Relationship between documentation and tasks

	Main tasks	**Documents established**
Production and internal control	- Production - Definition of the production process - Programming of the works	- Weekly work plan - Daily work plan - Follow-up sheet - Execution procedure - Technical report
Technical office	- Verification of the execution plans - Establishment of adaptation plans - Establishment of technical notes	- Adaptation Plan - Technical notes
Quality control manager	- Quality control of materials and execution methods - Verification and validation of critical points - Checking of the stop points - Declaration and follow-up of the correction of non-conformities - Validation of follow-up sheets	- Daily and weekly control plans - Procedure of control execution - Quality assessment report - Control and reception sheets - Validation sheets - Nonconformity sheets

3.4. Management of Nonconformities

A nonconformity is a situation in which a contractually specified requirement is not met. It is therefore, an event likely to impact the final quality of the work.

Any deviation from the tolerances specified in the quality assurance plan is considered an actual or potential nonconformity. There are two levels of nonconformity:

- *Level 1 nonconformity*

Nonconformity, which does not affect the final conformity of the work, which can be dealt with immediately or acknowledged by corrective measures known or proposed by the contractor on a case - by - case basis and subject to the prior agreement of the project manager.

Nonconformity calling into question the final conformity of the work, treatable in deferment by corrective measures known or proposed by the contractor on a case-by-case basis, and submitted to the prior agreement of the project manager.

3.4.1. Detection of Nonconformity

Each time a nonconformity occurs, the quality manager will open a nonconformity form. Several sources of nonconformity can exist. The most common are the following:

- When a material appears in the Material Receipt Sheet that has been rejected.

- When, in the execution control sheet, appears a batch rejected.

- When there are discrepancies between the execution method and what is indicated in the constructive procedure or in the corresponding execution criterion.

- When, in an audit report, there are substantial observations on the functioning of the quality system.

- When the project manager expresses, in writing, a nonconformity in any aspect of the construction site.

- When the result of the verification of an inspection, measurement, or test equipment, is outside of what is admissible.

When a nonconformity is detected, the person in charge of quality by batch will proceed to fill in the "Nonconformity form", which should establish:

- The person responsible for the execution.

- The specific identification of the material or documentation affected.

- The description of the nonconformity, indicating its possible causes and the effects that it could induce, indicating the source that has issued it. If the origin of the nonconformity comes from a receipt, an execution control sheet, or a receipt test, the number of the receipt or sheet will also be indicated.

- The person responsible for the control.

- The date and person responsible for opening the form.

Afterwards, the person in charge will send the above-mentioned form to the Project Manager and to the Works Supervisor so that they propose the solution or solutions to be adopted to correct the defects or imperfections found.

3.4.2. Processing and Archiving of the Nonconformity

The works manager, in consultation with the project manager and after studying the circumstances of the nonconformity, will decide and record in the "Nonconformity form":

- The solution adopted to resolve the nonconformity

- The preventive actions to avoid new nonconformities

The proposed solutions will be submitted to the quality manager for verification and then to the project manager for approval. The quality managers will verify the achievement of the adopted solution.

If the result is correct, the nonconformity will be considered corrected, and the closing date of the nonconformity will be noted.

The quality manager will classify the nonconformities

By the group and will keep a list of the nonconformity cards, in which will appear: the order number of the

Nonconformity, the description and identification of the nonconformity, and the date of opening/closing of the card.

3.4.3. Example of Non-Conformities Encountered on Site

a) Anomaly in the Concrete

In this part, we will give an example of concrete as it is the most used material in the construction process, from the beginning of the works, the company must give a formulation study of the concrete to be used during the construction site.

This study is necessary to determine the proportions of the constituents (sand, gravel, cement, water and admixture) to obtain good concrete.

The study of concrete composition consists of defining:

- The origin of the concrete constituents
- The quality of these constituents
- The dosage per m3
- The consistency and resistance of the concrete

In the case of non-respect of the construction standards, a certain nonconformity can appear during the works [4].

Table 2 Possible causes of nonconformity in concrete

Type of anomaly	Solutions to adopt
Failure of the main concrete plant	Call in the concrete plant of secure if not stop concreting
Failure of the concrete pump	A back-up pump or crane with dumping bucket will be provided
Breakdown of the mixer truck	If the breakdown is important, empty the concrete into another mixer truck while respecting the time limit fixed by the agreement, after this time the concrete must be rejected
Concrete temperature above 32°C	The mixer truck is to be rejected
Rainy weather	Provide a polyethylene sheet to protect the concrete surfaces and blow out the water at the bottom of the formwork with compressed air
Stormy weather	Stop the concreting works

Moreover, quality is achieved when the needs of the client are met by the work, which has been delivered to him.

The designer must transpose the needs, more or less defined by the client, into plans, specifications, descriptions, etc. These in turn form part of the requirements that the contractor must meet, these requirements are mentioned in the table below.

Table 3 Quality standards to be met when making concrete

Materials	Quality to control	Test	The requirements
Sand	Cleanliness	Sand equivalent	≥ 80%

Continuation of Table 3

Gravel	Fineness	Fineness module (MF)	2.2. ≤ MF ≤ 2.8
	Water content	Water content	To be taken into account when correcting water dosage
	Granularity	Particle size analysis	Curve spindle
	Cleanliness	-Surface cleanliness	P ≤ 2%
		- Plasticity index	Not measurable
	Form	Flattening coefficient	≤ 30%
	Hardness	Micro-Deval in the presence of water	≤ 3%
	Granularity	Particle size analysis	Curve spindle
	Water absorption	Measurement of the water absorption	≤ 5%
Mixing water	Chemical analysis	- Suspended solids content	≤ 2 g/l
		- Dissolved salt content	≤ 2 g/l
Cement	- The cements to be used shall meet the standards - Cements of the same specification shall come from the same factory for each complete part of the work		

3.5. Other Common Anomalies and Adapted Solutions

Table 4 Some anomalies during the execution of the excavations

Type of anomaly during the execution of the excavations	Solutions to adopt
Offset of the dimensions in plan	Carry out the earthworks from the faulty side to the bottom of the excavation
Bottom of excavations in positive sides	Manually stripping the overhanging thickness
Bottom of excavations in negative sides	Remediation with clean concrete
Presence of water in excavations	Depletion by pumping

Table 5 Some anomalies during the execution of the formwork/unformwork

Type of anomaly during the execution of formwork/unformwork	Solutions to adopt
Uncleaned casing skins	Cleaning with a wire brush
Surface to form skins not coated with release agent	Approving release agent before concreting
Failure to check stability of branches	Strengthening detected areas of weakness
Presence of water at the bottom of the formwork	Compressed air blowing
Appearance of shallow pebble nests	Levelling with mortar
Pebble nest with steel appearance	Levelling using a mortar with a product approved by the project owner

Table 6 Some anomaly during the execution of the reinforcement

Type of anomaly during the execution of reinforcement	Solutions to adopt
Supply of steel with stains such as - Oil and grease - Lumps of earth - Non-adherent rust particles	Cleaning with a cloth or wire brush
Non-solid ligatures	Reinforcing weak areas with other tight ligatures
Cutting length of a steel bar shorter than the theoretical length	Scrapping the bar

3.6. A Proposal to Anticipate Non-Conformities and Improve the Quality Process

The methods used in the process of quality management are different and they cannot be treated in the same way, they rather respond to a specific need and not to the entire process.

In this sense and after analyzing the context of the project, the needs of the company and methods proposed in the scientific and technical bibliography, we conclude that it is necessary to develop a formalized process of quality management. This process will consist in identifying, analyzing and evaluating the parameters likely to cause a nonconformity.

The main purpose of the process is to detect the probability of a nonconformity. It consists in producing a general schedule including all the operations and phases necessary before the launching of the work by specifying what should be useful for each task, and this by defining the role and responsibilities of each person and by defining the procedures facilitating the management of each phase.

The proposed tool implies an organization spread over several months, this tool couples a chronological and organizational procedure corresponding to a schedule of tasks to be accomplished and follow-up tools in the form of technical sheets to achieve a reduction in uncertainties by creating the conditions of forecasting and collaboration between the actors.

The proposed data sheets allow to keep traces during the whole execution of the project to preserve the benefits.

Tables 7 and 8 below constitute a reference of the quality scheme for each operation.

For the variables corresponding to each task, the values obtained during the constitution of the project on the durations, delays, complexity, and priority are directly transmitted in Table 8 [5].

Table 7 Characteristics of a stain and its acceptable score

The characteristics of the stain	Unit	Risk	Acceptable score
Duration	Day	Uncertainty	
Initial date	Date	Uncertainty	
Final date	Date	Uncertainty	
Previous task	-	Change in schedule	

Continuation of Table 7

Complexity	From 1 to 10	Increase or decrease in the degree of complexity	Below 6
Priority	From 1 to 10	Increase or decrease in the degree of priority	Above 6
Progress	From 1 to 10	Uncertainty	Above 90%

Table 8 Characteristics of an actor and its acceptable score

The characteristics for the actors	**Unit**	**Risk**	**Acceptable score**
Participation	From 1 to 10	Increase or decrease in participation	Above 8
Availability	From 1 to 10	Increase or decrease in availability	Above 8
Competence	From 1 to 10	Uncertainty	Above 8

Concerning the actors and resources, we calculate an arithmetic mean score per phase.

In general, several actors are involved in a phase. We had entered the phases for which the actors had "decision-maker", "controller" and "director" responsibilities.

The system calculates arithmetic averages of the scores obtained during the constitution of the project on availability, competence, and the actors participating in a phase.

Example: The score for the availability of actors for a given phase is calculated by the following formula at:

$$N_{av-act-phase} = \frac{1}{n}\sum_{i=1}^{n} N_{av-act(i)}$$

where $N_{av\text{-}act\text{-}phase}$ is the score for the availability of actors for a phase, $N_{av\text{-}act(i)}$ is the availability score for an actor (i), and n is the number of actors for the phase.

The note of the competence, participation, are calculated in the same way for a given phase.

Table 9 Characteristics of a resource and its acceptable score

The characteristics for resource	**Unit**	**Risk**	**Acceptable score**
Quantity	From 1 to 10	Uncertainty	Above 80%
Quality	From 1 to 10	Uncertainty	Above 90%
Work time	Day	Duration	Above 8
Resource utilization	Day	Uncertainty	Above 8
Security of the supplier	From 1 to 10	Uncertainty	Above 8
Acquisition time	Day	Duration	Medium and long term

Several types of resources are used in the project phase. The system calculates arithmetic averages of the scores obtained on the quantity, quality, and supplier safety of the resources used in a phase.

Example: The supplier safety score for a given phase is calculated using the following formula:

$$N_{safety-res-phase} = \frac{1}{n}\sum_{i=1}^{n} N_{safety}$$

where $N_{safety\text{-}ress\text{-}phase}$ is the safety rating of the resource provider for a phase, $N_{safety\text{-}ress(i)}$ is the supplier's safety score for resource i, and n is the number of resources for the phase.

The quantity and quality score of the resources are calculated in the same way for a given phase.

Acquisition time is qualified by the majority of responses given in the scale as "available, short term, medium term, long term" for resources that are used for the same phase.

The target values are defined by the project managers and may differ from one project to another.

Delay and increase in duration are expressed in working days. The impact of quality and safety is rated on a scale of [1 to 10]; 1 for low quality impact, 10 for high quality impact.

For each of these dimensions, the risk of a nonconformity is calculated as the product of the probability of the occurrence of the risky event and the impact i:

$R_{N.C} = P_{RE} \times I$

where:

$R_{N.C}$ is the risk of a nonconformity;

P_{RE} is the probability of the occurrence of the risky event.

The system makes a qualitative analysis of the non-conformities by the project phase. When several non-conformities of different origins, either chronological or organizational, are detected (whose impacts are already measured for this phase); the risks of delay, duration, quality, and safety in this phase are obtained by the method: the sum of risks of the same origin.

Example: the sum of the delay risks is the product of the impact with the probability of the phase:

$$R_{deadline} = \sum_{i=1}^{n} P_i \times I_d$$

The sum of time, quality, and safety risks are calculated in the same way for a given phase.

The impacts of non-conformities are assessed according to the following dimensions:

- Impact deadline $I_{deadline}$, which indicates how much of the day the delay is expected
- Impact duration $I_{duration}$, which indicates how much of the day the duration of the spot increases
- Impact quality $I_{quality}$, which indicates how much the expected quality level decreases
- Impact security $I_{security}$, which indicates how much the expected degree of security decreases

Noteworthy, the conformity is controlled when the rate of nonconformity realized for each characteristic is lower than the rate of nonconformity objective of the company, for that we call upon the capitalized knowledge of the company on processes and similar projects, which consists in estimating the non-conformities forecast from the returns of experience of the past projects.

3.7. Application of the Methodology

After analyzing the variables of the different dimensions of the project and entering the values of each parameter that can influence the progress of the project in the system, the user has a general overview of the project.

In this system, the user can visualize the whole project by phase, concerning:

- The life cycle of the project with the values time, duration, progress, quality level, safety level, complexity, priority,
- The project actors with the values of availability, competence, feedback, safety rating of the actors,
- The project resources with the values of quantity, quality, supplier's safety rating, and necessary acquisition time.

Table 10 Construction site supervision

	Project phases	**Start date**	**End date**	**Duration/day**	**Complexity**	**Priority**
The stains	Submit application	03/01/2018	09/01/2018	6	1	10
	Strategic study	09/01/2018	24/01/2018	15	3	10
	Contractualization	03/08/2018	17/11/2018	110	4	10
	Administrative procedure	17/11/2018	17/12/2018	30	4	10
	Site organization	17/12/2018	18/02/2019	61	5	10
	Realization of the building site	18/02/2019			5	10
The resources	**Project phases**	**Degree of quality**	**Degree of security**	**Quantity**	**Degree of use**	**Acquisition time**
	Submit application	100%	100%	10	10	Available
	Strategic study	90%	90%	10		Medium term
	Contractualization	100%	90%	10		Medium term
	Administrative procedure	80%	80%	9		Medium term
	Site organization	90%	80%	6		Medium term
	Realization of the building site	80%	50%	6		Short term
The actors	**Project phases**	**Participation**	**Availability**	**Competence**	**Degree of advancement**	
	Submit application	10	8	8	100%	
	Strategic study	10	8	8	100%	
	Contractualization	10	7	7	100%	
	Administrative procedure	8	7	8	90%	
	Site organization	9	6	5	90%	
	Realization of the building site	9	6	5	90%	

We enter all the information provided and the calculated data in a simulation table, which guides the user to better know the project, this process also helps make a qualitative analysis of the plan "time, duration, quality, and safety", we can easily visualize the progress of the project.

The information entered by the user and data calculated are as follows:

- The start date for the first phase and its duration,
- The final date, which is calculated from the start date and the duration,
- For the next phase, the start date corresponds to the final date of the previous phase,
- The final dates of each phase are calculated,
- The grade of quality and safety expected for each phase.

The progress is calculated by the process with the following formula:

$$Advancement\,\% = (fd-cd)/cd \times 100$$

fd - expected final date

cd - current date

Then, complexity and priority scores are given for the chronological steps on a scale of 1 to 10. The initial date, the final date, the duration, the degree of progress, and the degree of quality will allow to conduct the project simulation before and after the analysis of non-conformities, the degree of complexity will allow to identify the risks, and the degree of priority will allow to identify the priority chronological steps. The degree of priority is considered identical for all phases.

Concerning the actors of the project, the availability and competence scores are entered, on a scale of 1 to 10. The calculation rules have already been specified.

Concerning the availability, the user has considered that they are moderately available. For competence, the score is considered average.

For the resources we can make an initial analysis regarding human resources, materials, equipment, and documents, we can contact the departments responsible for resource management to obtain more information on the available resources. Then, during the project, the information can be updated in the database.

The requested information on quantity, quality, supplier, and acquisition time is entered. The phases of resource use are provided by the database. The calculation rules have already been specified.

Once the information has been entered into the system, a summary table is available, which allows the whole project to be viewed by phase.

In the system, the average scores of the variables concerning the phases, the actors, and the resources are systematically calculated by the tool from the scores entered previously and from the phases of use of the resources and phases during which the actors have missions, by applying the calculation rules already mentioned.

The summary table allows the user to have a global vision of the project and to have first opinion on the identification of nonconformities.

4. Results and Discussion

The formalized process mainly helps identify and predict nonconformities in a systemic and formalized way from the strategic analysis of the project to the downstream phase. This process has as main goal the improvement of the project quality approach, it guides the user to better know the project, to question the project, the life cycle, the actors, the resources, and other factors that can influence the project progress.

If we can identify, from the upstream phase, the risky events that may cause nonconformities during the project life cycle, we can apply action plans early enough to remedy the undesirable effects.

On the other hand, this process also helps perform a qualitative analysis on the level of “time, duration, quality, and safety”, we can visualize the progress of the project. The tool allows us to perform a simple quantitative analysis, but it also allows us to have a global vision on the impacts of time, duration, and quality for the whole project and by phase.

After the simulation, we found nonconformities in some project phase, especially in the construction site realization phase concerning the availability, the competence, the degree of use of the resources, the degree of security and the quality, and this can be due to several reasons for example a lack of competence of some actor and bad feedback with some actors (Figure 8).

In fact, this model is also a memory tool for the company and the different communities of the construction site, it provides the user with a global vision of the parameters that can cause a nonconformity, this model can be updated by the user either by changing or modifying the values, and the objective is to determine the nonconformity forecast corresponding to each characteristic of the construction, for the whole duration of the construction site.

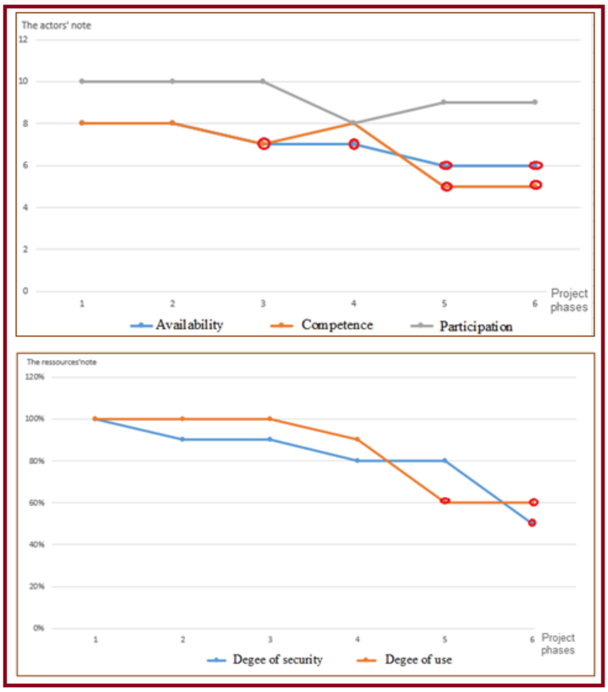

Fig. 8 Project phases with potential for nonconformity

More sophisticated quantitative analysis methods can be applied to improve this tool. The tool allows to visualize the sources of the nonconformities. This is important for project managers to apply effective action plans.

This evaluation and analysis process can therefore be repeated during each phase of the project, each time integrating information from the feedback (deleting/adding elements, updating values, etc.). In addition, it will be useful to share the feedback with others who are doing project management and risk management for similar projects [6]-[7]. One of the advantages of this project is that we had feedback from previous phases when applying our process. We could directly compare the results obtained on the identification and analysis of risks with the reality.

Our perspective is to simplify the application of the tool, to make it more efficient, to think about its interfacing with other existing tools, and to make improvements on the quantitative analysis method. We should apply the tool to several case studies, on the one hand to obtain the users' opinions, and on the other hand to obtain the feedback. Here, project managers can benefit from the feedback of similar projects and they can apply the process more easily. If used on several real projects, the quantitative analysis will become more relevant with the feedback on the impact and probability values.

5. Conclusion

For improving the quality approach of construction projects, we formalized a quality management process that combines the chronological and organizational approach. We collected feedback from case studies of real projects on actors, tasks, resources, risk events, and action plans. We have simulated the project with deadlines, durations, quality, and safety levels.

The proposed model highlights the different components of the project (actors, resources, tasks) and how each vision is focused on one of these components. Using this process, we have identified the non-conformities encountered during the project, which will allow us to adapt an action plan to remedy the nonconformity found.

Our concern has been to develop a coherent global model that formalizes these interactions, allowing non-conformities management integrated into the project management.

The perspective is to create, within the company, an internal dynamic to communicate this tool to the users, to facilitate its application and to sensitize the people within the company at the level of its application, and this by writing a set of documents intended for the actors of the project, these documents make it possible to familiarize the actors with the problematic of the risks of the project and provide them with keys of reading essential to improve their practices.

This work is not exhaustive and must be enriched by other feedback. It highlights the importance of sharing knowledge and experience in this type of project. Knowing that a project involves a large number of stakeholders and that each one has its own specific objectives, good project management and good operation management require better collaboration and communication between the stakeholders and better knowledge and information sharing.

References

[1] CHAHROUR F. *Mise en place d'un Management en Mode Projet Groupe*. 2007

[2] LEROY WARD, J. *Dictionary of Project Management Terms*, Third Edition. 2011

[3] MENG X. The effect of relationship management on project performance in construction. *International Journal of Project Management*, 2011, 30(2): 188-198.

[4] DELATTE N. *Failure Case Studies: Civil Engineering and Engineering Mechanics*. 2008

[5] LESSARD D, SAKHRANI V, & MILLER R. House of Project Complexity - Understanding Complexity in Large Infrastructure Projects. *Engineering Project Organization Journal*, 2013, 4(4): 170-192. https://doi.org/10.2139/ssrn.2259247.

[6] AULICINO P, & MORAND D. Management du risque projet: Revue de pratiques et méthodes internationales en génie civil. *Communication aux premières Journées du Pôle Ville de l'Université Paris Est Ville, Transport et Territoire*, 2010

[7] JABBOUR F. Méthodes et Procédures de gestion des risques dans les projets de Génie Civil. Master Sciences de la Terre et Environnement Ecologie. 2009.

参考文:

[1] CHAHROUR F. 以小组项目模式实施管理。2007.

[2] LEROY WARD, J. 项目管理术语词典，第三版。2011.

[3] MENG X. 关系管理对施工项目绩效的影响。国际项目管理杂志, 2011, 30(2): 188-198.

[4] DELATTE N. 失败案例研究：土木工程和工程力学。2008.

[5] LESSARD D、SAKHRANI V 和 MILLER R. 项目复杂性之家-了解大型基础设施项目的复杂性。工程项目组织。工程项目组织学报，2013, 4(4): 170-192. https://doi.org/10.2139/ssrn.2259247。

[6] AULICINO P, 和 MORAND D. 项目风险管理：土木工程国际实践和方法回顾。2010 年巴黎东城、交通与领土大学城市极点初期的交流

[7] JABBOUR F. 土木工程项目风险管理的方法和程序。地球科学与环境生态学硕士学位。2009.