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DEVELOPING RFID-BASED ELECTRONIC SPECIMEN AND TEST CODING SYSTEM IN CONSTRUCTION QUALITY MANAGEMENT*

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Abstract– Although the collection of a detailed, accurate and sufficient volume of information, and subsequent timely delivery are vital for effective quality control and management in construction, existing methods for material and specimen tests and laboratory activities are manually reliant on the human recourse to paper and pencil. Data collected using manual methods are time and labour-intensive. They are also error-prone due to the reluctance of workers to monitor and record the flow of large quantities of tests. This study investigates an automated approach that deals with a Radio Frequency Identification (RFID) facilitated quality management system. The proposed system focuses on the gathering, monitoring, managing, and sharing of accurate data amongst all participants (i.e. consultants, contractors and owners) and also in the material test laboratory. In this research, the need for a new coding system is highlighted in which RFID tagging has to be taken into consideration. In order to automate the task of specimen identification and quality data collection in any laboratory activity, each RFID tag is equipped with a unique Electronic Specimen and Test Code (ESTCode). An ESTCode is used as a specimen and test identity code, which forms the base of reports and contains related information for a particular specimen and test. In order to form the backbone of technology adoption in real scenarios, and to identify driving factors in this field, this paper also introduces an implementation framework for the selected technology in construction quality management.

Keywords– Automated data collection, construction projects, electronic code, quality management, RFID

1. INTRODUCTION

Construction processes demand heavy exchange of data and information amongst all the parties involved. This makes construction one of the most information-intensive industries, and requires close coordination amongst a large number of specialised but interdependent organisations and individuals, to achieve the time, cost and quality goals of construction projects. Quality inspection and management plays an essential role in managing the construction industry, where projects need to be completed within a defined budget and schedule. Laboratory work is of great importance to efficient quality management in construction phase of any project. Identification of specimens, recording and updating related information, data analysis, information transmissions; rapid and easy access to initial data and results all are significant aspects of laboratory work for testing specimens of construction projects. Laboratory activities comprise a great number of materials and specimens which have different sizes and shapes, and large amounts of data, information, and results which need appropriate methods of management for their successful organisation [1].

Existing manual recording methods for controlling and managing information in material sample and specimen tests and laboratory activities in general utilise paper-based documents [2]. In these methods,

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inputting, retrieving, analysing and disseminating the result data instantaneously requires a significant amount of time and effort [3]. Effective and immediate access to information minimises the time and labour used for retrieving information related to each part of project quality test, and reduces the occurrence of ineffective decisions made in the absence of information [4].The process of identification and capturing quantities of test data during a construction project, for the reason of quality management, needs to be improved in terms of accuracy and completeness. This leads to the elimination of unnecessary communication loops and secondary tasks caused by missing or inaccurate data. This suggests the need for a fully automatic data collection system to capture quality information at various phases, to integrate this data in a database automatically to minimise errors, and to enable real-time reporting. Radio Frequencies (RF) based information and communication technologies, such as Radio Frequency Identification (RFID) tags have matured and become commercially available to potentially support automated data collection in construction [5]. Although various studies exist for using new technologies in construction, studies focusing on detailed application of fully automatic data collection, and information management models in construction quality management and control are scarce [1]. The applications to an open environment like construction sites are still unproven.

This paper develops the RFID-facilitated automated data collection system integrated with a portal system. It focuses on the real-time collection and exchange of information of material test results and other laboratory activities amongst all participants. Transmission of data from the RFID reader to the central database will be carried out with the help of Wi-Fi within the building, and Global System for Mobile Communications (GSM) in the open environment.

2. PROBLEM STATEMENTS

Construction is both complex and highly fragmented. Currently construction quality management uses paper-based information communication, non-automatic information management activities, and traditional information communication methods. Traditionally, data collected for a large number of specimens on a daily basis, using manual methods is time consuming, labour-intensive, inaccurate, and error-prone. This produces large amounts of paperwork and leads to multiple data handling, which is difficult to search and access. Inevitably, some information becomes unavailable to project participants, in turn, negatively impacting on effective decision making. Consequently, there is a time and location gap between the test laboratory and project participants. The problems therefore, lie within the areas of both data collection and management. Construction quality management can be improved by applying automated data collection technologies to collect and exchange the quality result data amongst the participants (e.g., consultants and contractors). This enables contractors to check consultant or owner compliance when needed. Moreover, sharing certain quality data can help managers to enhance project planning and control, by tracing problems and suggestions and solving them quickly.

3. PRACTICAL ISSUES ASSOCIATED WITH THE USE OF RFID IN CONSTRUCTION

One of the current significant technologies in the world of automatic identification and data capture technologies is RFID, which has received much attention of late. RFID has been identified as one of the ten greatest contributing technologies of the 21st century, because of its potential benefits such as ready availability, ease of handling, and affordability [6]. In earlier research, Jaselskis *et al.* [7] summarised RFID technology and surveyed its potential applications in the construction industry including, concrete processing and handling, cost coding of labour and equipment, and material control. RFID has been used in some recent research to improve the process of capturing quantities of work data at construction sites, in terms of accuracy and completeness, to eliminate secondary tasks caused by missing or inaccurate data.

This minimises the time and labour used for retrieving information related to each part of construction [4, 8]. Quality management performance can be improved by applying RFID-based systems where availability of information leads to enhancing the efficiency and effectiveness of collected data acquisition [2, 9].

4. RFID TECHNOLOGY

RFID is a method of remotely storing and retrieving data by utilising radio frequency in identifying, tracking, and detecting various objects which can help improve the effectiveness and convenience of information flow in construction industry [5]. This technology consists of tags (transponder) with an antenna, a reader (transceiver) with an antenna, and a host terminal. The RFID reader acts as a transmitter/receiver and transmits an electromagnetic field that ‘‘wakes-up’’ the tag and provides the power required for the tag to operate [10]. An RFID tag is a portable memory device located on a chip that is encapsulated in a protective shell and can be attached to any object which stores dynamic information about the object. Tags consist of a small integrated circuit chip coupled with an antenna to enable them to receive and respond to radio frequency queries from a reader (Fig. 1). Tags can be categorised as read-only (RO), write once, read many (WORM), and read-write (RW) in which the volume capacity of their built-in memories varies from a few bits to thousands of bits [5]. RFID tags can be classified into active tags (battery powered) and passive tags, powered solely by the magnetic field emanated from the reader and hence have an unlimited lifetime. Reading and writing ranges are dependent on the operation frequency (low, high, ultra high, and microwave). Low frequency systems generally operate at 125─135 KHz. High frequency systems operate at 13.56 MHz, ultra high frequency (UHF) use a band anywhere from 433 MHz to 956 MHz and microwaves operate at 2.45─5.8 GHz [Ibid.]. Tags operating at ultra high frequency (UHF) typically have longer reading ranges than tags operating at other frequencies. Similarly, active tags have typically longer reading ranges than passive tags. Tags also vary by the amount of information they can hold, life expectancy, recycle ability, attachment method, usability, and cost. Active tags have an internal battery source and therefore have a shorter lifetime of approximately three to ten years [11]. The reader, combined with an external antenna, reads/writes data from/to a tag via radio frequency and transfers data to a host computer. RFID tags are more durable and suitable for a construction site environment. RFID tags are not damaged as easily and they do not require line-of sight for reading and writing. They are reusable and can also be read in direct sunlight and survive harsh conditions [12].

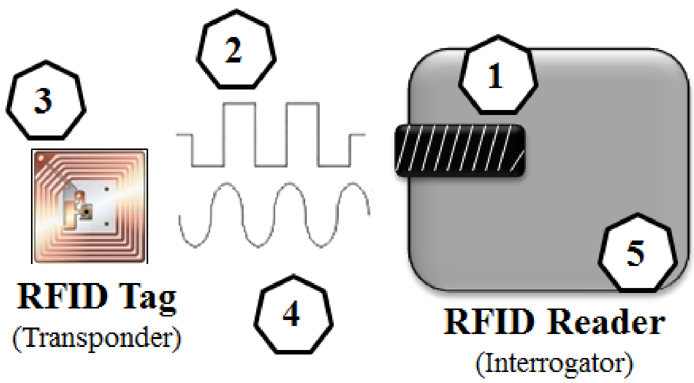

Fig. 1. RFID system

RFID technology may be solely used, but will gain value if used in combination with any data transmission technology such as General Packet Radio Systems (GPRS), and any platform for the sharing of collected data such as a portal system. A web-based portal is an ideal platform for sharing information, and leads to reduction of errors and increased efficiency of the operation processes. When a portal is used, all quality-related information that is centralised in a project database can be obtained only via a web interface. The portal provides an organisation with a single, unified database, linked across all functional systems, both within and between organisations. The portal also provides authentication and access control mechanisms to allow project participants to access information based on user privileges and activity-related units [10].

5. THE ELECTRONIC SPECIMEN AND TEST CODING SYSTEM

Embedded RFID tags in the material, specimen, and laboratory components may be used in various forms, and can carry specimen and test-related information. Another approach is to use the tags only for identification. In this instance, information is stored in database systems. One of the challenges of an effective construction quality management system is designing an effective construction quality tagging system. To cope with the degree of compatibility a global technical standard code, in the form of a new Electronic Specimen and Test Code (ESTCode) system is investigated by the author in this research. Each RFID tag is equipped with a unique ESTCode. ESTCode is the next generation of specimen identification and supports the use of RFID. ESTCode as a specimen and test identity code is used as the basis of reporting and contains related information for a particular specimen and test. This coding system is comparable with the EPC global UHF Electronic Product Code (EPC), which was developed to provide a degree of compatibility with global technical standard codes in different industries [13]. Using an ESTCode makes unique identification of all specimens and tests possible. The ESTCode system is divided into numbers which can identify the laboratory, material and test type. These numbers are used to identify unique specimens. The ESTCode number is attached to a tag, and by using RFID, ESTCode can communicate its numbers to a reader, passing them on to a computer system. Illustration of an ESTCode is shown in Fig. 2.

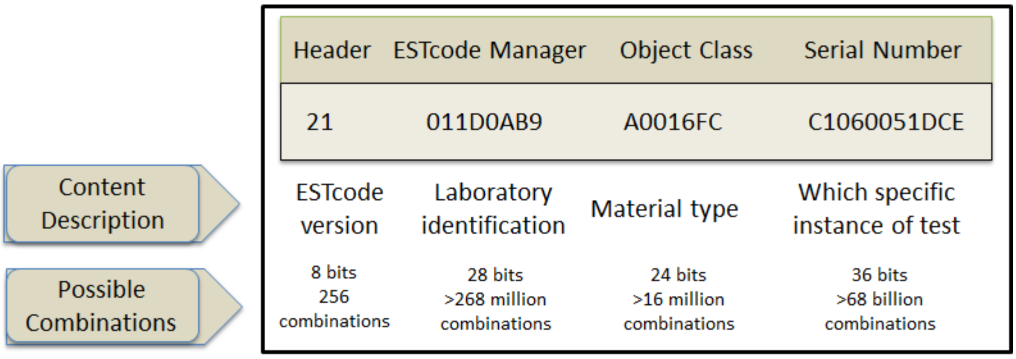

Fig. 2. Illustration of an ESTCode

6. IMPLEMENTATION PROCESS AND GUIDELINES

Initially, in order to achieve success with the RFID-based automated identification and data collection system, a management team must be created at the early phase of the project and the team made responsible for purchasing and implementing the system. The team can originate from the client side, from the main contractor, or indeed a combination of them both. Secondly, necessary training is required for laboratory workers and managers to ensure successful implementation and operation of the system. Thirdly, a pilot test should be run before the actual implementation of the system commences to identify any malfunction issue.

There is also a need for a framework, which should clarify the implementation requirements, and addresses all key issues in the selected technology field in an efficient way. This will lead to facilitate the strategic adoption and deployment of technologies in construction quality management. Available frameworks and reports from other industries and other related domains in the construction industry such as Building Information Modelling (BIM) [14, 15], virtual design and construction [16], building product models [17], and asset lifecycle information system [18] may help the industry for successful implementation of technologies in real world scenarios of construction quality management. Figure 3 shows three main parts of the possible framework which will support technology usage in Construction Quality Management (CQM).

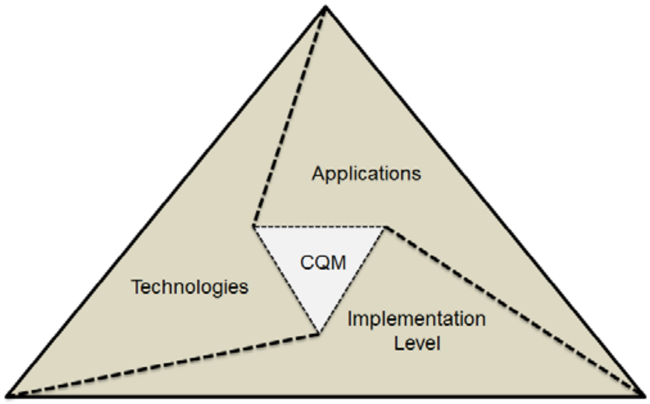

Fig. 3. Construction quality management (CQM) and technologies

Technology implementation requirements are represented in the framework which is shown in Fig. 4. The framework comprises three main parts:

- Technology implementation level
- Technology utilisation and standards
- Technology applications

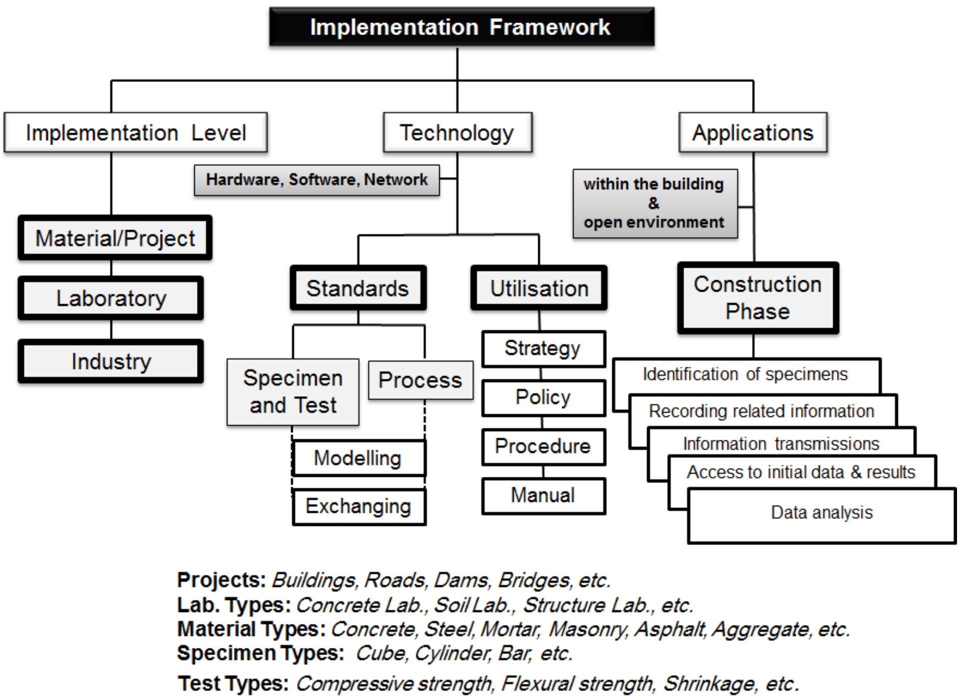

Fig. 4. Implementation framework for technology in the construction quality management

a) Technology implementation level

Three levels of implementation in this framework include the material and project level, the lab level, and the industry level. Due to the fact that different levels of implementation require different criteria for utilisation and standardisation of processes, these levels of implementation need to be considered at the same time for specific technology implementation. This not only improves inter-organisational communication and coordination, but also enhances information sharing and intra-organisational collaboration amongst the project participants. This leads to an approach with an integrated practice.

b) Technology utilisation and standards

Amongst the three main parts of the framework, 'Technology' is further divided into two important categories; standardisation, and utilisation.

Although technology standards may be available from an industry perspective, issues of the technology standards and practical details should be addressed for the three levels of implementation. These details support an approach of integrated practices amongst the involved participants of any project by the modelling and exchanging of any processes within the construction industry.

According to Jung and Joo [14] the utilisation variables consist of strategy, policy, procedures, and manuals, which are vital for successful implementation. Strategy and policy direct all activities within an organisation, and consequently characterise distinct requirements of information systems [Ibid.]. Therefore, for practical implication and successful implementation of technologies in construction quality management, implementation strategies and policies should be examined and evaluated.

Industry needs to focus on creating a learning atmosphere through education programs and training facilities, which will lead to an improvement in technology adoption at an industry level. This will increase the ICT capabilities of laboratories. In addition, at the industry level in any country, national bodies should create awareness about the technologies and their implementation processes. This will lead to an increase in the level of practical knowledge for all concerned, generating an interface between industry and academics through conferences and seminars.

Designing technology interfaces require procedures as tools for systemisation or standardisation of technology applications in construction quality management. This always leads to obtaining the same results under the same circumstances. Finally, well organised manuals can facilitate automated operations by reflecting distinct characteristics of a project or an organisation [19].

c) Technology applications

Applications of selected technologies, in construction quality management, should cover lifecycle phase of the projects during construction. This phase has its own characteristics and environment, and hence classification may differ depending on its different needs. There are important functions for these technologies in the construction phase. This framework highlights some of these management functions, including identification of specimens, recording related information, access to initial data and results and data analysis. The identified applications should support the two environments of within the building and in the open environment in any construction project.

In this approach, the proposed system could be divided into two major parts; hardware and central station. The hardware mainly consists of two types of hardware components, namely, Personal Digital Assistant (PDA) with an RFID reader, and also an integrated system using a combination of RFID, GPS, and GSM. The central station consists of two servers, the application server (portal system) and the project database server. The process flowchart of RFID-facilitated material and specimen test is shown in Fig. 5.

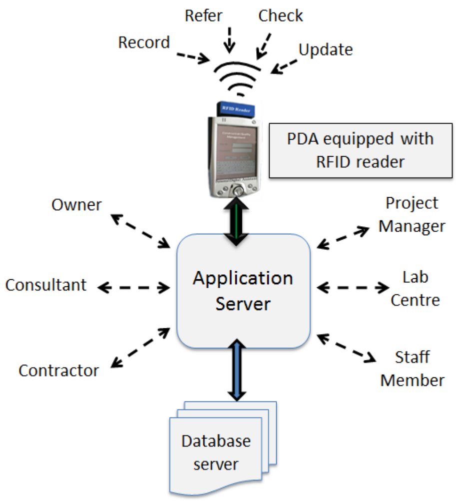

Fig. 5. Process flowchart of RFID-facilitated quality management

The collection of data begins when an order for conducting test on materials or specimens is being placed. Once the material or specimen is ready for testing, it will be attached with an RFID tag containing a unique ID and its specific information (i.e. ETSCode). Laboratory staff will attach RFID tags to all specimens and samples of materials. The information is stored directly on the tags and also in the database systems, and will be indexed with the same unique ID as the objects. In order to set up this technology-based system, two methods of implementation can be applied for internal and external use:

i. Internal type: In this configuration, a portable reader which is plugged into the PDA, or uses Wi-Fi as data transmission technology, should be carried by a key laboratory worker to identify, update, and collect tagged items (i.e. material sample or specimen) during test lifecycle. To support automatic data collection in a laboratory, a fixed RFID reader which is wired to the computer system with some stationary antennae could be attached and installed in any certain area. As data is updated on the tags and they came into reading range of readers, they will be identified automatically by the readers and their information is transferred to the computer via wire or Wi-Fi technology. This. In turn, then updates the project quality database with the test information.
ii. External type: In this configuration, a portable reader connected to the provided system (Figure 3) should be carried by a key laboratory worker. During the test process and at times of moving or picking up of any specimens or materials sample, the information on the RFID tag is captured and deciphered by the RFID reader. The ID and related information of the specimen is then sent to a database via GSM technology. In addition, GPS technology will be used for locating and positioning the specimens [20, 21]. The system antennae (i.e. GPS and GSM antennae) are required to be placed at the point able to receive and send signals.

The proposed system could be programmed to generate reports and alerts. The report of tracking information for a particular test is usually based on the material or specimen identity code (i.e. ESTCode). The subsequent reports include a list of tests to be ordered, a cumulative list of tests flow, and a list of actually finished tests. These alerts include a list of tests that should have been ordered, but were not, a list of tests that were expected but were not finished, and tests which are incompatible with the quality requirements.

d) Tagging of specimens and materials

Tags need to be attached to pre-defined locations in specimens or on the item itself, and instructions need to be passed to the workforce, and the quality control team. The tag location can be individual for each specimen. However, some common rules and best practices about the location should be agreed to guarantee the readability of tags and facilitate the later reading process. In choosing the attachment method for samples of materials, the reusability of the RFID tags should also be taken into consideration. To minimise the performance reduction of the selected technology in contact with metal and concrete, RFID tags need to be encapsulated or insulated [22]. Other important factors that should also be taken into consideration, relate to the interrogation range, the amount of data to be stored on the tag, the capability to alter the contents on the tag after it has been initially programmed, and low cost and low power consumption. For example, passive RFID is most appropriate where little or no need to change the tag contents or sensing capability or data storage is required. On the other hand, active RFID is best suited where more reading range, sensing capability, and data storage capabilities are required.

e) Information acquisition and communication

As stated previously, tags would initially have a limited memory. Therefore, the subset of information stored on the RFID tags has to be chosen carefully based on the requirements. Types of information that need to be stored on the tags or remote databases could be divided into the following groups:

- *Identification-related* information such as specimen and material ID or serial number.
- *Task-related* information such as test information and instructions details.
- *Status-related* information such as current status (e.g. finished, ongoing test) and spatial information of the object.

The proposed system is able to collect real-time quality data in an accurate and automated fashion. Collective information is sent automatically to the project database. This means that all the information is available in one place, so that all construction project participants can access data in a cost-effective way and in a timely fashion. Thus, an electronic exchange of information is created in this research, which provides real-time information and wireless communication amongst all project participants. Support can then be given to project managers whilst monitoring and controlling progress during the construction of the project. Collected data can be used through a portal system or any other application where an adequate data structure needs to be identified in order to store, share, and manage large amounts of collected data, and integrate the collected information with project management tools. Figure 6 represents the schematic process models of RFID usage in laboratorial works in the construction industry.

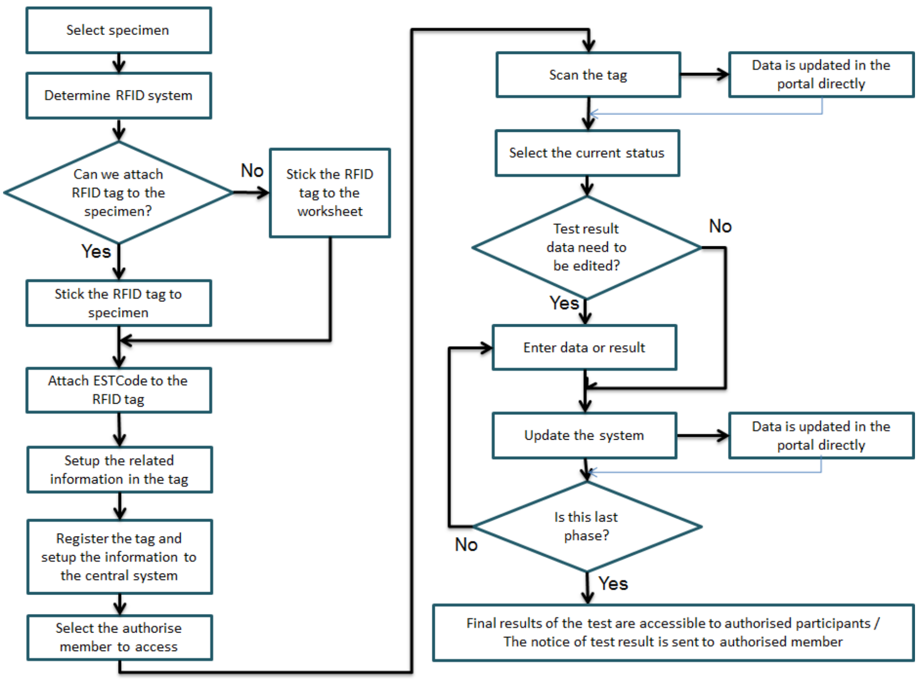

Fig. 6. Schematic process models of RFID usage in laboratorial works

7. CONCLUSION

In this research, a combination of RFID, portal, GPS, Wi-Fi, and GSM technologies are a powerful portable data collection tool enabling identifying, updating, collecting, storing, sharing, and reusing quality test data accurately, completely, and almost instantaneously. A new Electronic Specimen and Test Coding system (ESTCode) is instigated by the authors in this approach, and each RFID tag is equipped with a unique ESTCode. Most importantly, the innate benefit of using the proposed system is the efficiency of quality information acquisition and information communication. Information updates and announcements are synchronously sent via the portal, which permits real-time control enabling corrective actions to be taken. The proposed system effectively increases the accuracy and speed of data entry by providing clients, consultants, and contractors with the real-time related information of tests results. Implementing the proposed system will lead to reducing the labour costs and eliminating human error associated with data collection during construction quality inspection and management.

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