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Advanced technological implementation of construction and demolition waste recycling

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Abstract

In the shade of rural development plans and the constitution of sustainable environmental construction practices, the utilization of construction and demolition waste recycling becomes significant more than ever in order to protect the human built environment from the consecutive impacts. During the past couple of decades, the implementation of recycling techniques had been improved in such a way that, for example, Australia is domestically producing a considerable amount of recycled aggregate and uses such material in the applicable construction areas such as road pavements and concrete products. This paper is inspiring the use of Internet of Things and a novel approach for the consumption of recycled aggregate in concrete, called CO_2 Concrete. Data had been collected from the interviews with the industry senior experts. Extensive literature review and the data resulted from laboratory experiments on the use of recycled aggregate in concrete contributes to the body of the present paper. Also, a set of computer programs had facilitated the deployment of Internet of Things in practice.

Keywords:

Sustainable development; Construction automation; Recycled aggregate

Introduction

In the shade of the global population growth and the increasing demand for housing and civil infrastructure, the need for sustainable urban development becomes significant[1-3]. Construction sector is known as one the most environmentally impactful human activities across the varieties of industries by having a high rate for extraction of raw materials and natural resources. The tendency of environmentally conscience communities and enterprises is not only to recycle a large percentage of construction and demolition waste, but to aim for zero waste, which means ensuring that all products be made to be reused, repaired or recycled back into the marketplace. Zero waste plans have been adopted in developed economies around the world and by the local governments in Australia and New Zealand. Due to this rapid growth of population and the deriving need for a wider infrastructure, the construction industry is booming in the middle-east with 117 mega projects totaling in 1 trillion Tomans worth of value[4]. This indicates the necessity of implementing a comprehensive construction and demolition waste recycling plan in the region before environmental impact of waste generated becomes a dilemma. Recycled aggregate is produced at mobile or fixed centralized crushing operations, where the construction and demolition waste are being delivered. The crushed materials are being screened to produce products of desired size distribution. Recycled aggregate had shown to be an effective alternative to natural aggregate to meet the increasing demand for road construction materials as road base or subbase since it provides sufficient mechanical properties including bearing capacity, resilient modulus and specific gravity [5-7].

Nikmehr et al [8] states that the main reason for construction and demolition waste generation in middle east is due to the lack of skills and experience of construction workers. She had also stated that the lack of awareness for the importance of recycling is another major contributing factor in the middle east. The ranking of main causes of waste generation on construction sites had been reported as followed in the same study:

1. Lack of knowledge of construction workers
2. Prevalence of traditional methods of construction in middle east
3. Lack of knowledge of demolition contractors
4. Wasteful use of materials on-site

5. Inappropriate packaging
6. Low quality of building materials
7. Inappropriate methods for handling on-site
8. Inefficient procurement
9. Inappropriate inventory
10. Inappropriate methods for shipment
11. Frequent demolition

Addressing the first, sixth, eighth, and ninth items this paper proposes the implementation of robotics in construction for the 1st issue, utilization of CO2 Concrete technology for the 6th item, and an organizational structure for the other 8th and 9th issues.

Kartam et al. [9] states that prior to establishing e recycling mechanism there are requirements to be met. In a free-market situation, he suggests that price and quality dictates the acceptance of system or a product. A shortage of both natural aggregate and access to landfills is known as to be an effective method encouraging the use of recycled aggregate. An organized collection and transportation of recycled aggregate ensures the reliable supply of suitable recycled materials. In terms of the mechanism behind the correlation of price, quality, and quantity of recycled aggregate, "*The general theory of employment, interest, and money*" [10] is a proven theory almost for a century now. The shortage of natural aggregate and limited access to the landfill sites can be achieved by government intervention via the means of taxation instruments. The organization structure proposed in this paper, also, provides a systematic approach towards the implementation of construction and demolition waste recycling.

Methodology

Field observations and interviews in Hamedan, Iran, allow the planning to be classified in the best appropriate manner by taking the industry's demand into account. These include interviews with concrete batching plant operators to identify the existing demand for the consumption of recycled

aggregate. Also, the observations from the landfill sites reveal the quantity of supply of construction and demolition waste as the input capacity for the recycling plants.

In order to address the issues encountered with the participation of skilled and educated construction workers, this paper proposes the utilization of automation that decreases the impact of human intervention in construction activities, not to mention the promotion of productivity in the sector. Narrowing down in this aspect, principles of electronics had been taken into practice to develop a wireless device which is able to be scaled in an autonomous IoT (Internet of Things) system.

To ensure the high quality of recycled aggregate being delivered to consumers, laboratory tests had been conducted evaluating the performance of CO_2 Concrete that resulted a promising approach to enhance the variety of mechanical performance of concrete including compressive strength, workability, permeability, durability and shrinkage.

At the end, based on the principles of human resources and construction managements, an organizational chart had been proposed which ensures the effective 10 long-term strategic plans.

Discussion

Before any planning for the utilization of construction and demolition waste recycling in any part of the world there's a need for the evaluation of the systematic infrastructure exist. This includes but not limited to having (a)a proper overlook on the number of trucks available for the deposition of the wastes; (b) an understanding on the specification of crushers type available; (c) an overview on the neighboring of the region; (d) an understanding of the volume of waste generation and the concrete demand of the region. For the case of Hamedan, 20 trucks are available in the region particularly for this reason each with a loading capacity of 9-12 tonnes. Crusher is priced at 1.5 Billion Tomans. The construction and demolition wastes are being stacked up in Robat-e Sheverin close to the airport. The area in which the deposition of landfill occurs add up to a total of 390,000 m^2. Reports from site visits indicate that the average height of the landfill hill top reaches 50m in

altitude. From that, the volume of current construction and demolition waste exists in Hamedan equals 7,500,000 m^3. Figure 1 below shows the condition and geolocation of the landfill area.

Figure 1 Actual footage of region subject to recycling plans. Above: The texture of the buildings in terms of materials used in the regional areas of Hamedan. **Below:** The volume of the landfills in Robate-Sheverin

In order to be able to consume the recycled aggregate produced in the plant, a quantified measure of the concrete demand in the region was required. The interviews with concrete batching plant operators shows that in the first half of the year when the weather is perfectly suitable for concreting, the total concrete production of all 15 concrete batching plants in the region are

supplying 800 m^3 – 1000 m^3 per day. In the second half of the year, during the raining seasons, however, the concrete production capacity falls down to 450 m^3 – 650 m^3 per day.

Figure 2 Aerial view of the region subject to recycling services including the essential dimensions. Above: 20 km radius of service center to the deposition site. **Below:** Area of the landfill stack.

Robotics in construction

The modern construction practice requires the implementation of robotics more than ever due to increasing number of controls on health and safety, insurance costs, and labor wages. Although construction industry suffers from its high labor intensity, the emergence of self-driving cars equipped with artificial intelligence can be a promising approach towards a safer and more

productive practices. Perhaps, Building Information Management (BIM) systems had been up-scaled significantly in the context of software development, still, the integration of BIM with construction machineries remains almost unattended. Smith states that [11] it is anticipated that up to 2.7 million US construction workers compromising almost half of the total workforce in the same sector would be replaced by robots by 2057. If true, sever social consequences arrive such as high unemployment rate, economic depression, increase in homelessness, etc. In fact, the driven factor for such consequences of automation returns to the idea that the business owners welcome labor cost savings for the promise of higher productivity [11-14]. Addressing the issues brought up by Smith, it can be seen as a rationale that robots are essentially being created to ease the human wellbeing. It is debatable that a number of jobs would be diminished caused by the presence of robots in the workplace, however, historically this trend had been in place since the beginning of humanity by the emergence of technological advancements.

From the technical point of view in the implementation of construction and demolition waste recycling facility in Middle-east, the utilization of IoT is planned which facilitates a wireless communication between machineries operating on site. The basic machineries required for recycling plants are crushers, screens, loaders, and trucks. A well-equipped plant powered by IoT needs an operation room where the machines could be controlled from there. Due to the complex mechanical structure of loaders and trucks, this research focuses only on the communication of operation room, crushers, and screens.

An electronic module had been assembled which makes the wireless communications possible. Arduino UNO (Figure 1 is the microprocessor which had been reinforced with the computer program below integrated with Blynk IoT cloud service:

```
#define BLYNK_PRINT DebugSerial
#include <SoftwareSerial.h>
SoftwareSerial DebugSerial(2, 3);
#include <BlynkSimpleStream.h>
char auth[] = "Null";

void setup()
{
  DebugSerial.begin(9600);
  Serial.begin(9600);
  Blynk.begin(Serial, auth);
}

void loop()
{
  Blynk.run();
}
```

The above program is a wireless switch to turn on/off a machine from a screen. The program will be installed down to the Arduino hardware which will be sending digital signals to the machine. The program is also simultaneously installed on the Blynk cloud service that communicates with the control system. In order to be able to run the recycling plant on IoT configuration pictured in figure 1, an Arduino kit will be hooked up with the power switch on the crusher. Once the switch button in the operation room had been turned on, the Blynk signals the Arduino kit on the crusher which turns the machine on for operation. This approach ensures the safety of construction workers and can be seen as a reduction in insurance costs. The vibrating sieves could be also operating in the same manner by the utilization of IoT.

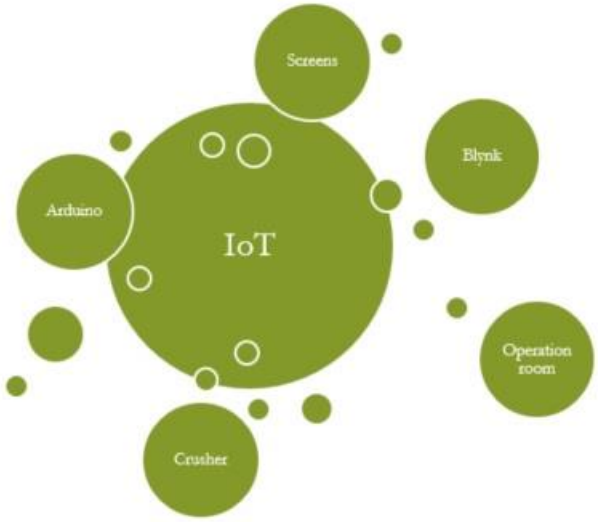

Figure 3 Schematic view of IoT integration

The present electronic module operates in low voltages of about 5V. However, to power up high voltage machineries, a 3 Phase power is suggested to be utilized.

The current cloud based system is functional on Android and iOS devices. Further explorations on the application of an operation software for Windows devices reveals the suitability of using C# codes to develop a well-tailored software. The C# codes could be modified based on the order specification of the project regulator/owner depending on types of the machineries being procured for project delivery. However, for the sake of this research, the following codes had been compiled successfully with the results shown in figure 4. In a nutshell, the program reads the data received from the software windows and based on the conditions in place commands the hardware to operate. In this example a ON/OFF switch would be signaled, although it can be running more complex functions such a controlling a conveyor belt with variable speed.

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace Arduino_Switch
{
    public partial class Form1 : Form
    {
        public Form1()
        {
            InitializeComponent();
            serialPort1.Open();
        }

        private void radioButton1_CheckedChanged(object sender, EventArgs e)
        {
            serialPort1.Write("A");
        }

        private void radioButton2_CheckedChanged(object sender, EventArgs e)
        {
            serialPort1.Write("J");
        }

        private void radioButton3_CheckedChanged(object sender, EventArgs e)
        {
            serialPort1.Write("B");
        }

        private void radioButton4_CheckedChanged(object sender, EventArgs e)
        {
            serialPort1.Write("J");
        }
    }
}
```

Figure 4 Windows software demonstration of the system used in operation room to control the machineries.

CO_2 Concrete

Previous case studies on the supply chain barriers in the use of recycled aggregate [15] reveals that due to the high water absorption of recycled aggregate, concrete batching plants are not eager to use such environmental material in their mix. The new emerging technology called CO_2 Concrete is aimed to enhance the properties of recycled aggregate. The process involves the injection of carbon dioxide in a physical interaction of the gas with recycled aggregate placed in a pressure chamber for a certain duration of time [16]. The porous structure of recycled aggregate, initially, compromises a few performance issues with the concrete made all of the binded to the high water absorption. These issues namely are *faster slump drop*, *higher shrinkage, lower workability, higher permeability, higher corrosion rate, lower compressive strength*. Such issues, in fact, are the reason to the lack of interest amongst concreters to use recycled aggregate in their products. The driving initiative behind the proposal of CO_2 Concrete technology returns, first, to the respectful implementation of sustainability principles, and secondly, the financial benefits gained as a result of lower costs for the supply of concrete ingredients. An initial investigation on the market capacity had indicated the 1/6 as the ratio for the unit price of recycled aggregate over the unit price of natural aggregate. The CO_2 Concrete is advantageous since it resolves the performance issues encountered with the use of recycled aggregate in concrete. The physical interlock of CO_2 gas inside the pores increases the density of aggregate and thus reduces the water absorption causing the relevant issues disappear. Butera et al. [16] extensive studies on the mechanical performance of CO_2 concrete made with recycled aggregate is partially summarized in

the following table 1. The first column indicates the replacement ratio of natural aggregate with recycled aggregate.

Percent replacement (%)	Chamber duration (min)	Chamber pressure (KPa)	Slump drop (mm)	28 days Compressive Strength (MPa)
0	0	0	160	32.14
30	0	0	150	33.46
100	0	0	140	25.7
30	30	75	130	34.28
100	30	75	220	21.66
30	30	150	140	31.51
100	30	150	210	19.46
30	90	75	140	35.19
100	90	75	190	22.22
30	90	150	150	32.36
100	90	150	210	27.37

Table 1 Mechanical performance of CO_2 concrete made with recycled aggregate

Organizational structure

Addressing the issues stated by Nikmehr et al. [8] in regard to lack of effective procurement method and inventory/asset management, the present project in Hamedan follows the organizational structure as pictured in Figure 2. The IT department is committed to ensure the secured and consistent communication of machineries. Using GPS systems, the movement of trucks could be tracked that the data collected and stored on the cloud could be used by accounting and finance department. Sales department will be promoting the recycled aggregate

product targeting concrete batching plants and road pavement contractors. Operations is responsible for the management of trucks and crushers. The Office or Real Estate, on the other side, is ought to arrange the commissioning of land, utilities with respect to the use of renewable energy. Security must be present at the plant gateway to ensure the secure access to the facilities inside the plant. Also, as the project is set to have the participation of international experts a comprehensive secure banking system is required allowing the transactions between different regions.

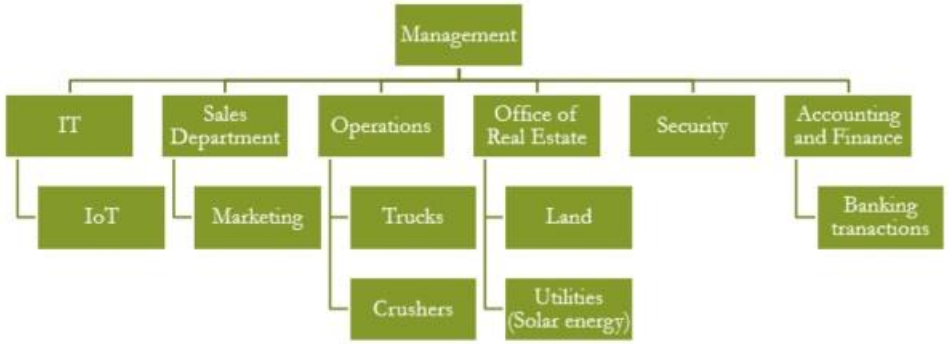

Figure 5 Organizational structure of the construction and demolition waste recycling plant in Hamedan

Regarding the financial viability of the entity, it has been stated during the interviews that since the cost of mining explosions are rising in the middle-east, the use of recycled aggregate is a perfect environmental alternative in that regards. Critically thinking, if the consumption of recycled aggregate reaches to the point where it passes the use of natural aggregate, the demand for demolition would increases ultimately which is not a sustainable approach as the service of life the buildings decrease.

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Conclusion

A set of issues exist in the implementation of construction and demolition waste recycling including but not limited to: lack of skilled workers in the sector; inefficient procurement method; and inefficient inventory. This case study presented the considerations and the methods employed in Hamedan, Iran upon implementing recycling plant operations in order to address the main three issues. Utilization of robotics, CO_2 Concrete technology, and an appropriate organizational structure are discussed and agreed to be effective methods. Utilization of robotics in the designated recycling plant is based on the IoT analogy where the electronic devices are able to communicate via wireless connection. CO_2 Concrete technology had been promoted which prior to the implementation in the full commercial scale requires a bigger carbonation chamber. The performance of CO_2 Concrete in the laboratory scale, however, shows a promising results. At the end, the organizational chart presented is planned to be implemented in Hamedan's recycling plant. The financial budgeting of the departments proposed are still in negotiation.

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List of the figures

List of the tables