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ON-SITE COMPLIANCE CONTROL PERFORMED THROUGH MOBILE TECHNOLOGY FRAMEWORK EVALUATION

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Abstract- During the execution phase of a project, the control of the conformity, performed either by the supervision or the contractor, has no evidence, reacts to facts and needs a methodical approach. The shortcomings of this control directly affect the final quality of the work, having an impact on direct and indirect costs during the construction phase. Moreover, it enables systematic errors in construction projects, makes it difficult to determine its causes and origins, thus preventing their mitigation through preventive actions. In the present work, a methodology is developed that enables the registration and management of occurrences related to compliance checking of the works, through a web application supported by mobile and cloud technology. The presented methodology focuses on an approach that includes "As-Built" documentation as a means to support the registration of information related to compliance checking, allowing a more organized management of this information. The present methodology was applied in construction works, from the perspective of the contractor and supervision, in a case study context. The conclusions of this study show that the developed methodology results in greater assertiveness for compliance checking, providing complete records with organized information and lower costs.
Keywords – On-site Compliance Checking;Mobile and cloud technology in building construction; Compliance Checking framework, SICCO.

1. INTRODUCTION

Construction is an industrial process that aims to produce a product according to the requirements specified in the design. Compliance checking is a system composed of several mechanisms that aim to validate it. This validation is done by a set of characteristics associated with the construction process itself. The validation of such characteristics is complex, as it requires human intervention in different spaces and times, requiring a high degree of coordination, registration, sharing, and analysis of the information, taking a long time to those who perform it. The effectiveness and efficiency of this validation are far from being compared with other industrial processes, and this fact is mirrored in the results of profitability, slippage, and wastage of the construction sector. Although many companies involved in the construction sector have a quality management system in place, the latter, which "obliges" them to control the compliance of the developed product, this control goes through the filling of forms and bureaucratic records, often in the cabinet or yard, without the intention of controlling, but only to comply with the ISO 9000 standards. The real control is done on site, mostly visually and randomly, with few records and organization, making it difficult to compile the information regarding the compliance of the works. The absence of records and standardization in this control turns the act of controlling extremely personal, depending on the knowledge and experience of those who perform it. This dependency, though in part inevitable, makes it more challenging to achieve the goal of industrializing construction, or at least bringing it closer to industry levels, where standards of predictability, cost control, and efficiency are substantially higher. The process of on-site compliance checking, as well as all the underlying communication, is far from efficient.

In this work, a novel framework to perform on-site control supported by mobile and cloud technology is presented and applied in four different construction projects. A comparison between the proposed framework and the current one employed by many construction companies nowadays is established and discussed based on communication efficiency throughout five compliance control procedures.

This work aims to prove that mobile and cloud technologies potential can be better explored with a proper classified information system that integrates compliance control procedures in one single place. The latest can improve wasted time by site engineers in tasks that do not aggregate value such as data compilation and storage.

2. STATE OF THE ART

2.1 On-site Compliance Control –

Quality management systems in construction are based on product certification, process regulation, final product acceptance, fundamentally during the implementation phase. This implementation phase may be carried out by external supervision or by the contractor as a means of internal control to ensure the final quality of the product to be delivered and to reduce its execution costs [1]. This concept, known as compliance control is based on ISO 9000 standards and is part of the so-called Service Engineering. The primary objective application is to ensure that the work is executed by the project and to be

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successful, effective communication among all project participants is a crucial factor. It has been proven that communication failures are an essential factor for cost overruns and over time, both at the project and implementation levels [2]. That said, on-site compliance checking should involve all the "As-Built" information related to such control to increase its effectiveness, but also to obtain better quality results from a general perspective.

2.2 As-built information and documentation–

"As-Built" information or documentation is defined by the collection of records during construction, generated during the progression of the works [3,4]. This information aggregates value in monitoring, planning, and decision making throughout the construction phase [5]. Abdel-Monem and Hegazy [2] mention that "As-Built" information records may consist of telephone calls, emails, and text messages. Li E Poon [6] consider that this information is also beneficial for site safety management. Goedert and Meadati [7] describe that information records (information requests, calendars, work orders, and drawings) are part of the "As-Built" information, which are key components for efficient management also in the maintenance phase of buildings. During the construction phase, a large number of building records are issued (e.g., calendars, construction details, cost information, daily reports, photographs, and drawings), but this information is not correctly integrated into the "As- Built "[4]. Not accurate"As-Built" information contributes to errors, omissions, as well as budgetary and temporal slippages [5]. Besides, the lack of such documentation in later stages of the project leads to delays in operations and tasks of building management [8]. Consequently, large amounts of time and money are wasted on tasks that do not aggregate value, such as searching and verifying the "As-Built" documentation during the maintenance phase [5,7]. Despite the current recognition of the importance of "As-built" documentation in compliance checking and control, most of the work focuses on its use in isolated processes in both design and construction a or maintenance phases. This work, therefore, requires a comprehensive and integrated view of compliance control procedures.

2.3 Mobile technology and Cloud Computing applied to Compliance Checking–

Several researches focus on exploiting the potential of using cloud and mobile technology for compliance control. On-site compliance reaches a new level through mobile technology since it allows real-time sharing of information, immediately accessible by any intervener in the process [9]. Cheng [10] compares the costs of implementation and use of the license "Stand-alone" with a mobile system, concluding that in addition to all the advantages of the "cloud" (sharing of real-time information, remote accessibility by any device, less use of hardware) the latest also has economic benefits for companies regarding implementation costs. Kim [11] goes further and approaches a theoretical, conceptual model for compliance control via mobile technology that consists of 3 modules: locations through cameras, task management with geographic location and reading of digital or augmented reality maps and sharing of real-time information through the synchronization of CAD Installations, but also recognizes that these 3 modules are not sufficient for all compliance control requirements.
Although, since the appearance of mobile technology, the number of works on its use at the construction field has increased exponentially, few go beyond conceptual models, they focus only on singular procedures of compliance checking and control. The present state of the art lacks a centralized and integrated system based on mobile and cloud technology that covers all the procedures of compliance control in the construction field.

2.4 Traditional framework for on-site compliance checking

Compliance checking on-site is nowadays already performed recurring to mobile devices and cloud computer technologies, however there is still much potential of these technologies to be explored. The current framework of control, referred to in this work as “traditional framework”, lacks on information classification and data integration. This problems lead to time wasting among all the compliance checking procedures, increasing the probability of misinformation and do not aggregate value for the control tasks. Moreover, data becomes difficult to gather, analyze and share. In this subsection, some compliance checking general procedures are presented. Following, an information flow of one of the procedures addressed in this research performed according to the traditional framework is presented and its drawbacks are discussed as well.
In the following table 1, five main procedures of compliance control performed on-site are presented and described by the authors. It deserves to be noted that there can be more onsite control procedures such as material reception, material approval, on-site meetings and more, but the authors considered these five as example due to their generic application in all type of projects, importance and frequency.

Table 1- Compliance Checking Procedure

Procedure	Description
Inspection Routines	Periodic inspection of specific tasks, at technological and materials level, using checklist forms.
Work orders	Formal communication that assigns a specific order to those involved in the construction process, such as operational or supervisors.
Request for information (RFI)	Formal communication related to questions and clarifications regarding the execution of the work and project.
Defect Management	Procedure for management and formal communication of product defects, which aims to register, diagnose and promote corrective actions. The process begins in the detection and ends in the resolution and subsequent analysis of the detected faults.

Daily Site report	Daily site report procedure, which aims to record all relevant occurrences in work, as well as the accounting of labor, tasks and equipment in that period.

Authors considered the information flow of the procedure “daily report” as an example to be analyzed in this work. This procedure aims to record the daily occurrences in the construction site and it is the basis for the monthly report that generally construction managers have to present to the client and stakeholders. As presented in figure 1, this procedures gathers a significant amount of information from different sources and it is performed on a daily basis, therefore the authors considered it to be a good example to explain all the information flow obstacles.

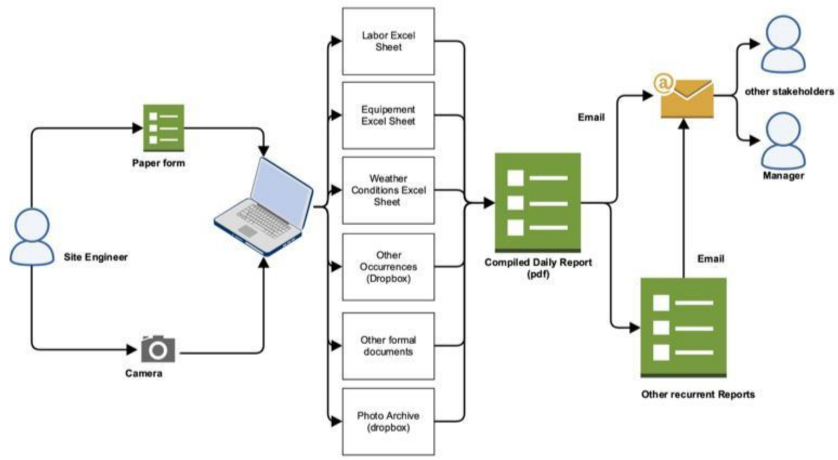

Figure 1. Information flow for the “daily report” procedure of traditional framework

As described in figure 1, site engineers collect work progress photos with their camera or mobile device and upload them into a cloud server. They also have to register the number of workers on-site divided by teams or company, usually on an excel sheet known as labor map. A similar record is made for the equipment and machinery also using an excel sheet. The weather conditions as well as other relevant occurrences on that working day are registered on another excel sheet. Any relevant communication, document or form from that day has to be uploaded to the cloud server in order to keep that record. In short, all inspections, authorizations, drawing changes or any other official communication has to be scanned and stored in the company server.

Later on, all this records have to be summarized and compiled into periodic reports, daily, monthly or in any other frequency depending on the project. Lastly, the reports are forward to the quality department, managers and project stakeholders.

All data is collected on-site through a paper form and then registered in the computer. Then, this information coming from different sources and formats is compiled manually into a pdf format report daily. Other manual compilations are required for different periodic reports, and after, these reports are send by email to the stakeholders.

Although mobile devices are used to take photos, and computer is used to upload the records into the server, this framework involves a large amount of manual information collection in different formats, that requires manual compilation and sharing. In addiction of the wasted time on this compilations, all this data is not proper classified in order to be accessible and analyzed.

In short, authors believe this framework is wasting a large amount of time and effort from site managers and at the same time is not aggregating any value to the control tasks. An integrated system that classifies and stores this information is needed and the authors believe the new proposed system in this next section 3, would bring benefits to the traditional compliance framework performed on-site.

3. PROPOSED MODEL

The present work presents a conceptual framework of an on-site compliance checking system, performed with mobile devices, covering its main procedures. The primary objective of the presented framework is to centralize and integrate all the "As-Built" communication of compliance control procedures to mitigate communication failures, which are one of the leading causes of the lack of quality. This work aims, first of all, to systematize the procedures, but also to make them faster and more transparent with the use of mobile and cloud technology.

The procedures are addressed individually from the collection of information through the respective forms, processing and storage of the data, query and transformation of this data into KPIs or fast-reading charts, as shown in figure 2:

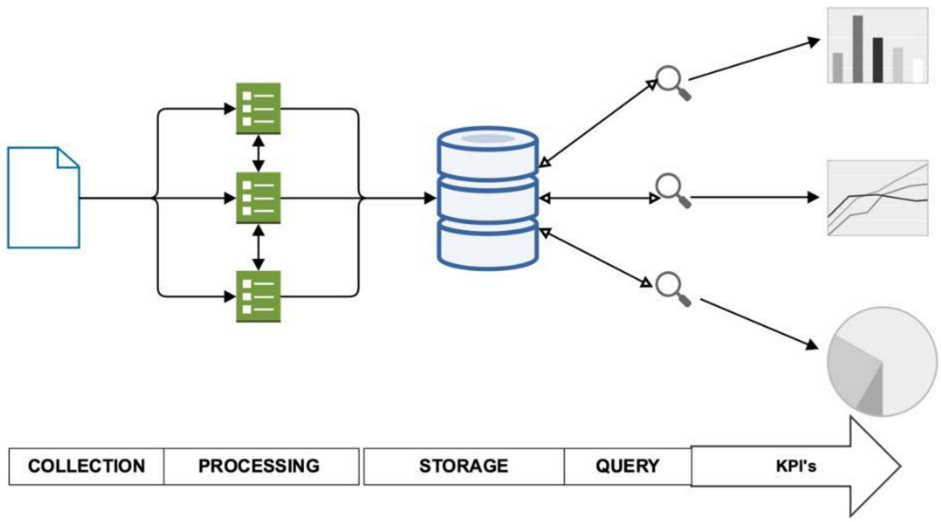

Figure 2. Information flow for the proposed framework

The data collection of each procedure is done on-site through a mobile device (smartphone or tablet) by the quality supervisor. These records are collected by on-line forms with all the requirements for the management and processing of each procedure. Then, the data is processed according to each procedure flow of action. The responsible engineers are automatically notified of the occurrences, the information is shared in real-time with the stakeholders and classified with each specific requirements (for example task, deadline, corrective measures). After processing the information, it is stored in a cloud server, accessible by the stakeholders, where it is organized to enable intuitive queries.
Proper organization and processing of the records for each procedure enables to work this data and to represent it under graphical or key performance indicators (KPI's) form.
The classification of information plays a fundamental role both on data processing for each procedure and performance indicators (KPI´s). This classification is performed on the registration forms of each procedure by the person who records and manages the procedures. Figure 2 shows an example of a registration form referring to the "Work Order" procedure, where the fields that classify the collected information can be observed:

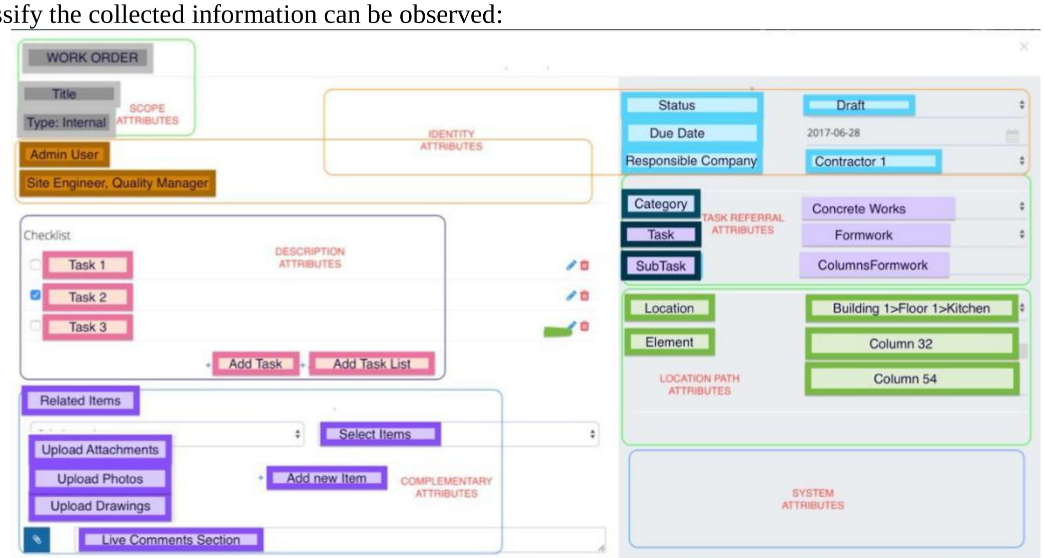

Figure 3. "Work Order" Form

As shown in figure 2, the procedure is identified by the title, the category to which it relates, as well as the task, location and construction element. It is also possible to attach drawings, photographs, and other attachments to each form, as well as live comment on them. The responsible and the deadline are also essential fields for a correct classification of the information. All these mentioned fields are present in all forms of the procedures as a way to classify the registered information, enabling a correct processing and storage and performance analysis generated by indicators and graphs. However, depending on the processing flow of each procedure, more specific fields are added to the forms automatically.

4. CASE STUDY

4.1 Research Methodology –

In order to validate this work, the presented framework was tested side by side with the traditional framework at the construction field. The traditional framework of compliance checking is performed with paper checklists by site engineers, using the traditional excel sheets. The proposed framework was performed by external supervisors. Each part was performed separately with no interference on each other so the results could be compared.

Subsequently, a qualitative analysis was carried out to compare both frameworks in terms of communication effectiveness and efficiency, as communication problems play an essential role in the effectiveness of on-site conformity control. The referred analysis was based on five criterion: data collection, data storage, information access, time spent on all process and probability of loss of information. In the next section, the selected projects are presented as well as a grading table for these criterion.

4.2 Case Study Introduction–

The validation of the proposed framework is presented under a case study format. Four different projects were selected, one where the compliance control is performed by the contractor, two by the supervision and other one by the sub-contractor.

Table 2 shows the projects where the framework was validated, as well as the type of entity performing the compliance checking.

Table 2 - Case Study Project Type

Project	Type	Supervisor Entity
I	Complex Building Rehabilitation	Supervision
II	Standard Building Rehabilitation	Contractor
III	Geotecnhical Project	Supervision
IV	Industrial Pavillion	Sub-Contractor

After the application of the proposed model, it was possible to compare it with the traditional on-site compliance checking framework. A comparative analysis was carried out based on five criteria (A-E), each graduated from 1 to 5, 1 being the most unfavorable and 5 being the most favorable. The table below shows the graduation of each criterion:

Table 3 - Grading of Case Study Evaluation criteria

Level	A-Data Colletcion	B-Data Storage	C-Information Access	D-Time spent in the process	E-Probability of loss of information.
1	More than one step to collect the data, several records in different places, impossible to perform onsite	Data Storage is performed manually, in different places and formats, highly difficult to query and access	Late access to information, performed manually, manual sharing is required	Paper work activities exceed task time itself	Very High, decentralized information, no standardize format of data
2	More than one step to collect the data, difficult to perform onsite, inputs are required	Data Storage is performed manually in more than one place , some difficult to query and access	Real time access to information ,performed manually , accessible in one device, depending on internet connection	A lot of time spent on paper work activities that do not aggregate value to the task itself	High, information partially centralized , no standardize format of data
3	More than one step to collect the data , difficult to perform onsite, inputs are required	Data Storage is performed manually in one place only , some difficult to query and access ;	Real time access to information ,performed manually , accessible in any device, depending on internet connection	Significant amount time spent on paper work activities that do not aggregate value to the task itself	Medium, information Partially centralized, Partially standardize format of data
4	Only one step to collect the data , inputs are	Data Storage is performed automatically in one	Real time access to information ,performed	Insignificant amount time spent on	Low, full standardize data format ,

	required	place only , easy to query and access ;	automatically , accessible in any device, depending on internet connection	paper work activities that do not aggregate value to the task itself	partially centralized
5	Only one step to collect the data, no required inputs	Data Storage is performed automatically in real-time in one single place , real time access to every data regardless of location or device	Real time access to information ,performed automatically , accessible in any device, regardless of internet connection	No time spent in paper work activities that do not	Very Low, full standardize data format , fully centralized

4.3 Results –

Table 4 shows the results of the comparative evaluation between both frameworks, where framework 1 is the traditional one, and framework 2 is the proposed framework:

Table 4 - Performance Evaluation Traditional Framework vs Proposed Framework

Proj.		Criterion A		Criterion B		Criterion C		Criterion D		Criterion E	
	Proc.	Framework 1	Framework 2	Framework 1	Framework 2	Framework 1	Framework 2	Framework 1	Framework 2	Framework o 1	Framework 2
I	Inspection Routines	3	4	3	4	2	4	3	4	3	5
	Defect Management	3	4	2	3	2	4	2	3	2	5
	Work orders	2	4	2	3	2	4	3	4	1	5
	RFI	3	4	2	3	3	4	2	3	2	5
	Daily Report	1	5	1	5	1	4	1	5	2	5
II	Inspection Routines	3	3	3	4	2	4	3	4	3	5
	Defect Management	2	3	2	3	3	4	2	3	2	5
	Work orders	2	4	3	4	2	4	3	4	3	5
	RFI	3	4	2	3	3	4	2	3	2	5
	Daily Report	2	5	1	5	1	4	1	5	2	5
III	Inspection Routines	3	4	3	4	2	4	3	4	3	5
	Defect Management	3	4	3	4	2	4	2	3	2	5
	Work orders	2	4	2	3	2	4	3	4	2	5
	RFI	3	4	2	3	3	4	2	3	2	5
	Daily Report	1	5	1	5	1	4	1	5	2	5
IV	Inspection Routines	3	3	3	4	2	4	3	4	3	5
	Defect Management	3	4	2	3	2	4	2	3	2	5
	Work orders	2	4	3	4	2	4	3	4	2	5
	RFI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Daily Report	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total		2,4	4	2,2	3,7	2,1	4	2,3	3,8	2,2	5

The comparative analysis presented in Table 4 shows that the proposed framework with IT support is more effective compared to the traditional framework. It should be noted that the compliance checking procedures adopted by the companies were very similar, and their assessment was very similar, although it was carried out by different actors in all cases. Also, the evaluation of each criteria is almost unanimous, and regarding criterion E, all the evaluators agreed to give maximum evaluation to the proposed framework performance, in order words, the probability of communication failure was considered very low in all cases. Concerning the traditional framework, a less favorable performance under the "Daily Work Report" procedure is highlighted., both in criterion A (information collection) and B (information processing) and C (access to information). This less favorable performance reveals an even greater need in the computerization and systematization of these procedures, but also a greater urgency to do so since this specific procedure is performed on a daily basis.

5. CONCLUSIONS

The conclusions of this research shows that the developed framework results in greater assertiveness in the compliance control procedures, providing complete records with organized information and lower costs. The present study shows that the application of the proposed framework using mobile devices makes it possible to perform a more incisive, organized and complete control at information level, in addition to reducing the time spent. The traditional framework performance has some drawbacks related to information gathering, access to information, consequently, a higher probability of communication failures. Given this, and because most of the analyzed procedures are performed on a weekly and sometimes daily basis, there is a substantial lack of effectiveness and efficiency, resulting in more time spent on tasks that do not aggregate value, but mainly in a higher probability of rework occurrence caused by communication failures. Through the presented case study, it is concluded that the proposed framework proves to be more effective in fulfilling all the analyzed criteria, compared to the traditional framework. The authors concluded with this results, that mobile and cloud technologies potential can be better explored with a proper data classification system like the one developed on the proposed framework.

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