

Development of Construction Material Waste Management System

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Received on:21/9/2014 & Accepted on:7/5/2015

ABSTRACT

Construction materials waste management is the process of implementing a strategy that is capable to reduce construction materials waste to the minimum. This research aims at developing a construction materials waste management system that can serve construction projects at the local construction industry in Iraq in minimizing waste at the execution phase and raising the interest in waste minimization by all participants. Results of a previous research held by the same authors are employed in the developed system as warning thresholds. The system is employed and tested in six under construction projects in Karbala then evaluated by five principal staff members in each project through a questionnaire form. The system proves to be easy to install, data input is smooth, output is reliable, interaction between the user and the system is efficient, results are accurate, integration between the developed system and MS-project is effective, storage management is productive, early warning of waste excess is active, role of the system in reducing the waste is fruitful, and employing the system in the local construction industry is possible.

Keywords: Construction materials waste, materials waste management, waste reuse, waste recycling.

تطوير نظام لإدارة نفايات المواد الإنشائية

الخلاصة

إن إدارة نفايات المواد الإنشائية هي عملية تطبيق إستراتيجية مقننة على تقليل الهدر في المواد الإنشائية إلى أقل حد ممكن. يهدف هذا البحث إلى تطوير نظام لإدارة نفايات المواد الإنشائية بإمكانه خدمة مشاريع التشييد على المستوى المحلي في العراق لتقليل النفايات في طور التنفيذ وزيادة اهتمام المعنيين بتقليل الهدر. تم توظيف نتائج بحث سابق لنفس الباحثين في تحديد حدود العتبة المستخدمة في النظام. تم تطبيق النظام في ستة مشاريع تحت التشييد في كربلاء ثم تقييمه من قبل خمسة من المعنيين الأساسيين في كل مشروع من خلال نموذج استبانة. وقد أثبت النظام إنه سهل التنصيب وسلس المدخلات ومخرجاته معولن عليها ويتفاعل بكفاءة مع المستخدم ونتائجه دقيقة وتكامله فعال ببرنامج (MS-project) ونجاح إدارته للخزين وإنذاره المبكر بتجاوز النفايات كان فعالاً كما كان دور النظام بتقليل الهدر مثمراً وإن تطبيق النظام في صناعة التشييد المحلية أمراً ممكناً.

INTRODUCTION

The construction industry plays a leading role in improving the quality of human life. On the other hand, it has a destructive impact on the environment in number of ways including the generation of waste. Construction waste is increasing in the local Iraqi construction industry, as the rate of construction is increasing. Waste management actions must be afforded to reduce waste at all phases of design and construction with special consideration to the long-term environmental and economic impacts of continuous waste generation.

Research Objectives

The study aims at developing a computerized system to be used as a tool for managing construction waste in the local construction industry, through applying materials supply chain criteria, identifying possible ways to reduce waste, exploring the possibility of reusing waste at subsequent activities of the same project, and suggesting solutions for waste recycling.

Research Justifications

A successful construction waste management reserves the environment by utilizing the use of natural resources in addition to the economic benefits gained through reducing the construction cost. For many developed countries the construction waste management is no longer an option but became a necessity.

Research Hypotheses

Adopting a computerized construction waste management system will help in achieving maximum exploitation of resources and create clean construction sites free of construction waste to a reasonable extent.

Research Methodology

A thorough survey of the literature is conducted through the net to explore widely used construction waste management techniques. Results of previously determined waste percentages of the major construction materials at the local construction industry in Karbala are employed as thresholds. A computerized construction waste management system is developed to facilitate the implementation of waste management concepts of reducing, reusing and recycling in the construction practice at local scale. The system is implemented in real life and evaluated by experts through questionnaires.

FUNDAMENTALS

Till the late 1900s, construction waste management has simply been seen as a disposal issue only. It has required a change in the state of mind to include waste reduction and recovery in each stage of the construction project life cycle mainly including design, procurement, construction, and disposal. Recently, the construction waste management approach has been diverged from a traditional to a holistic mindset by emerging a number of new concepts that have led to change in the overall mindset of waste management. These concepts can be summarized as follows[1]:

- A life-cycle perspective that takes into account the construction waste management at all stages of the project.

- A comprehensive construction waste management that gets over the solutions of handling and discarding of waste, to the solutions of reducing consumption and enhancing efficiency of resources usage.
- Employing an integrated construction waste management system that acquires effective organization, cooperation, and participation of all parties involved.
- Applying the principle of producer responsibility on construction waste management.

These concepts might create a suitable work environment for waste management. So the disposal of waste to landfill is no longer the cheapest option, but reduction, reuse and recycling of waste are being the most economical and effective options.

Sources of Construction Waste

It is estimated that (33%) of the construction waste is due to unemployment of waste reduction measures by architects during design^[2]. On the other hand various project parties contributed directly or indirectly to raise the generated waste. However, there is a general consensus that design changes occurring whilst construction is a main factor that generates the construction waste^[3]. Specifications complexity and lack of execution information lead to assumptions made by contractors and sub-contractors, which result in over-ordering of materials^[4].

Generated waste during the execution phase is mainly due to poor communications leading to mistakes, bad overlapping between design and construction, bad estimating, bad transportation, bad storage, bad handling, bad workmanship, lack of supervision, and inefficient site management. Lack of knowledge about waste reduction techniques during the execution phase minimizes the possibility to avoid a lot of the generated waste in construction sites^[5].

Types of Construction Waste

Construction waste is often a mixture of inert and organic materials. Inert waste is normally used in public filling areas and site formation works, in which the remaining wastes are often mixed and contaminated. It is not suitable for reuse or recycling, but disposed of at landfills. Inert waste materials are described as soil, mud, concrete, reinforced concrete, asphalt, brick, sand, cement mortar, aggregate, rubble, and rock^[6].

Construction activities also generate chemical and other special wastes, which are normally regulated strictly for special treatment as they can easily cause pollution to the environment or serious risks to health. The separation of chemical and harmful wastes from other types of construction wastes helps the adoption of specific methods for each different type of waste effectively^[6].

Advantages and Impediments

Comprehensive reviews are encouraged to provide waste management measures in construction activities and to explain the effects of various effects on the environment including land use and deterioration, resource depletion, waste generation, and various forms of pollution^[7].

Advantages

Peng and Scorpio (1997) have stressed that reduction of construction waste is one of the best economical and environmental solutions. Lingard et al. (2000) added that social benefits are also included such as the avoidance of creating new and

undesirable landfill sites, stemming potential environmental health risks associated with waste and its disposal, in addition to reducing the cost of construction[8].

One of the economic benefits of waste minimization and recycling can be achieved through the possibilities of usufruct from specific waste materials and disposing the rest at no charge or reduced cost, with subsequent reduction in materials going to landfill^[9]. Managing construction material waste can in fact achieve higher construction productivity, time saving, and better safety. While, disposal of extra waste may take extra time and resources that may slow down the progress of construction adding surplus costs. The contractor can submit a lower bid price by lowering the production costs due to higher efficiency of resource usage[8].

Today about (80–90%) of the total amount of construction and demolition waste is recycled in most of the developed countries. So, it is economical to develop the technologies needed to implement and control the recycling of construction and demolition waste[4].

Impediments

Since 1970s, governments, contractors, and researchers are working hard to develop an efficient and cost-effective environmental management measures to reduce construction waste in a worldwide scope. However, the total amount of construction waste is still out of control due to the following causes^[10]:

1. Massive construction and lack of waste managing tools.
2. Insufficient budget and ineffective service fee.
3. No co-operation between adjacent communities.
4. No definite regulations.
5. Lack of skilled personnel.
6. Absence of waste recycling programs.
7. Inadequately facilitation of construction waste management.
8. Lack of public participation.
9. Lack of government legal enforcement.

MECHANISMS

Minimizing construction waste has been generally dealt with through three major directions; process reengineering, technology innovation, and deployment of modern information technology. According to Angelo (2000) the sustainable solutions can be summarized as follows[10]:

1. Minimization of waste by reusing construction waste.
2. Improvement of products quality.
3. Recycling the waste.
4. Sustainable development of project designs.
5. Increase of components durability.

In an attempt to lay down some mechanisms for construction waste management, (Fishbein and Coventry et al., 1999) established a set of construction waste prevention strategies based on effective coordination of materials management, which include efficient purchasing and ordering of materials, just-in-time delivery, careful storage and usage of materials in order to minimize loss, maximize reuse, prevent undoing and redoing, and reduce packaging waste[5].

(Chen et al., 2002) presents a crew-based Incentive Reward Program (IRP) using a barcode system to reduce the avoidable wastes through rewarding workers according to the amounts and values of materials saved in their operations. The IRP-based

barcode system is integrated with the Global Position System (GPS), the Geographical Information System (GIS), and the Wide Area Network (WAN) technology to facilitate material and equipment (M&E) management to control and reduce construction wastes and to increase the efficiency of onsite (M&E) management[11].

A qualitative approach to assess and control construction waste is to calculate the Construction Pollution Index (CPI), which is a qualitative measure of construction pollution by identifying and categorizing the sources of pollution and waste on construction sites. When integrated with MS Project, it serves as a computer tool which can automatically determine the generated pollution and waste over the project duration. It also, shows a distribution diagram to assist the project managers to identify worst periods in terms of emission of pollution, and to take necessary preventive measures to reduce the amount of pollution and waste[7].

Planning and Modeling

The waste management mapping model (WMMM) is one of the effective tools that is used to assist in planning waste management procedures on construction sites. It can also serve as a device for comparing waste management practices in several construction sites (both good and weak practice areas can be identified). Developing an effective (WMMM) for a particular project requires recognizing the standard measures that used for reducing the generated construction waste from each construction activity. These standard measures can be classified into seven groups; legislative, public filling facilities, landfill areas, on-site sorting facilities, environmental management system, waste reduction framework plan, and recycling scheme[12].

A field study by (L. Y. Shen, 2001), targeted the waste handling process in six building construction projects in Hong Kong. He developed an alternative waste management mapping model as shown in figure (1). This model introduces a waste management plan (WMP) before the commencement of construction. The plan specifies the device needed for wastes handling and mitigation measures that should be implemented from the beginning of construction[13].

Waste Management during Design

Inefficient execution plan, inefficient material management, and incorrect or non-constructible design result in significant amounts of waste^[12]. Design waste is defined as "the waste arising from both additions and/or omissions by the designer, including less opportunities of reusing the generated waste in the same project". To manage the construction waste effectively, it is required to reduce the waste generated from design[14].

In the UK, Glass et al., (2007) developed one of the most extensive studies on waste dimension during design. He reveals that construction waste management is not a priority in the design process. Designers seem to take the view that waste is mainly produced during site operations and rarely generated due to design. However, about one-third of the construction waste could essentially arise from design decisions. Results also indicate that a number of drawbacks such as: lack of interest from clients, lack of attitudes towards waste minimization, and lack of training all act as disincentives to a proactive and sustainable implementation of waste reduction strategies during the design process[3].

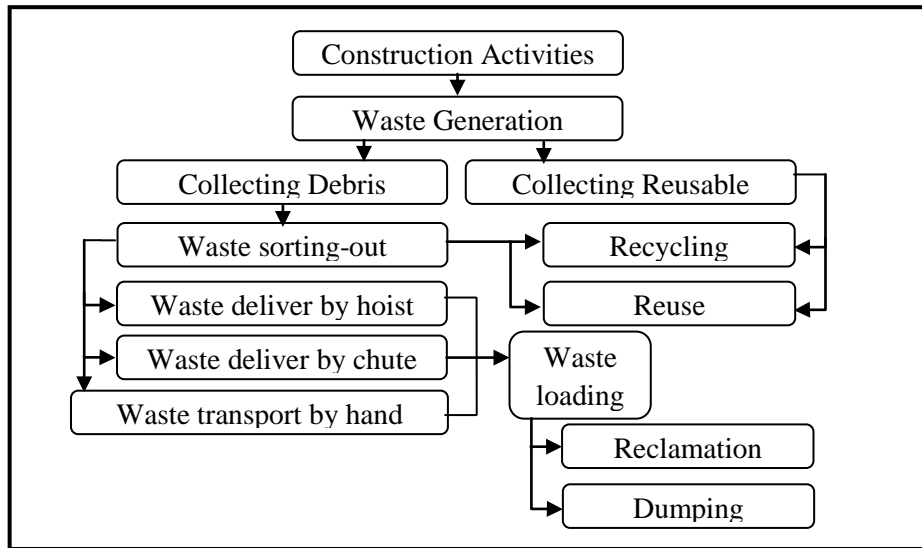


Figure (1): Waste Management Plan^[13]

Coventry and Guthrie (1998) suggested three key roles that designers should play, namely: giving advice to clients, initiating waste reduction at a project level, and improving design practices generally[3].

In order to reduce design waste, four major aspects must be taken into consideration: contract conditions, design issues and construction techniques, construction materials specification, and education[3].

The Three Rs' Principle

The Three Rs' principle (Reduce, Reuse and Recycle), also known as the waste hierarchy, is being widely adopted during the last few years and many waste minimization and recycling guides have been produced[13]. Construction waste reduction is the most preferred method to reduce both toxic construction and the quantity of waste generated. The waste reduction begins at the design phase. Then, it transfers to the construction materials management system during the construction phase[15].

According to Sim (2005), there are some opportunities to reduce the construction waste during design phase, which include specifying durable and maintainable materials so that frequent replacement is avoided and specifying reusable or recyclable materials to prevent those materials from entire landfills. On the other hand, the waste reduction at the construction phase will translate directly into cost savings. One of the measures has been the just-in-time ordering so that materials arrive when they are needed whilst minimizing damage of materials[15].

Many types of construction waste materials are reusable. Most of these materials come from demolition and renovation projects in addition to new construction projects. Such materials include: brick, concrete, and aggregate. The reuse of construction materials in the developed countries are usually made by contrapuntal organizations[6].

Recycling provides the opportunity to reclaim valuable resources and minimize the amount of waste placed in landfills. Recycling involves separating non-reusable materials such as unslung reinforcement steel bars from the demolition concrete and

debris of glass. The recyclable materials are then processed and returned to be used again as a part of other products[15].

THE DEVELOPED SYSTEM

Most of the generated waste in the local construction industry can be avoided by implementing few preventive measures, mostly related to managerial actions[16]. The construction industry is usually considered as an open loop system that consists of input, processing, and output. An attempt to achieve higher efficiency in materials usage is made by adding a feedback flow of waste materials which convert the open loop system to a close one[17]. This might create a fundamental change in the philosophy of construction wastes. Figure (2) shows what is meant by both open and close loops systems.

A system is developed to facilitate the implementation of waste management hierarchy concepts (Reduce, Reuse and Recycle) with an attempt to convert the traditional open loop system to a close one. The system is developed to serve as a tool to be used by construction engineers during the execution phase.

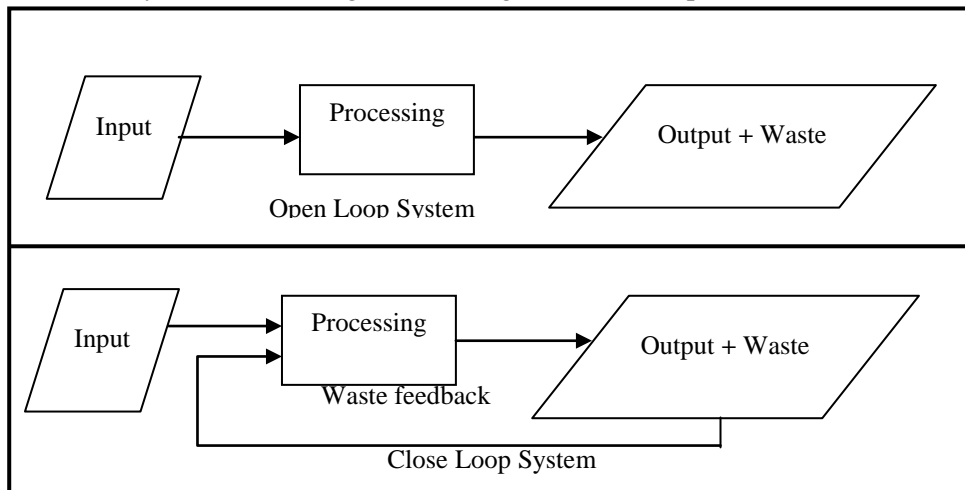


Figure (2): Open and close loop systems of construction materials flow^[17]

Principles of the System

The following principles are put forward when developing the system^{[18][19]}:

- Easy to install and operate.
- Do not need excessive input data.
- Capable to comprise all necessary information in its database.
- Provides understandable and useful reports.
- Flexible and capable to handle wide range of applications.
- Compatible with other systems that are used in the same field.
- Economical in terms of installation, operation and maintenance. In addition to be tested and verified.

Basic Criteria of the System

The developed system is designed to apply the following waste hierarchy:

- **Reducing the waste:** The developed system employs the trendy principles of supply chain method (SCM) with the concept of 'just-in-time' delivery (JIT) to supply construction materials to construction sites.
- **Reusing the waste:** The developed system offers possible ways to reuse waste materials in the same project through functioning as an expert system. The system can be updated with new possible reuse options.
- **Recycling the waste:** The developed system provides possible options for recycling construction materials waste that cannot be reused. The system can be updated with new possible recycling options whenever emerged.

Functions of the System

The functions of the developed system comprise the following:

1. Inter basic information of the project such as location, cost, and duration.
2. Import and update the timetable of the project from MS-Project.
3. Determine quantity needed in progress for each material concurrently.
4. Optimize the available space of material storage.
5. Determine optimal demand dates.
6. Prepare a daily report about each material with e-mail possibility.
7. Alarm an early warning in case of excessive waste.
8. Offers all the possible ways to reuse waste in the next activities.
9. Offers opportunities of recycling materials that cannot be reused.

The framework of the developed system and its programming interlinks are summarized in figure (3).

System Interfaces

Running the system does not need any special training above minimal computer skills for the system is designed to be user-friendly and self-exploratory in which the interfaces enable the user to run the system easily. The followings are the interfaces of the system:

Main Interface

The main interface represents the key guidance gate to the system's main functions, namely: New project, Follow up, Work items, Orders due, and Waste management. In order to impart privacy, the name and logo of the user's organization appear in this interface only when dealing with its own projects. Name of the project is also shown, followed by some general information about the project as shown in plate (1) in figure (4). This information will be fed in the next interface, so it will not appear in the first inception interface.

New Project Interface

Information from the timetable of the project will be retrieved from the correspondent MS-project files. A click on the "New Project" icon will connect the system automatically to the path of the MS-project file. An interaction window will call for the following information as shown in plate (2) in figure (4):

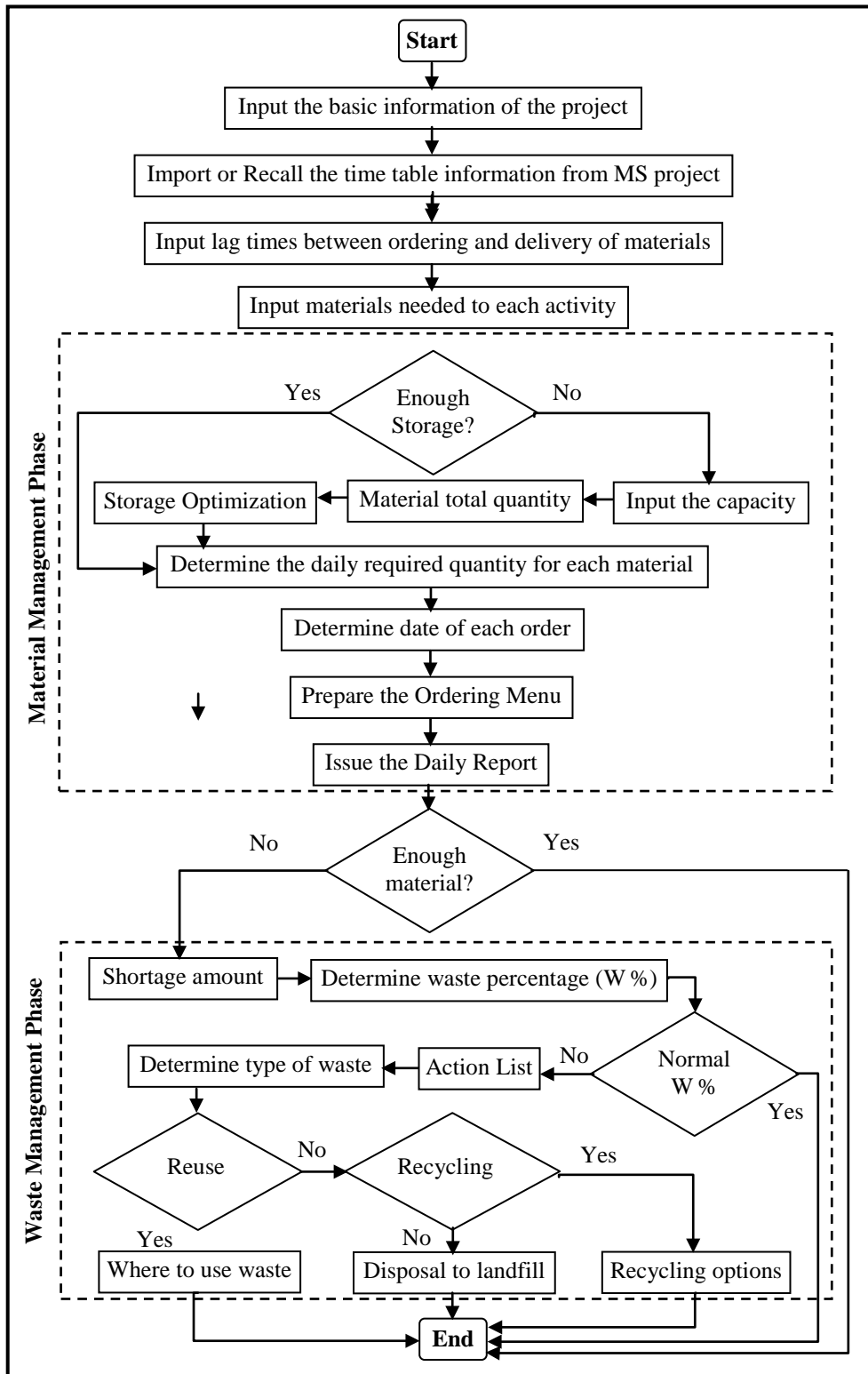


Figure (3): Flow chart of the developed system activities

- General information about the project.
- Expected lag time between material ordering and delivery.
- Intended capacity of storing areas for each material if any.
- Working days per week.

Work Items Interface:

When click on "Work items" icon, an interface appears showing the project activities in addition to its start and finish dates as shown in plate (3) in figure (4). The system asks the user to enter the amount of work in each activity and to describe the type and quantity of materials required to produce one unit of each activity.

Follow-up Interface:

The project information can be updated by clicking on the "Follow up" icon. Materials can be added, lag times can be altered, and MS-project timetable can be updated. The follow up information interface is shown in plate (4) in figure (4).

Materials Management Interface (Orders due):

"Orders due" icon represents the panel of material management outputs. Offering all related up to date information. The system issues a daily report about the construction material status on the site. The daily report consists of two main tables; demand table, and status table. The "demand table" shows the materials need to be requested from the suppliers promptly. The "current table" lists the materials that are required to execute works of the next day. Plate (5) in figure (4) shows the "Orders due" interface.

Daily Report Output

The system produces a daily report and sends it to the administration by E-mail. The report shows the date, extinguished period, activities have to be executed, daily demand and status tables. Plate (6) in figure (4) shows a sample.

Waste Management Interface

When clicking on the "Waste management" icon and select the material under consideration, the system shows details information, including cumulative, ordered, used and available quantities up to date in addition to the percentage of waste. Plate (7) in figure (4) shows the waste management interface.

List of Actions Output

The system will automatically compare the actual percentage with the normal percentage that has been saved in the database as a reference. If it is higher than normal, the system shows a list of actions to be taken. The "list of actions" shows the possible causes of waste overrun for each material in order to take actions to avoid more waste as shown in plate (8) in figure (4).

Waste Report Output

The system issues a report showing each material waste and a chart to highlight the difference between ordered and used amounts.



Plate 1: Main interface

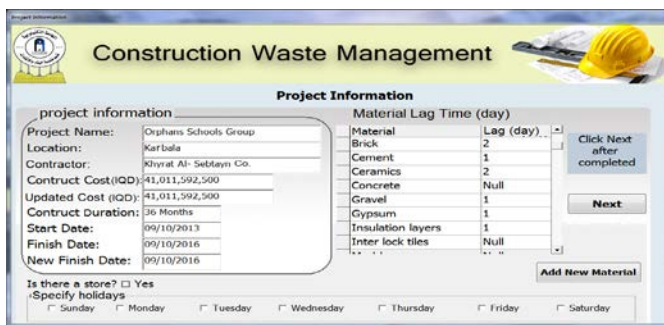


Plate 2: New project

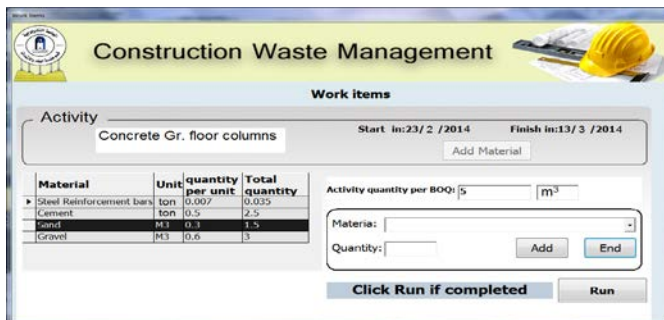


Plate 3: Work items



Plate 4: Follow up

Figure 4: System interfaces

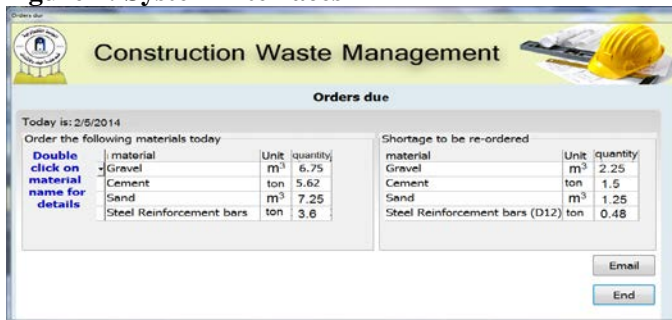


Plate 5: Orders due



Plate 6: Daily report output

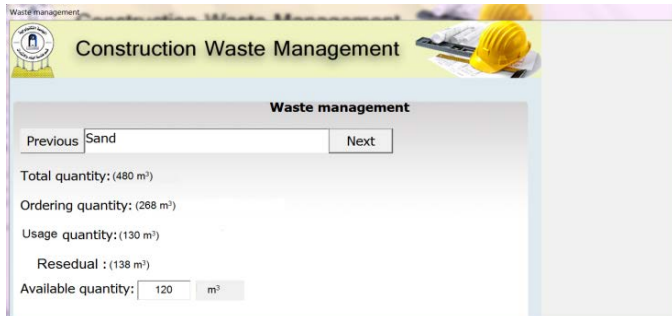


Plate 7: Waste management

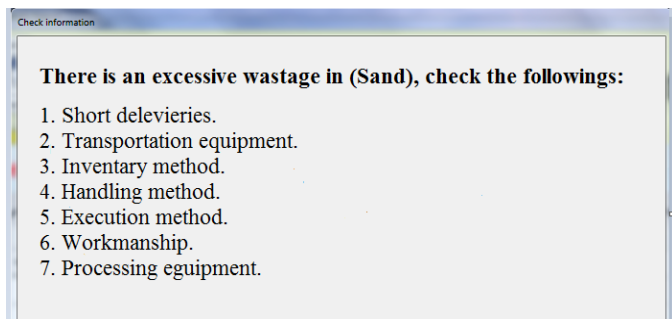


Plate 8: Actions list output

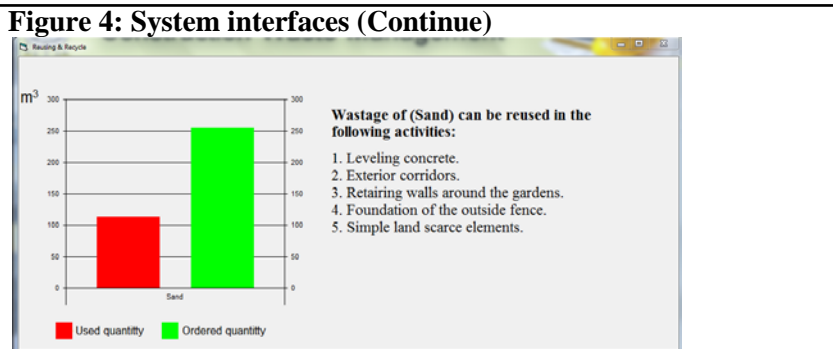


Plate 9: Waste Report output

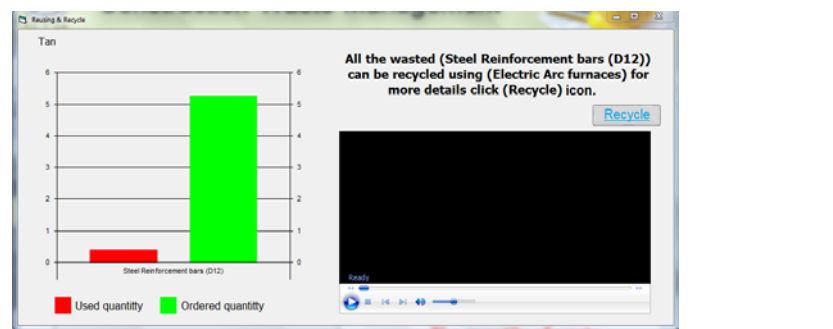


Plate 10: Recycling interface

Figure (4): System interfaces (Continue)

The most importance information given by this output is the advice where the wasted material can be reused in accordance with the Iraqi Engineering Specifications at the same project. Plate (9) in figure (4) shows a sample of the waste report output.

Recycling Output

The system displays some of the scientific approaches that are internationally adopted to recycle the construction materials waste. Usually the recycling process is carried by contrapuntal industrial institutions in the developed countries. Locally, there are no such firms, nevertheless, a series of recycling option for the wasted construction materials are provided by the system to raise the environmental awareness of contractors. Plate (10) in figure (4) shows a sample of the recycling interface.

System Evaluation

The developed system is implemented in six under-construction projects in Karbala. Projects and thresholds used in the systems are listed in table (1). Its performance is evaluated by experienced engineers in order to verify its flexibility, accuracy, effectiveness, and sustainability for application, find out application difficulties, and explore any additional arguments of the users. Direct interviews are also conducted with each project associated staff, including (the representative of the consultant firm, the resident engineer, the site engineer, the quantity surveyor, and the storekeeper). Interviews are documented by a questionnaire form that consists of two parts for specific ranked system characteristics and free respondent arguments. Table (2) summarizes the results of this questionnaire.

Interpreting the Questionnaire Results

It can be noticed from the ranked answers of the first part of the questionnaire that all respondents agree to an acceptable extent (good, very good, and excellent) that installing the system is easy, data input is smooth, output is reliable, interaction between the user and the system is efficient, results are accurate, integration between the developed system and MS-project is effective, storage management is productive, early warning of waste excess is active, role of the system in reducing the waste is fruitful, and employing the system in the local construction industry is possible. In the second part that is left for free respondents arguments, some has stated that the materials quantities per one unit of each activity have to be built in the system i.e. automatically determined by the system not by the user.

Table (1): Thresholds of the six under-construction projects

Project	Sand	Gravel	Cement	Steel	Brick	Stone	Gyps.	Tiles	Marble	Ceram.
Durrat Housing	12.00	10.33	5.38	4.81	14.50	11.62	17.84	10.17	-	9.67
Khatem Hospt.	11.92	10.72	5.03	4.34	15.32	-	-	-	-	-
Orphans School	13.01	11.01	5.29	4.64	-	-	-	-	-	-
Turkish Hospt.	12.04	11.44	4.72	5.27	15	-	-	-	8.93	10.75
Alsalam school	12.66	10.09	4.90	4.61	15.11	-	17.41	-	-	8.81
Almilad school	11.91	10.23	5.11	5.19	14.66	-	16.71	-	-	9.08
Thresholds	12.47	10.76	5.03	4.81	15.23	12.77	17.25	9.45	9.19	10.27

Table(2): Summary of the questionnaire results

Part-I- (Ranked Questions)							
Q.	System characteristics	Obtained frequency					Mean score
		V. P.	Poor	Good	V. G.	Excel	
1	Installation	-	-	11	14	5	6.6
2	Data input	-	-	15	4	11	6.73
3	Output display	-	-	-	13	17	8.13
4	User interaction	-	2	11	14	3	6.2
5	Accuracy of results	-	4	18	8	-	5.26
6	MS-project Integration	-	-	2	12	16	8
7	Storage management	-	-	11	12	7	6.73
8	Waste early warning	-	-	6	19	5	7
9	Reducing the waste	-	-	6	17	7	7.06
10	Applicability	-	4	16	10	-	5.4
Part-II- (Respondents' Arguments)							

Conclusions and Recommendations

A previous study conducted by the same authors had clearly pointed out the lack of efficiency in materials waste management at the local construction industry in

Karbala. This fact proves the need to develop a construction waste management system that can aid in enhancing local performance and can simply be employed.

CONCLUSIONS

According to the questionnaire answers, made by an expert staff of the six under construction projects the following conclusions can be drawn out:

- A serious absence of the appropriate knowledge of construction materials waste management.
- Most of the generated waste can be avoided by implementing few preventive measures, mostly related to managerial actions.
- The system is easy to use, flexible, and applicable.
- It is highly appreciated that the system imports the time table from (MS-Project) package program with the ability of updating.
- The system is reliable to assist in managing construction waste.
- The system supports the management to employ the supply chain method in construction material management.
- The system provides an effective tool to manage the inventory system.
- The system provides an early warning and suggesting solutions.
- It is highly appreciated by the experts that the system provides a remote notice to the management through sending a daily report by E-mail.

On the other hand, the system has some limitations, mainly because it is project oriented i.e. it is suitable for managing construction wastes at project level.

Recommendations

Researchers are invited to develop integrated packages that link waste management with material management, inventory management, project scheduling, resource optimization, and sustainable concepts. On the other hand, they are invited to expand the domain of the system to serve on the company level rather than the project level.

Future Studies

Develop a software package for fully managing construction waste. Waste management software program should include several important aspects. First; methods to catalog waste types, quantities, and costs. Second; a method to quantify, list, and choose disposal alternatives. Third; a method to display optimum waste management techniques. And forth; a method to log, track, and save waste disposal data for future studies. This type of software would provide contractors with a more standardized tool for better waste management.

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