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Influence of RFID technology on automated management of construction materials and components

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Abstract Recent research has indicated that even though construction materials and components may constitute more than fifty percent of total project costs, existing methods for managing them still depend on human skills. This traditional data collection is time and labour-intensive, error-prone, and unreliable, due to the reluctance of workforces to monitor and record the presence of large numbers of material. Automating the task of identifying and tracking construction materials can provide timely and accurate information on materials available to the manager. This paper investigates a new approach for integrating the latest innovations in ADC technologies for real-time data collection in construction. In this approach, the combination of Radio Frequency Identification (RFID), Global Positioning System (GPS), and General Packet Radio System (GPRS) technologies can facilitate extremely low-cost, infrastructure-free, and easy-to-implement solutions to uniquely identify materials, components, and equipment. The presented system is fully automatic and will lead to their location and tracking in three phases, namely, production sites (off-site), en-route (shipping), and construction job sites (on-site), almost instantaneously.

1. Introduction

Construction projects are extremely complex and often take place in an uncontrolled, unprepared, and dynamic environment where each project goes through several phases leading to completion. Because of this, modern construction management requires real-time and accurate information for sharing among all parties involved to undertake efficient and effective planning, as well as execution, of the projects.

Material is a critical element in civil engineering construction projects and can make significant contributions to the cost effectiveness of projects. This is because the amount spent on materials is higher than other inputs, and may account for 50%–60% of the total cost of a typical project [1]. Thus, planning and managing the logistics of materials is crucial, as they directly affect the construction schedule and the cost. For example, if a problem occurs, it would then trigger cascading problems in other parts of the project, which would result in production delays and cost overruns, as discussed by Cho et al. [2]. Lack of materials when needed, inadequate identification of materials, re-handling and inadequate storage are causes of delay or unnecessary work. Potentially, this could lead to a loss in workforce productivity and an increase in overall project costs.

Construction is identified internationally as a labour and information-intensive industry. This heavy exchange of data and information between project participants on a daily basis is a facet of major construction processes [3,4]. Thus, during the last two decades, real-time information systems have become an important tool in the management of construction projects. As far as the availability of technologies is concerned, a number of advanced technologies that are appropriate for construction are becoming more effectual. Their accuracy, reliability, and integrity are improving, while their costs continue to decline [5].

As previously stated, studies have proved that materials management plays an essential role in successful completion of any project in construction where the most important part of an effective materials management system is their identification and tracking along the construction. Automating the task of identifying and tracking the construction materials can provide timely and accurate information on materials availability for the

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manager. This could lead to a decrease in the standby time for unused materials and, also, to reduce the occurrence of ineffective decisions that are made in the absence of information [6]. Such technology-based management tools could link independent islands of communication in the construction phase, required for efficient identification, locating and tracking of materials throughout construction including off-site, en-route, and on-site, as discussed by Majrouhi Sardroud and Limbachiya [7]. Furthermore, this reliable automated management system increases productivity and cost efficiency in addition to improving scheduling, number of lost items, and site optimisation.

One recent advancement in these technologies is Radio Frequency Identification (RFID). This has been identified as one of the ten greatest contributing technologies of the 21st century [8] because of its potential benefits, such as ready availability, ease of handling, and affordability. RFID is a wireless sensor technology, based on the detection of electromagnetic signals and radio frequencies, which are used to capture and transmit data from or to a tag [9].

This paper investigates an RFID-based ubiquitous system, which involves the use of RFID, GPS, and GPRS technologies to obtain real-time information and the sharing of information amongst the involved participants of the construction project, such as materials manufacturers, suppliers, contractors, and construction site offices. This paper first reviews prior research and work that has been done by others, followed by the research methodology. An overview of construction materials management and general requirements of the proposed system are given in Sections 4 and 5. Section 6 deals with technology review and selection. Then, it reveals the architecture of the integrated system, followed by its implementation processes, limitations, and cost-benefit analysis methodology. Conclusions are drawn at the end of the paper.

2. Practical issues associated with the use of RFID in construction

Materials management is a distinct management system, which can make significant contributions to the cost effectiveness of construction projects. Materials play an essential role in construction to complete projects within project deadlines and budgets. Some authors have developed RFID based methods to automate the task of construction materials management [10–14]. RFID has been used in some efforts to improve tracking, delivery, and receipt and location of materials and components, such as fabricated pipes [15], structural steel members [16], engineered-to-order components [6], and interior decorating materials [17] in lay down yards and under shipping in construction. In addition, RFID has been used in some research to improve quality management performance [18].

Furthermore, RFID has been used in some research efforts to improve the process of capturing the quantity of work data at a construction site, in terms of accuracy and completeness, to eliminate secondary tasks due to missing or inaccurate data, such as a simulation-based framework for modelling information flow processes in highway projects [19], an ubiquitous system for context-specific information delivery [4], mobilised information frames in production management systems [20], lifecycle management of facilities and building components [8], and indoor localisation [21].

Locating tagged items effectively in construction supply chains and logistics can potentially facilitate great increases in productivity, where each project goes through several phases leading to completion [22]. In order to obtain real-time information and information sharing among the involved participants of the construction supply chain, some research efforts have been made to develop a system using RFID technology [23]. The findings from some research demonstrated that locating buried assets by applying RFID technology has a great potential for facilitating the accurate 3D data of underground infrastructures [24]. This could lead to a decrease in the risk during excavation of construction and renovation equipment.

3. Research methodology

To establish the background to the objective of this research, it was necessary to identify the existing needs and problems, and to define the corresponding objectives and scope. This necessitated a comprehensive literature review including studies related to RFID applications in construction, automated material management systems and technologies. The subsequent definition of the processes and functions for materials tracking, such as shipping, receiving, locating, issuing and organising space, are also needed. Supported by the literature review, general requirements and a technology selection criterion are developed. These requirements and technologies are discussed in Sections 5 and 6. Based on this criterion, the different available automated data collection technologies are analysed in terms of their suitability for materials' identification and tracking. Appropriate technologies for automating the identification and tracking of construction materials and components are then selected.

4. Construction material management

A report published by the Business Roundtable. [25] claimed materials management as a management system for planning and controlling all necessary efforts, to make certain that the right quality and quantity of materials and equipment are appropriately controlled in a timely manner with reasonable cost, and are available when needed. According to Stukhart [26], three broad categories of materials in a construction project are: bulk materials, engineered materials, and fabricated materials, which require different approaches during the planning and construction phases. These are explained below:

- *Bulk materials;* these materials are manufactured to industry codes and standards, and are purchased in quantity (e.g. pipes).
- *Engineered materials;* these materials, with a unique identification number, can be uniquely identified during the project life cycle and are specifically fabricated for a particular project.
- *Prefabricated materials;* these materials are typically fabricated in compliance with engineering specifications at a fabrication shop or site that is separated from the construction site, and are assembled together to form a finished part or a more complicated part (e.g. steel beams).

The first category requires relatively short times for delivery after an order is placed, while the second and third categories require increasingly complex submittals, usually including detailed drawings and samples; the time from the placement of the order to delivery on site includes manufacturing, as well as submittals and approvals, and can take several months [27]. Some major problems concerning construction material management are explained below:

- Materials required but not purchased ;
- Materials purchased but not received;
- Materials arriving at the site at the wrong time;
- Materials arriving at the site in the wrong quantity;
- Materials whose specifications do not match those in the purchase order;
- Unavailability of information regarding the status of orders;
- Lack of complete and up-to-date information regarding arrival of materials on the site;
- Lack of up-to-date information regarding site stocks;
- Extensive multiple-handling of improperly sorted materials in search of required pieces;
- Missing or surplus materials;
- Lack of storage space for materials on site;
- Waste of man hours searching for materials and tracking them;
- Materials that are issued to crafts and are then not used or installed.

There are three phases within the scope of the materials tracking process [22]. Figure 1 is developed to describe, in more detail, the materials tracking processes for the construction projects. Construction materials tracking processes can be divided into three main phases including: off-site (production) status, delivery (shipping) status, and on-site (job-site) status. For bulk materials, there are two phases, starting from the shipping phase. The materials logistics and supply chain process starts at the very first phase from fabrication of pre-fabricated or engineered materials at the supplier plant. Further steps in the off-site process include quality control, handling and storage, and picking up and loading. This is followed by shipping or transportation of materials to the desired location (job-site). The final phase of the material logistics is the on-site status of materials, which starts by receiving the materials on the construction job site. For most construction projects, these processes are typical; however, there are variations for projects, depending on specific circumstances.

Figure 1: Materials tracking processes for the construction projects.

5. General requirements of a material tracking system

Evaluating the design option for any automated materials management system requires sufficient information about the project characteristics, such as: mode of transport, storage, and disposal of materials, site access planning, extent of preassembly and modularisation, local environment and climate conditions. This system should also have additional characteristics of improved asset visibility and reduction in lost items, shrinkage, and wastage.

Several factors have to be dealt with when planning and designing automated materials management systems. Initially, they should have the ability to automatically identify and track materials with no, or minimum, human input, and to make this information readily and easily available. Besides being affordable and small, there are some general requirements that any automated materials management system must fulfil. For the purpose of this research, these requirements are classified as follows:

- *Safety:* Technology must work at any location and time and may not harm people.
- *Cost:* It must have reasonable set-up cost. For instance, GPS can provide positional accuracy, but tagging hundreds of items with simple but expensive GPS receivers would not be reasonably practical. Running cost should be minimal, and, in this manner, reusing tags will help the system to keep minimum variable inventory. The system needs to be capable of producing more work with fewer workers.
- *Accuracy:* Technology-aided tracking and locating processes should result in more accurate locations than those from manual localisation practices. For example, RFID technology is suitable for identification purposes in tracking individual items, but its current applications do not provide sufficient location accuracy without relying on a fixed communications network.
- *Network:* Network coverage should be the most suitable for small device communication, capable of scaling to meet the eventual needs of an application. The selection criteria are a mix of the following: Coverage, Wireless link distance and Data bandwidth.
- *Flexibility and scalability:* In order to successfully integrate with other project management systems, this system must be flexible in terms of its implementation, and have minimum infrastructure requirements for setting up the system. The system must be portable, so that the functionality can be transferred to new projects.
- *Ease of use:* It should be easy to mobilise, be simple and user friendly in its operations and, at the same time, reduce errors associated with human roles.
- *Ambient environment:* Technology must work well when natural illumination is low, obstructions are present, and the likelihood of signal multipath is high.
- *Ruggedness:* Such a system must be rugged enough to withstand harsh construction environments, which are inherently exposed to adverse conditions, such as: dust, rain, mud and snow.
- *Time:* It should take minimal time for initial set up. The effortless data collection processes must require less time for identifying and locating materials and equipment than manual searching.

These technology requirements set the basis for selecting an adequate group of technologies for the purpose of this research. As no commercially available technologies are able to accomplish all previous requirements, the author opted for an integrative approach of several existing technologies. These technologies and their integration approach are described below.

6. Technology review and selection

ADC technologies have matured technically and have become economically feasible and viable in recent years. The main categories of technologies that can contribute to real-time monitoring and control are identification technologies, positioning technologies, and wireless data transmission technologies.

6.1. Identification technologies

Identification is a powerful capability which is useful in classifying, counting and organising objects that are vital to many aspects of modern management. Automatic Identification (Auto-ID) technologies, also referred to as automatic data capture technologies, are used to gather data on objects or users, such as items, animals or humans, and identify them using minimal or no worker input. There are five major forms of Auto-ID technologies. These technology elements are: Barcode systems, RFID systems, Smartcards, Biometric systems, and Optical Character Recognition (OCR). It is important to consider the appropriate forms of Auto-ID to be used for any identification application. Variables should be taken into account, such as affordability, ease of use, data storage capacity, read range, life expectancy, multi label reading (rather than one at a time), fast read rates, resilience to ambient noise and interference, readability, reliability, and maintenance cost.

The mechanical contact used in the smart card is often impractical, and a contactless transfer of data between the data-carrying label and its reader is needed for this industry. Also, the weakness of the contacts to wear, corrosion and dirt is one disadvantage of the contact-based smart cards. Biometry is the general term for all measures that identify people by comparing unmistakable and individual physical characteristics. Although special fonts were developed for OCR systems which stylised characters so that they could be read both by people and machines, they have failed to become universally applicable. This is because of their very expensive and complicated readers in comparison with other Auto-ID technologies. Thus, two possible forms of auto-ID systems are Barcode and RFID.

Without a doubt, conceptually, RFID and barcodes systems are relatively similar, where both are proposed to present the capability of quick and reliable technologies in item identification and tracking. However, the two technologies have different methods for reading and writing data. With RFID systems, the reader interrogates or scans the tag using Radio Frequency (RF) signals, and does not need a direct line of sight between the reader and the tag. On the other hand, in the Barcode technology, a laser beam is used by the reader to scan a printed label and requires a direct line of sight between the optical scanner and the barcode labels. Barcodes use Universal Product Codes (UPC), whereas RFID uses Electronic Product Codes (EPC). In summary, there are some principal advantages that RFID has over barcodes. These are:

- Having a unique code, RFID tags are able to identify every item individually.
- RFID systems are capable of reading multiple tags simultaneously and instantaneously, and can cope with harsh and dirty environments. Theoretically, this allows a pallet of mixed products, containing individual RFID tags and equipped with an RFID reader, to read all tags within the palletised load, without having to physically move any of the materials or open any cases.

Figure 2: RFID system components.

- RFID tags can hold greater amounts of data, and data on tags can be read or updated without line of sight. In interactive applications, such as work-in-process or maintenance tracking, the read and write capability of an active RFID system is also a significant advantage.
- Tagged items can be automatically tracked without worker input, eliminating human error.
- RFID tags are reusable, more durable and suitable for a construction site environment, and they are not damaged as easily as barcodes.

6.1.1. RFID technology overview

An early, if not the first, work of exploring RFID is the landmark paper by Harry Stockman, "*Communication by Means of Reflected Power*" cited in [28]. A RIFD system consists of tags (transponder) with an antenna, a reader (transceiver) with an antenna, and a host terminal. Figure 2 shows these components. The RFID reader acts as a transmitter and receiver and transmits an electromagnetic field that "wakes-up" the tag and provides the power required for the tag to operate [23].

An RFID tag is a portable memory device located on a chip that is encapsulated in a protective shell and can be embedded in 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. 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. RFID tags can be classified into active tags (battery powered) and passive tags, which are powered solely by the magnetic field emanated from the reader, and, hence, have an unlimited lifetime. Other types of tag are ultra-low-cost tags, known as chip-less tags, which have a short read range.

Reading and writing ranges depend on operation frequency (low, high, ultra high, and microwave). Low frequency systems generally operate at 124 kHz, 125 kHz or 135 kHz. High frequency systems operate at 13.56 MHz and ultra high frequency (UHF), and use a band anywhere from 400 MHz to 960 MHz [29]. 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. Communication distance between RFID tags and readers may decrease significantly due to interferences by steel objects and moisture in the vicinity, which is commonplace at a construction site. Active tags have internal battery sources, and, therefore, have a shorter lifetime of approximately three to ten years [30].

The reader, combined with an external antenna, reads and writes data from, or to, a tag, via radio frequency, and transfers data to a host computer. According to Lahiri [31]

Table 1: Advantages and disadvantages of barcode technology and RFID system.

	Advantages	Disadvantages
Barcode	Affordable	Optical line-of-sight scanning
	Easy to use	Limited visibility
	Mature and proven technology	Restricted traceability
	Established quality standards	Incapable of item level tracking
	Reliable and accurate	Labour intensive
		Susceptible to environmental damage
		Prone to human error
		Limited memory
RFID	Non-line-of-sight scanning	Cost of tags and new infrastructure
	Simultaneous automatic reading	
	Labour reduction	Lack of training and limited knowledge
	Enhanced visibility and forecasting	Immature technology
	Item level tracking	Concern of return on investment
	Traceable warrantees	Lack of ratified standards
	Reliable and accurate	
	Information rich	
	Enhance security	
	Robust and durable	

and Finkenzeller [32], the reader can be configured either as a handheld or a fixed mount device. The host and software system is an all-encompassing term for the hardware and software component that is separate from the RFID hardware (i.e., reader and tag); the system is composed of the following four main components: Edge interface or system, Middleware, Enterprise back-end interface, and Enterprise back end [33]. Developments in RFID technology continue to yield larger memory capacities, wider reading ranges, and faster processing.

Table 1 represents the advantages and disadvantages of barcode and RFID systems. Although an established and affordable technology, barcodes used in construction suffer from the problem of having a short read range and durability: barcodes require a line of sight and become unreadable if they are scratched or dirty [34]. Barcodes may be very cheap, but their stumbling block is their low storage capacity and the fact that they cannot be reprogrammed. They require a clear line of sight between the reader and tag, can be obscured by grease and nearby objects, and are hard to read in sunlight. Unlike a barcode, with RFID, it is possible to read a large number of RFID tags through the packaging or the product itself, almost instantaneously. Theoretically, this means that you could take a pallet of mixed products, all of which contain individual RFID tags, and have an RFID reader read all the tags within the palletised load, without having to physically move any of the materials or open any cases [35]. The data capacity of the RFID tags enables it to carry more information than the barcode. RFID tags are reusable, less susceptible to damage and can be read through a variety of substances, such as ice, snow, paint, fog, crusted grime and other visually and environmentally challenging conditions, where barcodes would be useless. Furthermore, a significant difference is the amount of labour required. With barcodes, a person is required to scan each barcode manually, but with RFID, scanning is done by readers and does not require labour. The combination of all the above mentioned advantages will provide quick access to a wealth of information, eliminate human error, and reduce labour, which lead to reduced project activity time and a saving in project costs. Developments in RFID technology continue to yield larger memory capacities, wider reading ranges, and faster processing. Smarter, smaller, cheaper, and faster are the recurring trends in computer-related technology. Thus, it does not take much intelligence to predict the same for RFID [Ibid].

6.1.2. RFID applications in different industries

There are various applications of RFID technology in different industries; manufacturing, food, defence, pharmaceutical, transport, retail and healthcare are just some of the sectors where RFID has already been extensively applied [36]. Hospitals are tracking high-value assets including gurneys, wheelchairs, oxygen pumps and defibrillators. These systems reduce the time employees spend looking for assets, improve asset utilisation and enhance the hospitals' ability to performed scheduled maintenance. Paramount Farms, one of the world's largest suppliers of pistachios, uses RFID to manage its harvest more efficiently. NYK Logistics uses RFID to improve the throughput of containers at its busy Long Beach, Calif., distribution centre. Honda-UK Manufacturing Ltd (HUM), for instance, has initiated what could be one of the largest Ultra-High-Frequency (UHF) RFID installations in the automotive industry [37]. The company used the technology to track components as they traverse HUM's supply chain, moving from suppliers throughout Europe to HUM's manufacturing plant in England.

6.2. Localisation systems

Localisation systems fall into two main categories including Radio-Frequency (RF) based systems and non RF-based systems [38]. All these technologies have been developed for use in indoor or outdoor object positioning and locating.

6.2.1. Non RF-based localisation

Infrared, audio, ultrasound, vision, and Laser Detection and Ranging (LADAR) techniques can be recognised, non RF-based, object localisation systems. The best example is the bat location system, where a pulse of ultrasound is emitted from a transmitter attached to the target object, and the signal is received by receivers. The distance from the transmitter to each receiver can be calculated, based on the Time-Of-Flight (TOF) and the speed of sound in air. Generally, non RF-based localisation systems are relatively mature, but they are at risk from environmental conditions. For example, audio systems are sensitive to noise, and obstacles can easily block laser systems in their application space.

6.2.2. RF-based localisation systems

RF-based localisation systems include the Wireless Local Area Network (WLAN), RFID, and Global Navigation Satellite

System (GNSS) localisation. This technique uses WLAN devices as localisation sensors and beacons, and localises the object according to the signal strength information between the object and the beacons. Although WLAN systems have several advantages in comparison with non RF-based systems, due to their low price and low power consumption, WLAN devices are usually required to be wired to a computer or a controller. This does not make WLAN localisation systems very portable, and only good for indoor environments [38].

RFID localisation is comparable with WLAN localisation in theory, and, due to the nature of RF signals, developed algorithms for WLAN systems are also appropriate for RFID localisation. It naturally employs the RF signal strength, instead of the TOF of the signal, to measure the distance. The most important advantage of RFID systems over WLAN systems is the wireless nature of RFID technology. RFID tags are portable and do not require cables for communication, nevertheless, the RFID system is also an indoor localisation system.

GNSS is an outdoor satellite-based, worldwide, radio-navigation system, which is most widely used for localisation applications. It is a network of satellites that transmit HF radio signals, which provide reliable location and time information to identify geographic locations (longitude, Latitude, and Altitude) of any user, at any time, anywhere around the world and under any weather conditions. According to Caldas et al. [39], GNSS employs the TOF of RF signals to calculate the distance to each satellite by measuring the time delay between the transmission and reception of each GNSS radio signal, and applies the principle of triangulation in order to find a three dimensional position. In other word, GPS uses a lateration technique to compute its own position by measuring its distance from multiple reference points with known locations. There are two GNSS currently in operation, the US GPS and the Russian GLONASS [40]. In some countries, the GPS is not as developed as it is in America and European countries. In this case, similar satellite navigation systems can be used, which are being developed by other countries including: Galileo, a global system being developed by the European Union, which is planned to reach full operational capacity in 2014, Beidou, IRNSS and QZSS, which are the People's Republic of China, Indian, and Japanese navigation systems, respectively [35]. GPS is the best known and currently fully operational GNSS. Extremely heavy foliage or underground places like tunnels would cause the signal to fade to an extent where it can no longer be heard by the GPS, and the receiver no longer knows its location. In this case, to compute the receiver position inside GPS blind areas, the proposed system will use the RFID reader to save tag-IDs on the way through a tunnel or inside GPS blind areas. Each tag-ID shows a unique location [Ibid]. Another solution is to use a combined global navigation satellite system, which uses the GPS, GLONASS and Galileo systems together (a constellation of about 75 satellites of the three systems). This greatly increases the visibility of the satellites, especially in urban areas. Even though the time and coordinate systems used in those systems are different, the three time systems are all based on Coordinates Universal Time (UTC), and the three coordinate systems are all Cartesian. Consequently, their relationships can be determined, and any system can be transformed from one to another.

6.3. Wireless data transmission technologies

Recently, a broad range of wireless technologies and their devices have emerged and been developed based on Wireless Personal Area Networking-WPAN (e.g. Bluetooth), Wireless Local Area Networking-WLAN (e.g. Wi-Fi) and Wireless Wide Area Networking-WWAN (e.g. GSM). Bluetooth is a technology specification for low cost, short range wireless links between portable handheld devices, mobile phones and PCs, which acts through 2.4 GHz and covers a range of up to 10 m.

WLAN featuring Wi-Fi (It stands for "Wireless Fidelity"), and ZigBee, technically known as 802.11b and 802.15.4, can act through a 2.4 GHz radio-band [41]. Their networks consist of coordinators, routers and end-devices with excellent communication ranges of approximately 50 m and 1000 m, respectively. Wireless Wide Area Networking (WWAN) has the ability to cover a widespread area. Satellite-based and ground-based mobile phones are probably the most widely adopted WWAN. The idea of cell-based mobile radio systems appeared at Bell Laboratories in the early 1970s. In 1982, the Conference of European Posts and Telecommunications formed the Groupe Spécial Mobile (GSM) to develop a pan-European mobile cellular radio system (the acronym later became a Global System for Mobile communications).

General Packet Radio Systems (GPRS) is a non-voice value added service that allows data to be sent and received across a mobile telephone network, and designed to run on GSM, a worldwide standard for cellular communications. GPRS is a packet switched "always on" technology, related to MMS (Multimedia Messaging Service) and ICS (Internet Communications Service). In other words, GPRS can send any sort of message that includes text, pictures and sound, and there is no limit to the amount of data that can be sent. In GPRS, when information is sent from one, it travels directly to the other almost immediately. Because GPRS uses the same protocols as the Internet, the networks can be seen as subsets of the Internet, with the GPRS devices as hosts, potentially with their own IP addresses [42].

7. Architecture of the proposed integrated RFID–GPS based system

Although automating site tracking processes could eventually be achieved with other technologies, this research introduces the pioneering combination of GPS, RFID, and GSM technologies for this purpose. Even though each of them can be used as a stand-alone system in construction, their combination will significantly raise the consistency and reliability of the system as a whole, thus, greatly assisting the data collection process. When configured together, GPS and RFID receivers can establish their own coordinates and quickly identify the presence of several tagged items.

In this research, the RFID–GPS based mobile, a pervasive and ubiquitous system, was developed. This system was divided into two main parts, namely, hardware and a server. Figure 3 is a schematic representation of RFID–GPS based management tool architecture. The hardware of the system mainly consists of three types of hardware component, namely:

- RFID technology (RFID readers, antenna): RFID was selected as the technology in the Identification segment, and RFID tags were used for identifying and monitoring objects by using the RFID reader, which is connected to the system.
- GPS technology (GPS receiver): GPS was selected as the technology in system positioning and the material location tracking segment. In order to track the location of materials, GPS was used for positioning equipment that transports materials, or positioning the location of the system.

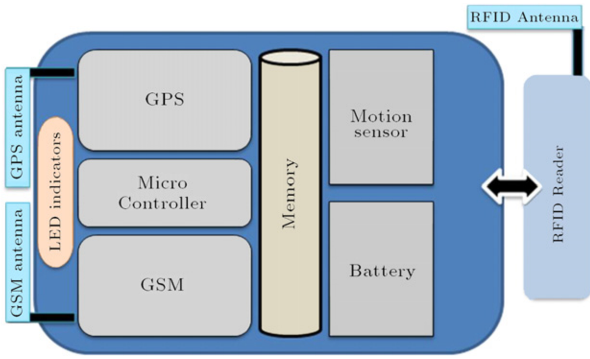

Figure 3: A schematic representation of the RFID–GPS based tracking architecture.

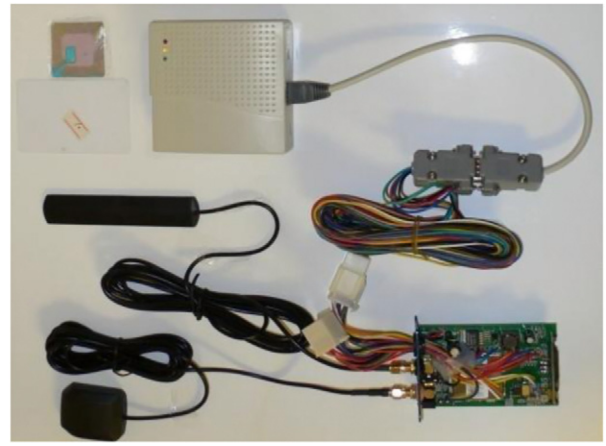

Figure 4: A sample RFID–GPS based integrated system.

- GSM technology: the system is then synchronised over the GSM network via SIM cards, and the information (ID, date, and location) retrieved from RFID readers and the GPS is transferred to the server in the form of GPRS. Therefore, data collection and transmission are done continuously and autonomously.

The server can consist of two parts: application server and database server (supplier database and project database). The application server could use different software for collecting, storing, updating, modifying, filtering, and sharing this data to act as a supply chain management, inventory control, materials location information, materials status, and other applications.

In this system, RFID tags are attached to any objects, such as materials, components, tools, equipment, and even labours. The system can be mounted on gates, internal and external transport vehicles, materials handling equipment, and people. RFID tags are scanned when they come into each reader's reading range, and information gathered from a RFID–GPS based system is then transmitted to the server. If the object is shifted or moved to a new location, this system can effectively track its location and movement. These advantages are due to the flexibility of the proposed integrated RFID–GPS based system. Figure 4 shows a sample of the proposed integrated system, which is capable of working just with the HF RFID reader.

7.1. Implementation process and guidelines

In order to achieve success with the RFID–GPS based automated data collection system: first, a management team must be created at an early phase of the project, which is responsible for purchasing and implementing the system. The team may be from the owner side, from the main contractor, or from both. Second, necessary training is required for construction workers and managers to ensure successful implementation and running of the system. Third, a pilot test should be run before the actual implementation of the system to identify any malfunction issues. Three phases have been considered for the automated supply chain and logistics of the construction, namely, (a) Production phase, (b) Delivery phase, and (c) On-site phase.

A schematic model of data collection during production, shipping, and on-site activities is shown in Figure 5. In this approach, collecting data begins when an order for the supply of materials or equipment is being placed. Once a component is manufactured, or the material is ready for delivery, it will be attached with an RFID tag containing a unique ID and its specific information. Another scenario for tagging materials and components could be conducted at the construction job site. Whereby, upon the arrival of materials, the RFID tag will be manually attached to materials and components.

In order to set up this technology-based data collection system, three methods of implementation can be applied:

(1) Portal type: In this configuration, a system outfitted with an RFID reader, with some stationary antennas, should be attached and installed in certain areas, such as the in-and out-gates of the production facility, construction site, warehouse, and lay down yard. As tags come into the reading range of readers or when tagged materials pass through the gate, they will be identified automatically by the readers and their information, including the corresponding reader location derived from the GPS, is transferred to the server via GSM technology, which then updates the project database with materials information including their locations.

(2) Equipment type: Almost every material and component used in construction is transported by internal and external construction vehicles, and lifting and hauling equipment. Monitoring equipment is not only necessary to ensure that materials will be transported to the right place at the right time, but will also update the related information of any piece of material. Each vehicle or piece of equipment (e.g. forklift) should be equipped with a system. The system antennas (e.g. GPS and GSM) require to be placed at the highest point of the equipment.

(3) Mobile type: A portable reader connected to the system should be carried by a key worker to collect and identify tagged items, by walking around or running any equipment.

The schematic representation of a typical RFID–GPS facilitated materials management activity timeline is shown in Figure 6. The process is implemented by combining the mobiles, equipment, and portals systems architectures. Using this intelligent system will add four parameters (longitude, latitude, height, and time) to every reading by the RFID reader.

Once the positions of the materials become known, they will be graphically represented by generating maps, using Google Earth and AutoCAD drawings, or any other format. The crew workers will use these maps in identifying and tracking the materials in the lay down yards. This system could be programmed to generate reports and alerts. The reports of tracking information for a particular product are usually based on the product identity code (e.g. EPC).

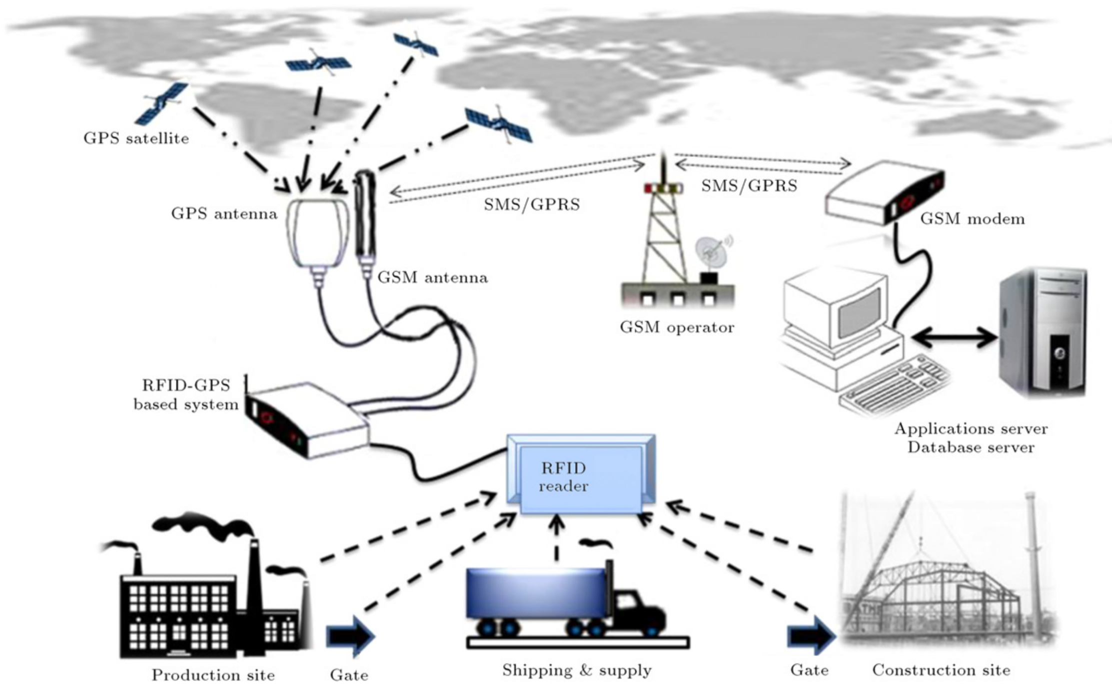

Figure 5: Automated data collection during production, delivery, and on-site.

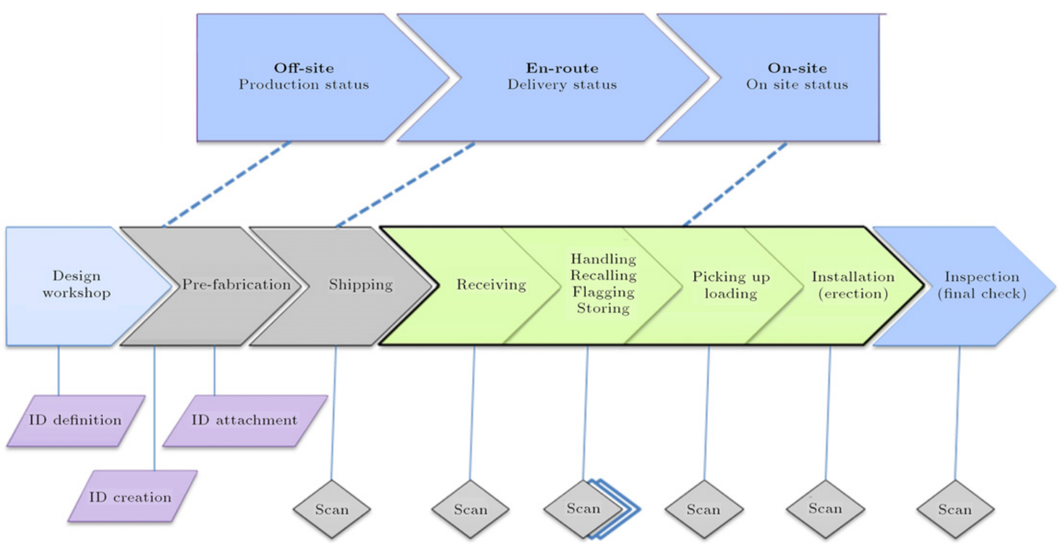

Figure 6: RFID–GPS facilitated material management activity timeline.

To improve the level of compatibility in using RFID technology, several different standards are developed and applied to it, which can vary between industries and countries. To cope with the degree of compatibility, a global technical standard code, the EPC standard, has been developed [29]. The Uniform Code Council (UCC), which oversees barcoding standards, licensed the EPC technology and formed EPCglobal [43]. The EPC is a sort of licence plate with a unique number, which allows clear identification of a marked object [32]. EPC Generation 2 is the standard, which was agreed upon and developed by a collaboration of leading RFID users and vendors, working through EPCglobal. In addition, EPCglobal has classified the RFID tags to improve tag design, development and use. This classification has become very popular since its specification, and is currently well-known in manufacturing and supply chain applications [44].

Protocols for communication between tags and readers are proposed by a number of organisational bodies and equipment manufacturers. The International Organisation for Standardisation (ISO) is the most prominent organisation creating standards for particular RFID uses. ISO, in conjunction with the International Electrotechnical Council (IEC), are working on standards for item management. The ISO/IEC standard deals with air interface protocols only, but, the EPC UHF standard deals with air interface protocols and data structure [35].

The EPCglobal-supported code is divided into numbers in four sections (header, manager number, object class and serial number), which can identify the manufacturer and product type, and uses a serial number to identify unique items (Figure 7). There are four elements that comprise the 96-bit capacity EPC [Ibid]:

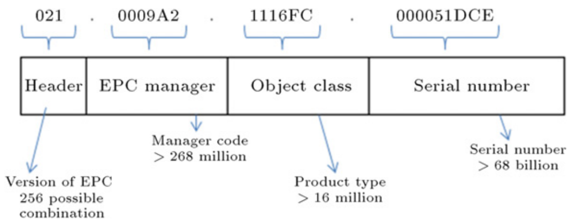

Figure 7: Illustration of an EPC class 1–96 bit.

- Header: Which is a specific format of EPC, and which identifies the length, type, structure, version and generation of EPC (up to 8 bits).
- Manager number: Which is about ownership of the set of numbers, and which identifies the company or company entity (up to 28 bits).
- Object class: Which is about the type of object, and which identifies the class of item, similar to a stock keeping unit (up to 24 bits).
- Serial number: Which is the unique instance of the object class being tagged (up to 36 bits).

The reports include a list of materials to be ordered, a cumulative list of material flow, dead inventory, and list of actually used materials. These alerts include a list of materials that should have been ordered, but were not, a list of materials that were expected but were not supplied, and materials arriving at the site which are incompatible with the purchase order. The proposed system has the flexibility of tracking the material, craft worker, tool, and equipment locations at different places, without investing in additional fixed infrastructure.

Automated inventory management, which relies on real-time and accurate information, necessitates the collection of data regarding all incoming and dispatched materials, automatically, continuously and almost instantaneously. Hence, the main benefit from the use of the proposed integrated system is to guarantees the availability of the right materials, in the right quantity, at the right place, when they are needed. Reducing the time spent searching for materials, assessing inventory status and decreasing the surplus and waste of materials are other benefits of utilising the proposed system. For example, the system prevents materials from potentially being misplaced, thus, it prevents ordering materials when they already exist on-site. In addition, the system permits ordering materials if their inventory level reduces below minimum when the work package start date approaches.

Collective information is sent automatically to the project database. This means that all the information is available in one place, so that construction players can access it in a cost-effective way, almost instantly. Thus, an electronic exchange of information is created in this research, which provides real-time information and wireless communication among all players, such as upstream parties (e.g. material suppliers) and downstream parties (e.g. contractors), to support project managers of each partner in monitoring and controlling progress in construction. Collected data can be used through a portal system, Geographic Information System (GIS), or any other application. An adequate data structure needs to be identified in order to store, share and manage large amounts of collected data, and to integrate collected information with project management tools. For example, the software can be pre-programmed to act as an automated alert system (e.g. shipping notification sent to contractor by manufacturer).

7.2. Tagging of materials

Tagging is recognised as one of the multi-phase processes and requires the co-operation of various parties to guarantee its functionality during the object life-cycle. Although the tagging of materials and components would occur at the production phase and in the fabricator's shop, the process could start at the construction job site when they are received. For both scenarios, RFID tagging has to be taken into consideration already during design and modelling. As discussed earlier, in this paper, there are many factors affecting the performance of tags. For example, RF transmission power at readable distance, failure of readings due to interference of metal, and/or noisy environment. This section deals with the characteristics of the construction materials and describes a procedure to find a tag with best performance.

There are two methods of tagging that can be applied to construction materials. If the target material is made of prefabricated items (e.g. precast concrete components) or packed materials (e.g. bricks), attaching a tag to each component and package unit would be effective. However, if the target material is a bulk, non-packed material (e.g. sand), which is delivered on site using bags and containers, having the invoice associated with an RFID tag would be more effective. Clearly, RFID tagging is most suitable for tagging on the package level, not at the item level, because the majority of construction projects comprises hundreds of thousands of individual items.

Deploying any automated data collection process in construction management requires various tags including: prefabricated tags, bulk material tags, equipment tags, tool tags, human tags, and space tags. Components and tool tags are attached to each of them to represent their attributes, while the bulk materials tag needs to be attached to their invoice. The equipment and human tags would be active RFID tags, which have longer reading ranges and can act as self-signalling tags working on their own batteries. Space tags are attached to any element of space to represent the three-dimensional positions of the point to which the tag is attached.

Tags need to be attached to clearly defined locations in an element, or on an object or package. Instructions and positions of tags need to be saved in the server and passed to the worker. It may be individual for each prefabricated item. However, some common rules and best practices about the location should be agreed upon to guarantee the readability of tags and ease the later reading process. In choosing the attachment method, the reusability of the RFID tags should also be taken into consideration, for instance, using rope makes the tag reusable. If the target material is made of metal, the tag needs to be mounted approximately 1 cm from the metal surface to avoid interference.

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, low cost and low power consumption. For example: passive RFID is most appropriate where the movement of the tagged item is highly consistent and controlled, and there is little or no need to change the tag contents, sensing capability or data storage. Active RFID is best suited where the movement of the tagged object is variable, and more reading range, sensing capability, and data storage capabilities are required.

7.3. Data on the tag or database

As stated earlier, considering the limited memory of the tags, the subset of information stored on the RFID tags has to be chosen 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 object ID, serial number, or production number.
– *Task-related* information, such as warranty information, handling, and installation instructions and details.
– *Status-related* information, such as current status (e.g. manufactured, installed) and spatial information of the item.
– *Operation-related* information, such as maintenance.

According to the literature review discussed in Section 2, storing information directly on RFID tags (data-on-tag) or storing information on remote databases (data-on-network) is an ongoing debate. In some studies, object-related necessary data were stored on a tag that was attached to the object. Some studies used RFID tags only to store an ID, and any additional data needed in relation to the object was kept in a remote database, which was indexed with the same unique ID. In some cases, network accessibility might not always be provided throughout the lifecycle of materials within the construction phase. Thus, the availability and accessibility of object-related data, without the need for a connection to the database, is one of the advantages of the data-on-tag concept. Even though this approach requires relatively expensive tags, due to their higher memory capacities, it provides anytime access to object-related information at all locations. For example, the construction workforce will access handling and installation information from the tag to correctly handle and install materials at the right locations. Both Read-Only and Read–Write tags can be used for this purpose, however, the tag needs to be re-writable if there is a need to update or extend information through different phases (e.g. production, delivery, storage).

Another approach that can be used to store object-related data is an integrated approach, which enables data availability under different conditions. In this approach, all related information needed when the object is outside the range of the network can be stored on the tag, and the rest of the data can be kept in the database.

8. Challenges and limitation of the system

A pilot application is necessary to face any problems or challenges, by adapting the technology in the most suitable way and proving system practicality. One of the expected challenges is social. Wide Implementation of such systems would bring resistance from companies, as these companies have been using traditional methods with which they are comfortable. In addition, applications of any technology in construction should be accompanied by its inspection and monitoring guidelines. It is also necessary to provide guidelines to run inspection and monitoring processes for the RFID technology itself during the implementation phase. Thus, extra effort and training are needed. Hence, it is important to provide strong incentives for enterprises to adopt the new technologies.

Although the cost of RFID tags has been reduced over past years and is comparable with barcode labels in using chip-less RFID tags, RFID technology is still relatively expensive and the cost of RFID tags in active technology should be taken into account. It should be noted that RFID tags are reusable, which may alleviate this challenge. Even though a power efficient technique, such as sleep mode, can provide a possible solution to the better performance of a battery's life cycle, the limitation of battery operation time, to allow for a normal workday (at least eight hours), exists. Thus, power can be identified as another challenge. For active RFID systems, the reader can be set to be triggered to wake-up by motion, activity, or on a set time interval if desired. For low power RFID systems, the tag goes to sleep in between transmissions, so, the reader needs to be on at all times, listening for tags, to wake up and transmit.

Although in the ISO and EPCglobal world, the standards for some frequencies are already approved, and the specifications for the Generation 2 (Class 0 and Class 1) tags have been published, the lack of a complete and international standard for RFID technology, and a lack of multi-protocol tags and readers are two important challenges. The aforementioned standards should deal with the technology in different countries in which RFID operational frequencies are different. Poor performance with RF-opaque (e.g. metal) and RF-absorbent (e.g. water) objects is another challenge. Custom tags are available to alleviate some of these problems for such particular types of RF-opaque and RF-absorbent materials, but they are expensive.

9. Cost-benefit analysis methodology

Implementing the new methodology and using a technology-based approach to automate construction management tasks requires a cost-benefit analysis, by carrying out a cost comparison between manual and RFID–GPS based systems. Although there are difficulties in determining the actual process time and required labour related to some tasks in construction management, a pilot test can help to compare the fixed and variable costs of implementation and operation, with potential benefits, by implementing the proposed system.

There are two categories of system costs, investment, and operation and maintenance. The fixed cost of this system depends on the amount of hardware installed, which is governed by the phases (e.g. production, shipping, and job-site) to be covered. The variable costs of this system consist of the cost of RFID tags, considering their reusability, wireless connectivity of the GPRS network, and labour costs for inspection.

The benefits from the usage of a technology-based materials management system may be discovered in many aspects of project practices. These benefits can be direct, such as a reduction in man hours, or indirect, such as an increase in productivity. The intuitive and intangible expected benefits from the use of this system may be the efficiency of information acquisition and communication, labour utilisation, and document management. Using such a system will automate labour-intensive tasks in material management, such as paperwork for recording, updating and reporting the material status through daily check-in and check-up activities. For example, reductions in crew, supervisor, and manager level labour costs for their time, which is needed for searching, tracking, recording, reporting, and transmitting, can be considered as benefits during delivery, storage, distribution, and installation. In addition to reduction in labour cost, cost saving on document handling and storage space, by reducing the volume of historical archives, should be taken into account.

It is important to note that the fixed costs for technology-based material management system remain the same at the level of first time implementation, even if the project duration increases.

10. Conclusions

This research presented a new approach for integrating the latest innovations in ADC technologies, which address a clear path to automate the tracking and monitoring of construction resources (e.g. materials and components), using minimal or no human effort. The selected technologies involve the use of combined GPS and GSM technologies equipped with RFID technology to obtain real-time and accurate information about construction resources. Collected information can then be shared among all players in construction including upstream parties (e.g. material suppliers) and downstream parties (e.g. contractors). The use of automated advanced tracking and data storage technologies can provide intangible and comprehensive benefits in communication and labour utilisation, and it can also facilitate extremely low-cost, infrastructure-free solutions to form the backbone of a construction resource management system (e.g. materials management system). In this approach, the combination of RFID, GPS, and GSM technologies, as a powerful portable data collection tool, enables the collection, storage, sharing, and reuse of field data accurately, completely, and almost instantaneously.

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