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# Application of RFID and Mobile Technology to Plaster Board Waste in the Construction Industry

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## 1. Introduction

Protection of the environment is one of the most sensitive topics of recent years and recognition of its importance is resulting in more effective recycling and reuse of material. Simply disposing of waste through landfill or burning, as was historically the case, will damage our environment. Nowadays, a number of government initiatives and environmental pressure groups are seeking more environmental, socially responsible methods of disposal. Undoubtedly, recycling is the best solution for protecting our environment by 'waste management'.

In general, waste management is the administration of collection, transport, processing, recycling and/ or disposal of waste materials (McBean et al., 1995). Currently, it usually includes reduction and auditing activities for the protection of human health and the environment by producing less waste and by using it as a resource wherever possible. This type of waste management is known as 'sustainable waste management' – reduction, re-use, recycling, composting and using waste as a source of energy (DEFRA, 2007).

Today, waste generation and disposal has become a serious problem. Each year, approximately 335 Mt of waste are produced in the UK most of which is produced in England. In 2005, 272 Mt were produced in England, much more than Scotland, Wales and Northern Ireland, which produce less than 25% of the total UK waste (DEFRA, 2007). Information from the Environment Agency (EA) and SEPA (Scotland's Environmental Regulator and Adviser) indicated there were 4.12 Mt of hazardous waste produced in England and Wales (EA, 2007), with an additional 4,430 tonnes produced in Scotland (SEPA (Scotland), 2007). In 2006, this increased to 6 Mt in England and Wales (EA, 2008a).

In general, waste is a combination of many types of material, and most of them are harmful and polluting. Waste takes many years to break down, and can pollute water courses and the land even when it is carefully disposed of, especially the hazardous or controlled waste. However, fly-tipping and incorrect land filling of these types of waste will cause heavy pollution and damage to the environment. The UK produces over 1 million tonnes (Mt) of plasterboard waste per annum, of which only up to 7% is being recycled whilst the majority has been land filled which causes a potential environmental problem. Plasterboard waste contains a high percentage of gypsum which has resulted in serious problems because of the emission of hydrogen sulphide gas ( $H_2S$ ) once it is land filled with organic waste. According

to DEFRA (Department for Environment, Food and Rural Affairs), it can be anticipated that the volume of plasterboard waste will increase over the next 15 years due to the expansion of usage and the rise in construction projects. Another example is medical waste; it usually contains infectious materials, drugs and sharp objects such as syringes, which are undoubtedly harmful waste that contains a large number of viruses, bacteria and harmful chemical reagents.

In the UK, only a few recycling facilities are available in England, and it is usual for the recycling companies to take plasterboard waste from construction or demolition sites themselves, and charge a transportation fee. Depending on the distance to the recycling facilities, transportation fees can be expensive, and exceed the landfill mono-cell costs. Consequently, increasing recycling is a viable route to prevent environmental problems. To improve the recycling rate, a tracking and auditing system is needed to prevent fly tipping and other illegal disposal. A novel waste management prototype is outlined based on identification technology, current waste management process and reasoning techniques.

In this chapter, RFID (Radio Frequency Identification) technology is introduced which can potentially improve the waste management efficiency. Radio Frequency Identification (RFID) is an automatic identification technology used in assets tracking and logistics support in supply chain management by substituting barcodes with RFID tags.

## 2. Plasterboard landfill and fly-tipping problems

Demolition waste and construction waste are becoming an increasing problem, particularly due to the re-development of urban areas. This type of waste typically contributes more than 30% of the total waste in the UK. For instance, in 2004, as Figure 1 demonstrates, construction and demolition waste accounted for 106.1 Mt, which is 31.7% of the total UK waste (DEFRA, 2006).

Plasterboard waste is a major contributor to the problem of construction and demolition waste. The application of plasterboard in construction began in the late 1960s, and its lifespan, which averaged 30 years, depended on the type of plasterboard used (MTP, 2007a), therefore current refurbishment and demolition activities will increase the amount of waste plasterboard created in this sector.

Information from Waste and Resource Action Programme (WRAP) in 2006 and the UK Department for Environment, Food and Rural Affairs (DEFRA) in 2007 indicated that more than 1 Mtpa (Million tonnes per annum) of plasterboard is generated by the construction and demolition sector, and only 70,000 tonnes are being recycled each year. It is anticipated that over next 15 years the volume of plasterboard waste will increase because of expansion in its use and the rise in construction projects (DEFRA, 2007).

Plasterboards are made from fibre materials and gypsum. Normally, the middle layer of the plasterboard is gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) which is sandwiched together by two pieces of fibre material such as paper or cloth. Plasterboard is relatively quick to fit in buildings, requiring a low level of skill; it is widely used in domestic and commercial situations, and usually used in the interior of buildings to provide a high quality finish.

The amount of plasterboard produced and consumed in the UK is about 3 Mt (million tonnes), and between 1 and 1.3 million tonnes of plasterboard waste is generated annually which is a significant amount (DEFRA, 2007). This waste comes from demolition and refurbishment activities, and also from new construction sites, which typically waste 12% of the total raw plasterboard materials (Lund-Nielsen, 2007).

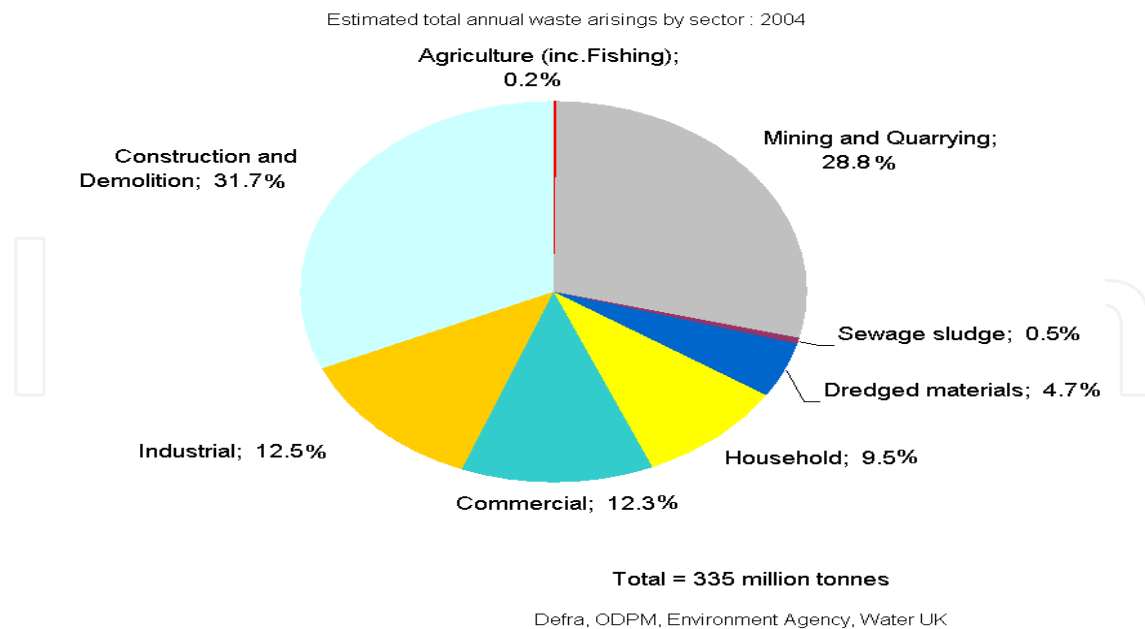
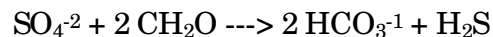


Fig. 1. Estimated Total Annual Waste by Sector in the UK 2004(DEFRA, 2006) (modified by authors)

Traditionally, landfill is the main method of UK waste disposal, and this includes plasterboard. However, plasterboard is made from more than 90% gypsum, and some fibrous materials, with less than 1% of other materials (PbrUK, 2007, Kleist et al., 2004). Plasterboard waste is therefore considered to be high sulphate waste, which can break down with other organic waste and emit  $H_2S$  gas, as represented in the following reaction:



Sulphate ( $SO_4^{2-}$ ) is the main component of gypsum, (which is  $CaSO_4 \cdot 2H_2O$ ), and  $CH_2O$  is the organic carbon in organic waste material (McBean et al., 1995). Hydrogen sulphide ( $H_2S$ ) gas is produced by the sulphate-reducing bacteria under anaerobic conditions in the landfill sites. 100 tonnes of landfilled sulphate can potentially produce 35 tonnes of  $H_2S$  (Heguy and Bogner, 2004). Plasterboard waste in landfill sites therefore poses a serious health and safety risk.

In December 2002, the European Council established criteria and procedures for the acceptance of waste at landfills referred to as 'European Council Decision 2003/ 33/ EC'. This document clearly indicates that 'Non-hazardous gypsum-based materials should be disposed of only in landfills for non-hazardous waste in cells where no biodegradable waste is accepted'(European\_Council, 2002).

In England and Wales, this decision has already been implemented in 'The Landfill (England and Wales) (Amendment) Regulations 2004'. This act extended the range of 'gypsum-based materials' to include 'Gypsum based and other high sulphate bearing materials', (Bradshaw, 2004) and a definition was necessary to determine what percentage of sulphate indicated 'high sulphate bearing materials'. In 2005 The Landfill Regulations were further amended, detailing the 'Criteria for stable non-reactive hazardous waste and non-hazardous waste deposited in the same cell with such waste', and stipulating that the sulphate level should be less than 20,000mg/ kg dry substance or less than 10,000 mg/ m<sup>2</sup>(Bradshaw, 2005).

In relation to the revised regulations, the Environment Agency (DEFRA) has published at least two documents to interpret the definition of high sulphate waste. It 'considers 'gypsum-based and other high sulphate-bearing materials' to be waste with more than 10% sulphate in any one load' (Bourn, 2005), and that 'gypsum based and other high sulphate bearing materials relates to both gypsum and other forms of sulphate containing waste with a content of more than 10% sulphate per load' (Guidance for waste destined for landfill). In addition, Regulatory Guidance Note 11 indicates that this type of waste should be landfilled in specially designed cells with their technical requirements (Bourn, 2005). This 'guidance' or 'requirement' is referred to as the '10% Rule' for plasterboard disposal (James et al., 2006).

The '10%' rule has however resulted in a problem, in that it seems to encourage 'diluting' plasterboard with other waste under the 10% threshold rather than segregating the plasterboard from other waste for recycling purposes (James et al., 2006).

In November 2008, The UK government removed the 10% regulation, and consequently the plasterboard waste needs to be separated from other waste (EA, 2008b). The changes to the regulation represent awareness of public interest in plasterboard waste issues, and since that time, plasterboard waste has to be landfilled in a mono cell, which almost doubles the normal waste disposal cost. Additionally, there is an increase in transportation cost to these special mono-cell sites for the waste producer. Consequently, fly-tipping or illegal disposal is becoming a problem and a specialist management system for the plasterboard waste will be required.

### 3. Landfill sites and fees

According to the regulations, landfill sites which can accept plasterboard waste should be specifically designed, with a 'mono-cell'. This type of 'mono-cell' is expensive to construct in terms of high investment and the duration of construction period (Bourn, 2005). Consequently, due to the limited capacity and high cost of the mono-cell, this method of disposing of low-value and large volume waste such as plasterboard is not the preferred solution.

	Pure (100%) Plasterboard Waste using Mono-cell	Recycling Plaster-board Waste	Mixed (<10%) Plasterboard Waste using normal Cell (NOT ALLOWED since 11/ 2008)
Transport Fees £/ t	Average £ 20 / t	Average £20 / t	Average £20/ t
Landfill Tax £/ t	£ 24 / t	N/ A	£ 24 / t
Operation fees £/ t	£95 / t	Unknown (from free to £75/ t)	£24.5 / t
Total £/ t	Average 139£/ t	Minimal cost £75/ t	Average £68.5/ t

Fig. 2. Estimated Fees for Disposal of Plasterboard Waste (Source: (MTP, 2007a, James et al., 2006, Turban et al., 2005, Pal. and Shiu, 2004)).

Information from WARP indicates that there are two sites which have been identified as accepting high sulphate waste: Winterton Landfill in North Lincolnshire and Harmondsworth Landfill in Middlesex (James et al., 2006). However, there appears to be no information showing how many sites in England & Wales are licensed to accept high sulphate waste. Most applications for construction of mono-fills are currently for asbestos, because high sulphate waste is relatively new requirement (MTP, 2007b).

Figure 2 compares the estimated fees for the different disposal methods of plasterboard waste. In 2008, there were still large amounts, more than 1 Mt per year, of plasterboard waste being landfilled in the UK, and there is no information that can confirm the landfill amount for the most recent two years; but undoubtedly, the removing of the '10% rule' from the regulations has been playing a significant role for improving the percentage of plasterboard which is being recycled.

#### 4. Plasterboard recycling

Recycling plasterboard waste is an important way to reduce the amount of plasterboard entering the waste landfill system and damaging the environment. There are different processing techniques for recycling plasterboard, but in general, they all include two major objectives: separation of gypsum from the paper, and crushing to produce a gypsum powder that is mainly used to make new plasterboard (Hamm et al., 2007, Hirz and Sterr, 1995, John and Knez, 1993, Tudahl and Bush, 2000).

Normally, the plasterboard waste usually contains impurities such as metal, plastic and other debris, which need to be removed before going to the feed hopper of the recycling equipment. This process is usually manual, but the removal of ferrous metal can be performed automatically using electromagnets (Turban et al., 2005, GRI, 2011).



Fig. 3. Locations of Current and Reported Potential Recycling Facilities/ Transfer Stations for Gypsum Waste within the UK (excludes new NWG Plants as Location not Revealed)(James et al., 2006)

Figure 3 shows the current location of plasterboard recycling facilities, and demonstrates that in some parts of the UK it is not feasible to collect and transport the waste, either because of issues of transport, or cost implications. Depending on the distance to the

recycling facilities, transportation fees can be expensive, and exceed the landfill mono-cell costs. Therefore, logistics is an important area affecting recycling throughput.

A typical method of transportation is implemented by Gypsum Recycling International Company, which compacts the plasterboard waste and transports it using specially designed vehicles (Turban et al., 2005). This requires a site to be selected and waste plasterboard is placed in a special container which is provided by or rented from this company. It then regularly sends a specially designed vehicle with an on-board crane and weight system to collect the waste, and transport it to the recycling plant (Turban et al., 2005, GRI, 2011).

## 5. Introducing of RFID

Radio Frequency Identification (RFID) is an automatic identification technology which has received much attention recently because of its application in assets tracking and logistics support to supply chain management from the substitute barcodes with RFID technology. In this section, RFID technology will be introduced from its history, principle, standards, system and application scale viewpoints.

### 5.1 History of RFID

RFID started in the Second World War, but the real progress was not made until mid-1960s, when it became practical and in a form that would be recognized today (Roussos, 2008). During the 1960s and 1970s, RFID became a more widely practical reality and turned from military to commercial usage. The Electronic Article Surveillance (EAS) is the first system used in commercial application that utilizes 1-bit tags to prevent theft of merchandise (Landt, 2005, Roussos, 2008). Although the system only has the feature to detect the presence or absence of a tag, it did not prevent EAS from becoming the first and widespread commercial use of RFID technology.

The first truly passive tags appeared in 1975, when an early and important development was made by the Los Alamos Scientific Laboratory and presented by Alfred Koelle, Steven Depp, and Robert Freyman (Landt, 2005), which indicates the complete first truly passive tag using backscattering development (Miles et al., 2008). During the 1970s and early 1980s, the large scale commercial usage began, but it was still limited by the electronic component and circuit technologies, most of the tags could only hold a few bits in that period. At the end of the 1980s, beside the significant and rapid development in electronic technology, which provided lower cost and higher performance, RFID technology became more practicable. In the following decades, many contactless applications using RFID appeared and RFID has become popular, particularly in access control and ticketing (Landt, 2005, Roussos, 2008).

The important expansion of RFID application happened in the early 2000s, when the enterprise information system had developed into the backbone of globe trade, and the supply chain introduced to the business process, which involved partnerships with millions of goods across the world (Landt, 2005, Lehpamer, 2008). Due to the precision and low cost of RFID technology, the large scaled RFID application was then expanded, and applied to many global companies during this period, such as DHL, Wal-Mart.

### 5.2 Principle of RFID technology

The basic principle of RFID technology seems simple and easy, and just two sentences can describe the whole procedure of RFID how works: 1) transmit adequate energy to power up

the tag, and 2) communicate with the tag to request and receive the identifier (Roussos, 2008). In fact, RFID technology has involved many electromagnetic theories and electronic technology. In addition, there are many totally different principles/ theories that could be applied to RFID technology and this results in the diverse performance of RFID (Chawla and Dong Sam, 2007). For example, most low frequency tags use Inductive Coupling phenomenon (like a power transformer) using 'Load Modulation' to communication with reader, thus the communication range is limited to a few centimetres (Miles et al., 2008, Roussos, 2008). However most large communication range RFID equipment have adopted Capacitive Coupling, that provides more than 9 meters range, from result in laboratory testing using Alien RFID ALR-8800.

RFID tags are usually categorized in two groups, active and passive system. 'Passive' usually indicate two meanings: it can be used to describe tag's communications context and may also be used to refer to the tag's power. In communications method, a tag can be called 'active' if it contains its own transmitter, which can broadcast data even when no reader is present, it may be referred to 'transmitter tag.' Where as passive tag relies solely on backscatter modulation of the reader's signal for communication with the reader and usually there is no transmitter onboard. In a power context, the term 'passive' and 'active' are often used to mean 'beam powered' and 'battery powered' as well referring to the tag-reader communications methods.

However, passive or active is only a method to generally describe a tag, there are many categorisation methods available, for example, tags can also be sorted by 1-bit or Multi-bit System, by their working band (Ultra High Frequency (UHF: 865-954 MHz) / High Frequency (HF: 13.56MHz)/ Low Frequency (LF: 125-134 KHz) tag), and even by their memory (writable or read-only tag) etc. The following section introduces some global standards for categorized tags from different manufactures.

### 5.3 The standard of RFID technology

A major RFID standard is the International Organization for Standardization (ISO), which issued about 50 standards related to RFID technology. However, to discuss the RFID standard, another important organization - Auto-ID lab must be mentioned, which was founded in 1999 for developing Electronic Product Code (EPC) technology for marking and identifying the goods in a global supply chain (Landt, 2005). At the same time, they started to develop a low-cost RFID system, which was already widely used in industry known as EPC G2C1, a part of 'EPCglobal' standard. In this section, some major RFID standard including LF, HF, and UHF will be discussed as follows (Landt, 2005, Lehpamer, 2008, Miles et al., 2008, Roussos, 2008):

*EPC Standards:* EPCglobal is an organization founded by Auto-ID in 2003 for pushing its low-cost RFID system utilization in global supply chains. The Auto-ID Centre developed its own protocol and licensed it to EPCglobal on the condition that it is royalty-free to manufacturers and end users who use the EPCglobe system. The aim is to construct the 'Internet of Things' which must based on a open and shared infrastructure for auto-identifiable networked objects (Roussos, 2008). Therefore, the structures and aims of the EPCglobal and ISO systems are fundamentally different. EPC standards were the competitor with ISO, which working in a similar system but much slower than EPC. After several years of conflict, they have now collaborated with EPC class 1 Generation 2 tags, and



introduced ISO standard as ISO18000-6 with a slightly modification(Landt, 2005). Currently, there are three major RFID EPC standards ('G' for generation, and 'C' for class):

*EPC G1C0* - published in September 2003, working in UHF band, a backscatter read-only tag that was programmed at the time the microchip was made (Landt, 2005, Roussos, 2008).

*EPC G1C1* - published in September 2003, working in UHF band, a passive read-only backscatter tag with one-time, field-programmable non-volatile memory (Landt, 2005, Roussos, 2008).

*EPC G2C1* - Much more powerful and modern tag published in December 2004. Working in UHF band, passive backscatter, and multiple read and write tag. Four memory banks are included on the chip: which holds two 32bit passwords in reserved memory bank, EPC information on the EPC memory bank(Barber and Tsibertopoulos, 2005). Tag identification bank contains tags own information such as the serial number, and the fourth user bank can be used freely by applications (Landt, 2005, Roussos, 2008).

*ISO Standards:* In recent years, ISO has approved serial RFID standards working in different band and for different applications, also including the UHF band. This consequently conflicts with the EPC Generation 2 class 1 standards. The UHF band standards took more time to be published (latest version published in 2006), that has a better interoperability in air interface with EPC G2 standards than the first version published in 2004. Excepting the conflict of UHF band RFID standard, ISO has also published several RFID standards(Kitsos and Zhang, 2008), and they are outlined below:

*ISO 14443*- A standard for payment systems and contactless smart cards, this is relatively complex as it involves payment function, working in 13.56 MHz band, short range communication usually in few centimetres (Landt, 2005, Roussos, 2008, Kitsos and Zhang, 2008).

*ISO 15693*- A standard for vicinity tags similar to ISO 14443, also working in 13.56Mhz band, communication range is larger than the ISO 14443, but only support simple data exchange (Landt, 2005, Roussos, 2008, Kitsos and Zhang, 2008).

*ISO 18000*- A standard for air interface including the LF, HF, UHF and microwave for active and passive RFID systems. It describes the physical layer specifications for communications between reader and tag.

#### **5.4 The performance of RFID technology in laboratory environment**

The experiments presented in this section aim to prove a concept for the design of 'Plasterboard Auditing and Tracking System'. The term 'passive' and 'active' used in this section refer to both communication and power context, i.e. passive tag are working in passive communication mode and with no battery on board.

The active tags such as the product of GAO RFID usually provide a large communication arrange and can be up to 150m. In this application the large communication range may result in conflict and incorrect reading. Battery maintenance and cost are also issues with active tags compared to passive tags, which only cost less than 10p and there is no need for any maintenance (no battery onboard). Consequently, from both economy and efficiency aspects, passive system is the most appropriate for this application.

However, the actual performance of RFID passive tags is difficult to confirm, because the literature shows a large difference in some cases between the communication range and performance. Some specialists claim that passive UHF RFID tags only provide a less than 0.5 meters range, but other investigators claim the range should be 1-2 metres, indeed, longer

communication range such as 2 metres to 5 metres can also be found in the literature (Landt, 2005, Roussos, 2008, Chawla and Dong Sam, 2007, Lehpamer, 2008, Min et al., 2007)

A laboratory based experiment is discussed to examine the RFID performance, using Alien RFID equipment for these experiments. ALR-8800 from Alien Technology was used and the UHF reader is operated in 865.7-867.5 MHz range. The reader supports two communication interfaces which are RS-232 and RJ45 for TCP/ IP communication. The Reader is also connected to a pair of antennas' one antenna is for transmitting the signal (write operation) and the other is used to receive the signal (read operation). The first experiment involves 7 different models of passive EPC G2C1 tags, 6 of them are the product of Alien Technology and one is BAP (Battery Associated Passive) tags from Power-ID, which has the battery to associate with. The equipment and tags are shown in the Figure 4.



Fig. 4. The Alien RFID Reader, Antenna and Tags

This experiment was conducted as illustrated in Figure 5, and setup for three different environments as follows:

1. To determine the maximum communication range in ideal environment (i.e. limited interference using paper rather than 'hand' to hold the tag).
2. To determine communication range in 'metal affected environment' from small metal objects were placed around the tags and the antennas (at least 1m from the equipment).
3. To determine communication range using hand held reader device in ideal environment similar to test 1.

Each scenario was tested 5 times and the result gave average range accuracy to 10 cm which is satisfactory for logistic tracking purposes. The experiment were conducted by using far to near movement to test the range i.e. the tags were moved from far to near until the tags were detected and then the measured distances recorded.

The results in the second column of Figure 6 indicates that, some of the passive tags performances are satisfactory for logistic tracking giving 7.5m on average, except the AL-9629, which is used for only item level application. The BAP (Battery Associated Passive) tags provided the best result and exceeded a 10m range.

The results indicate that the metal environment dramatically affected the tags' performance, and the read range was reduced to 3.4m for the AL-964X Tag and 3.5m for BAP Tag. The results showed that the BAP tag was only slightly better than the passive tags. In addition,

the handheld reader performance for each tag was also tested, and the results are shown in the last column of Figure 6. The results show that the range is reduced and only provides a maximum of 1.2 m and a few of the tags read < 10 cm.

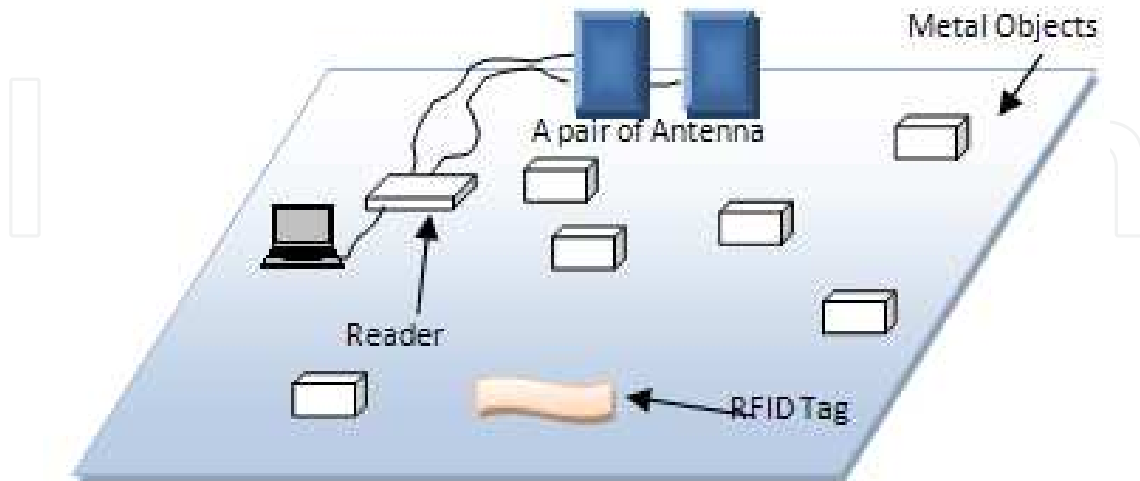


Fig. 5. Testing Setup for Environment Effects








Distance \ TAG Name	Free Testing (No attachment)	Metal Environment (Free Testing)	Hand-held Device (Free Testing)
 AL-9540	6.7m	3.2m	1m
 AL-964X	8.2 m	3.4m	1.2m
 AL-9654	7m	3.3m	50cm
 AL-9634	7.8m	80cm	30cm
 AL-9562	7.9m	80cm	20cm
 AL-9629	1m	0.2m	<10cm
 PowerID BAP Tag	10.2m	3.5m	1.3m

Fig. 6. RFID Test Results

## 6. Waste auditing system and knowledge hub

The plasterboard waste problem outlined would require an auditing and tracking system to provide verification and logistical support for authenticating environment disposal. Consequently, a prototype system was designed to ensure that plasterboard waste containers go to their correct destination, and provide verifiable evidence of each stage of the operation for auditing purposes and independent scrutiny.

### 6.1 System structure

The design will use RFID technology and digital imagery to integrate records including location, volume and weight, container movement, delivery tracking inventories and scheduling etc (Atkins et al., 2008). It works with the support of a knowledge management system which helps managers to make decisions of scheduled logistics of waste to treatment plants and also provides the instruction for operating staff to deal with the plasterboard waste and also other kinds such as medical waste etc.

The design of the prototype system can be viewed from two aspects: firstly, providing the evidence of plasterboard waste being sent to the correct treatment facility and preventing fly-tipping during transportation. This relies on comparison of the information from destination and the source sites, including RFID records, image or video records, operators checking and the possible use of built-in weight systems. The second aspect is the logistic / instruction support that helps management to choose the appropriate treatment facility to dispose of the waste and real-time instructions to the operating staff.

In addition, UHF RFID technology is introduced to the system which could provide automation on appropriate range and low cost by using passive tags. In the early stage of system design, Alien Technology AL-8800 reader and AL-9654 passive tags have been chosen for prototype design and feasibility evaluation. The system will use UHF tags which work in 865.7-867.5 MHz range, and the reader supports two communication interfaces which are RS-232 for serial connection and an RJ45 for TCP/ IP communication. Two antennas are linked to a reader, one for transmitting the radio power to the tags, and another one for receiving the feedback signal.

The prototype system was designed to consider three auditing aspects: 1, Auditing plasterboard material onto the construction site. 2, Monitoring the plasterboard waste removed from site 3, Checking that the wastes plasterboard has been sent to the correct destination.

An RFID tag is attached to the plasterboard stacks/ pallet for auditing of new material moved into the construction site. The main gate is equipped with an RFID reader then can monitor the transporting of plasterboard material. Once having successfully scanned a valid RFID tag, a record will be generated and sent to the central server with date, time, and ID number. These records can be checked to show how much plasterboard is delivered to the site.

The plasterboard waste container (skip or compactor skip) is marked with a unique ID and RFID tag in the demolition or construction site. The ID relates the information of the waste container, such as the total load, unloaded weight, location etc. This information is located in the central information server, and can be checked or updated by a hand-held RFID device. The operator can input real time information about the waste as appropriate using a mobile device equipped with RFID module.

When the waste containers are fully loaded, they are transported through a special gate to the recycling company or appropriate licensed landfill site. The gate is equipped with RFID sensors and digital imagery to create records which could be supplemented with mobile imagery and logging devices on site. The record is uploaded to the central information server and shows the logistics of the containers and the appropriate tonnages of plasterboard waste being transported or delivered to recycling and/ or landfill sites

Figure 7 is a Framework for Plasterboard Waste Management system using RFID technology and knowledge hub for tracking and verification purposes. The design will use RFID technology and digital imagery to integrate records including location, volume and weight, container movement, delivery tracking inventories and scheduling etc. It

works with the support of a knowledge management system which helps managers to make decisions on scheduled logistics of waste to treatment plants and also provides the instruction for the operating staff dealing with the plasterboard waste and also other kinds such as medical waste etc. All the RFID fixed readers are associated with imagery equipment, digital imagery could be automatically taken when a valid tag successfully scanned by RFID reader. These digital imagery records will be well documented as the evidence to verify the transportation.

Figure 7 also illustrates the system of a 'main construction demolition site' and near 'smaller construction demolition site' which are the two typical source sites. The plasterboard waste is designed to be bagged in the source sites during the demolition/ building process and a RFID tag is then attached to the container (bag, box, or bins etc.) immediately.

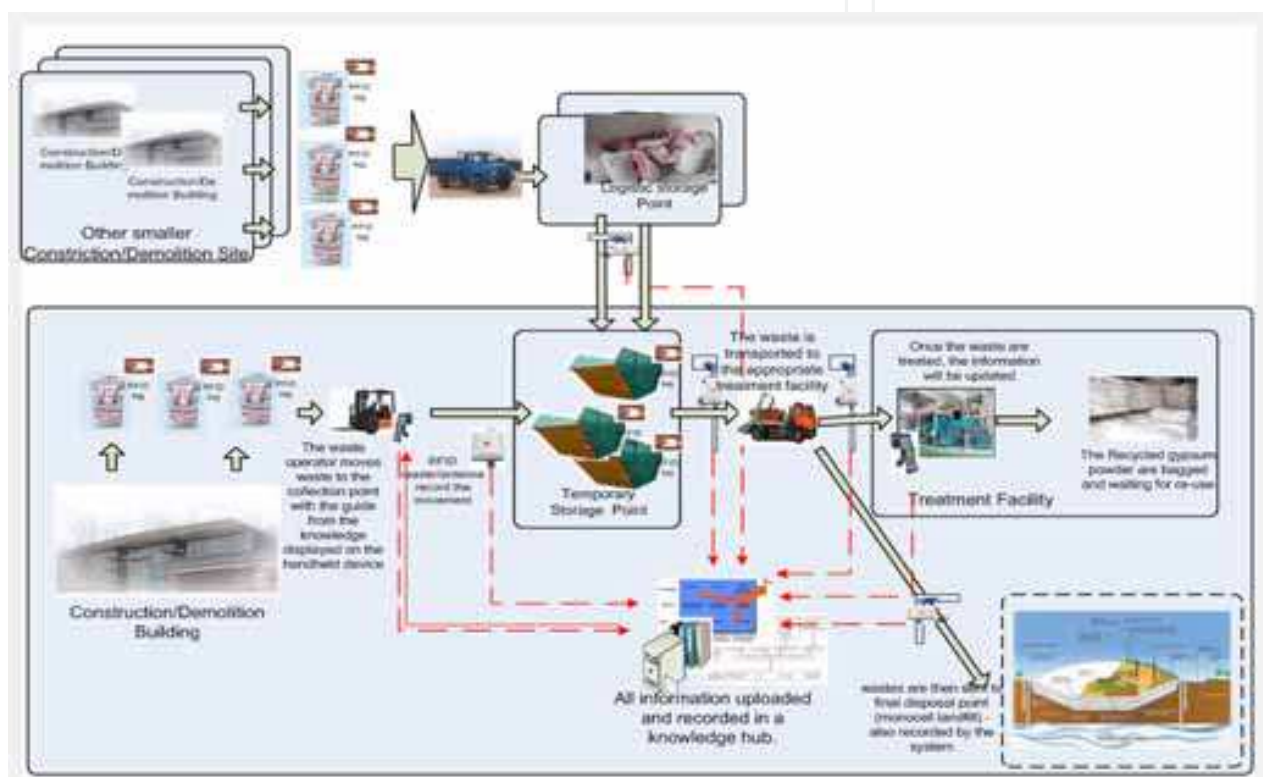


Fig. 7. Frameworks for Plasterboard Waste Management System

Plasterboard waste can go directly to the landfill with mono-cell. If the construction or waste company wishes to land fill them, the prototype system can fulfil the function of providing the evidence by records and image. The RFID equipment and RFID reader is set on the entrance of the landfill site to verify the arrival of the waste. When the containers pass this gate, a record will automatically be created and uploaded to the central server to show the logistics of the containers and the appropriate tonnages of plasterboard waste being transported or delivered to recycling and/ or landfill sites.

Hand-held devices are used by the operating staff involved in the system, including vehicle drivers, cleaners, demolition operators and waste managers etc. The device is a small sensor that links to the central server, and can display information from the system. The instruction and logistical support information will be automatically downloaded from the knowledge management system when it is required. The information notifies the operators which container should be transported or moved to the correct location in a specific time, and also

notifies the procedure of transporting this type of waste and any particular cautionary instructions.

## 6.2 Knowledge hub design

The prototype system is designed using a knowledge hub as the back end support, which includes a knowledge based system and reasoning to provide the logistical support for the waste management. The reasoning system is designed using Rule-based Reasoning, and the structure of the knowledge base is illustrated in Figure 8.

Figure 8 illustrates the structure of the knowledge hub system that is designed in four layers. The lowest layer is the hardware layer, called Data processing layer, which is the route for acquiring the data and information from the RFID and imagery equipment into the system (Zhang et al., 2008). The data gained from the equipments are separately sent to data bases, located in the second lowest layer.

The second lowest layer is the knowledge storage layer, called data integrate layer. This layer contained two databases which stores the RFID data and imagery data from lower layer, and another database is responsible for integrating the two types of information and prepares them ready for the next layer usage. In fact, this database is a 'fact' storage that used for the reasoning. In addition, the database can output 'fact' to a long term data storage data warehouse, and an OLAP (Online Analytical Processing) function can introduced into the system for better performance.

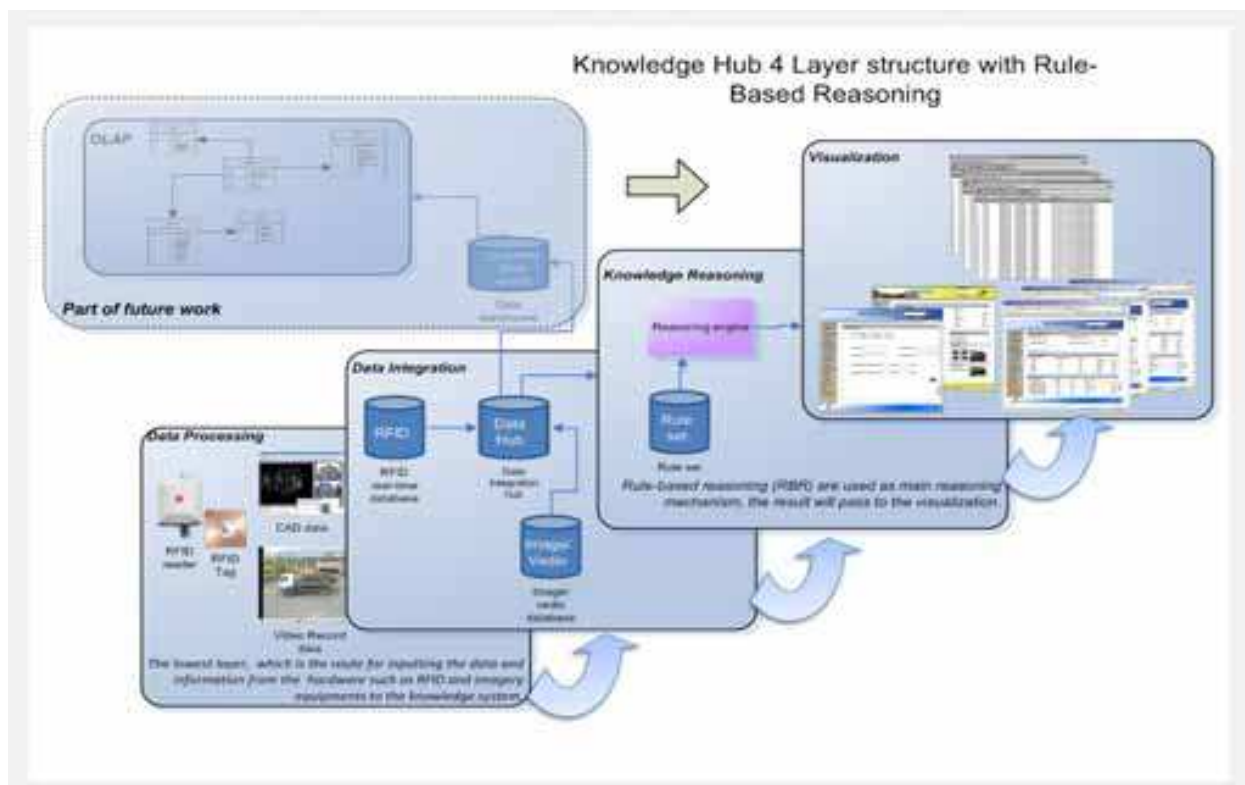


Fig. 8. 4-Layer Structure with Rule-Based Reasoning

The next higher layer is the core layer, which is called the knowledge reasoning layer. Rule-based reasoning is the main reasoning mechanism for generating the best solution for logistical and tracking support. The inference engine is the core of this layer that works with the rule base and the fact uploaded from lower layers.

The knowledge is stored in productive rule (IF...THEN...) format at the rule base. The three components compose the full Rule Based Reasoning system. The result of this layer is a suggestion solution' that is generated by the previously inputted rules, the reasoning aspect including the logistic suggestion and also the guidance for the waste operators, depending on the users requirements. Finally, the result is then passed to the highest layer - visualisation to provide the resolutions for decision support.

The highest layer bears the communication function between the system and users. This layer is called visualisation layer, which is designed to represent the logistical solution and the guidance in suitable client machine, either the desktop computer or hand held device. The visualisation layer can be associated with web-based application to represent data for easy access and flexible monitoring, and alternatively may use as individual programme to improve the security and more trustable evidence. The visualisation layer is also responsible for the user's command input; the command will pass to the lowest layer through the kernel module.

### 6.2.1 Adopting of rule-based reasoning

The rule-based system is usually called an expert system, and is the most popular choice for knowledge-based applications. A simplified definition of rule based reasoning is a technology in which knowledge is represented by a set of IF...THEN... production rules and data is represented by a set of facts(Giarratano and Riley, 2005). The rule will be executed when the fact matches the condition of a rule, and it may add or modified to fact for a new rule execution until the final result is determined(Giarratano and Riley, 2005).

Rule-based reasoning has some advantages compared with other reasoning technology and has been generally accepted as the best option for a knowledge-based system. It typically features natural knowledge representation, uniform structure, separation of knowledge from its processing and has the ability to deal with incomplete and uncertain knowledge. Some features of rule-based reasoning are suitable for the prototype system, and are discussed as follows(Giarratano and Riley, 2005).

Rule-based reasoning technology stores knowledge in IF...THEN structure meaning each piece of knowledge is relevantly independent from other knowledge. This structure is efficient for finding out the target knowledge when the waste regulation is amended. Secondly, the waste management system requires that knowledge should be easy to adopt into the reasoning system without complex transformation. In fact, it is better to input knowledge without any programme skills for ease of use and maintenance/ updating purposes. Individual knowledge storage is a key required feature that separates knowledge from the system and thus it could be removed without affecting the system design and a new knowledge base which contains the knowledge for other waste management areas could be supplemented.

### 6.2.2 Optimization module design

The reasoning layer is responsible for the optimized schedule plan, generates the real time guidance and reports on the current situation function, but the optimized schedule plan is the major task of the knowledge reasoning layer.

Normally, schedules include two aspects: the time plan and the route plan. However, considering the application is designed for a waste recycling company and most waste collection times are contracted, therefore the prototype system only needs to generate the

route plan and the time schedule has been assumed to be initially confirmed by contract between the waste company and the construction company.

The routing plan of the transportation can be seen as a classic TSP (Travelling Salesman Problem) question, which has the same requirement: the vehicle departs from the recycling facility, visit each site one time, and finally returns to the recycling facility. The major task of the reasoning layer is planning and finding an efficient route. It is also responsible for real-time planning in case of an emergency where a new route needs to be planned.

The requirement of the prototype system's application area restricts the route plan algorithm to matching the following features: 1) Inherent parallelism, which needs to consider more than one route at the same time 2) Efficient to solve TSP and similar problems. 3) Can be used in dynamic applications. Therefore, for this application, ACO (Ant Colony Optimization) will be introduced in the system that is responsible for generating the route plan (Colormi et al., 1991, Dorigo and Gambardella, 1997, Dorigo et al., 1999, Qiang and Qiuwen, 2008).

The ACO module is only dealing with the vehicle routing plan, therefore it needs to be independent from the main rule-base to reduce complications, and thus it does not need to be converted in production rule format. It only works when the vehicle type and target site has been decided by the rule based reasoning system; the vehicle and site information will be passed to the ACO module as the initial parameters, then the acceptable result can be generated in limited iterations and this is illustrated in Figure 9.

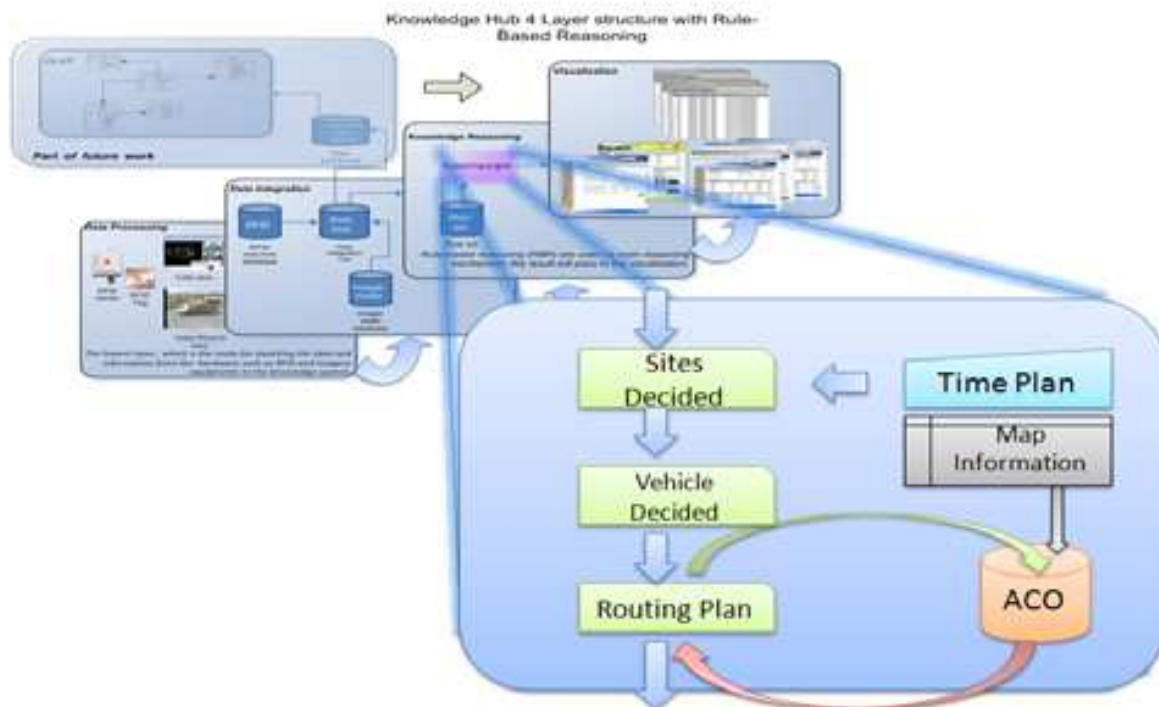


Fig. 9. The 4-layer Structure with ACO Module

The work procedure of the reasoning layer starts from the time schedule and routing plan. Firstly, the system will check the current time and query the database if there are any sites which need to be visited in this time (day, week or month) and also query the last operation



on that site to roughly estimate the tonnage of the waste. The estimating also takes into account the site project, construction progress and even its financial situation.

The next step is to decide the vehicle type and the number. After the site which must be visited in the next period has been decided and the waste tonnage of each site is estimated, obviously the total amount of waste will be known. The vehicle type can then be decided based on this information; the capacity of the vehicle should be larger than the tonnage and depends on the containers used on the sites. The rule-based system will be based on these 'facts' to reason out the vehicle type and number. Planning the details of vehicle routing is the function of the ACO, which firstly decides the routes to be calculated and the sites for a single trip. Then the exact route will be calculated by the ACO, in the prototype of the waste management system, only the original ACO will be introduced for evaluating purposes. After the routing has been decided, the details will be passed to the visualization layer for guidance.

Another important function of the prototype system is providing guidance to the operation staff to help them deal with the waste. It works as a handbook to remind them when, where and how to collect/ transport the waste. The transport plan is part of the guidance information that can give clear instruction about route choice and waste collect procedure to the vehicle drivers.

## 7. Conclusions

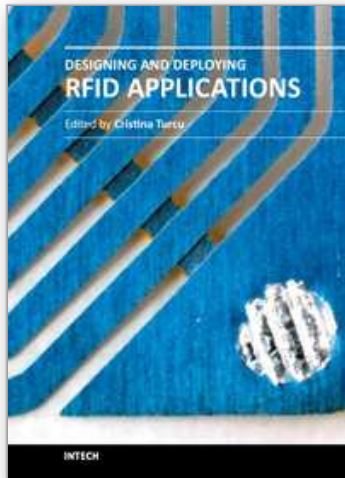
This chapter introduced the current plasterboard disposal situation and addresses the logistical problem which is a barrier to an increased recycling rate. In the UK only four known recycling facilities are available, all of which are located in England, and two of them in the London area. This situation has caused difficulties with transportation, and the recycling fees are higher than landfill if the source site is far from the facility. A prototype system for waste management is outlined which uses RFID technology for the main data collection methods, and rule-based reasoning and Ant Colony Optimization for auditing/ tracking the plasterboard waste and detailing the reasoning system and optimization methods. It also has the function to make a schedule plan and provide the guidance to the operation staff to ensure that waste containers are transported to the correct locations. The system can also handle emergency changes such as traffic hold-ups etc, as it will re-arrange suitable routes that reduce potential loss. The structure of a waste management and work process are introduced, including the four layer structure showing the reliance of RFID technology for collecting logistical data and digital imaging equipments are used to give further auditing evidence. The reasoning core in the third layer is responsible for generating schedules and route plans and guidance, and the last layer delivers the results to the users. Finally, the function of a prototype system for waste management was discussed which uses RFID technology for the main data collection methods, and rule-based reasoning and Ant Colony Optimization for auditing/ tracking the plasterboard waste movement.

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## **Designing and Deploying RFID Applications**

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Radio Frequency Identification (RFID), a method of remotely storing and receiving data using devices called RFID tags, brings many real business benefits to today world's organizations. Over the years, RFID research has resulted in many concrete achievements and also contributed to the creation of communities that bring scientists and engineers together with users. This book includes valuable research studies of the experienced scientists in the field of RFID, including most recent developments. The book offers new insights, solutions and ideas for the design of efficient RFID architectures and applications. While not pretending to be comprehensive, its wide coverage may be appropriate not only for RFID novices, but also for engineers, researchers, industry personnel, and all possible candidates to produce new and valuable results in RFID domain.

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