Ratnasabapathy, S., Perera, S. and Alashwal, A., 2019. A review of smart technology usage in construction and demolition waste management. In: Sandanayake, Y.G., Gunatilake, S. and Waidyasekara, A. (eds). *Proceedings of the 8th World Construction Symposium*, Colombo, Sri Lanka, 8-10 November 2019, pp. 45 -55. DOI: doi.org/10.31705/WCS.2019.5. Available at: https://2019.ciobwcs.com/papers

A REVIEW OF SMART TECHNOLOGY USAGE IN CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT

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ABSTRACT

The management of construction and demolition (C&D) waste, a major part of solid waste, is increasingly become a critical challenge in the quest of social, environmental, and economic sustainability. Innovative and smart technologies are emerging to provide inevitable benefits because of their capacity to enable digitisation, automation, and integration of Solid Waste Management (SWM) processes. Nevertheless, the application of such technologies in Construction and Demolition Waste Management (CDWM) has not gained the appropriate attention. This study aims to draw insights into the current and potential use of smart technologies in CDWM. A literature review-based approach surveyed both academic and applied publications to analyse the current and potential use of smart technologies in both SWM and CDWM. Altogether, 75 peer-reviewed articles and technical white papers were analysed. It was found that the usage of smart technologies is much advanced in SWM and the adoption is still at the prototype stage in CDWM. The results emphasise that the integration of smart technologies into multiple processes of CDWM would overcome many issues related to waste minimisation and management including waste estimation, waste reporting, and data management and waste diversion. The framework developed in this study contributes to the understanding of the potential role of each category of technologies in improving the waste management processes in the C&D sector. This review is useful to waste management practitioners, regulatory bodies and the government to understand the benefits of emerging technologies and to the development of effective strategies and future training programmes.

Keywords: *Blockchain; Construction and Demolition Waste Management; Information and Communication Technologies (ICTs); Smart Technologies; Solid Waste Management.*

1. INTRODUCTION

Solid waste generation is one of the most significant by-products of urban lifestyle (Hannan *et al*., 2015). Global municipal solid waste contributes to 2.01 billion metric tons/year and it is increasing rapidly due to the continuous growth in urbanisation and associated industrialisation. 3.40 billion metric tons/year is expected to be generated by 2050 (Kaza *et al*., 2018). Construction and Demolition (C&D) waste is one of the major parts of solid waste. C&D waste is a combination of different materials, including inert waste, non-inert non-hazardous waste and hazardous waste, generated from new construction, renovation and demolition activities and natural disasters (Chen and Lu,

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2017, Faleschini *et al*., 2017). The rapid growth of population associated urbanization and economic development call for increased demand for C&D activities which will significantly impulse the waste generation by the construction industry to rise across the globe. Globally, the construction industry is considered as the major waste generator which has led the industry to be the key contributor to environmental degradation and pollution (de Magalhães *et al*., 2017, Ding *et al*., 2018). The global construction sector contributes one-third of solid waste which is around 30-40 % of the total solid waste generation (Ajayi and Oyedele, 2017). This figure varies between countries subject to the factors related to the profile of the construction industry and the economy, legislation and cultural characteristics of the country (Duan *et al*., 2015). Failure to adopt effective management strategies will lead to detrimental environmental, socio-health, political and economic impact on both current and future generations.

Solid Waste Management (SWM) is a multidisciplinary activity, involving several processes related to planning, collection, logistics, monitoring, control, recycling, and disposal. As these processes involve sustainability in environmental, economic and social terms, they may create problems and hence need multi-criteria decisions at every stage of its life cycle (Melare *et al*., 2017). Managing solid waste would, therefore, be very costly (Lamichhane, 2017). While, Construction and Demolition Waste Management (CDWM) is considered as an inter-disciplinary area as it involves social, environmental, economic, institutional and political aspects while it faces challenges from the perspective of engineering, technology, management and policies and legislation (Arshad *et al*., 2017, Jin *et al*., 2019). Nonetheless, recent studies have focused on finding solutions with the use of advanced Information and Communication Technologies (ICTs) to face those challenges in waste management. Rapid improvement in the capacity of innovative technologies enables digitisation, automation, and integration of the construction process at all stages (Oesterreich and Teuteberg, 2016).

Several past studies have recognised the potential use of various ICTs brought by the revolution of industry 4.0 in improving waste management practices (Jin *et al*., 2019). These emerging ICTs are being adopted in different solid waste management processes to provide widespread solutions to achieve the goals of sustainability (Melare *et al*., 2017). However, limited attention is paid to the application of such technologies in the CDWM stream as compared to the SWM stream. This bounds understanding of their potential application, where the construction sector is ignorant hence is not yet ready to transmit and extract their real value in CDWM. In this context, the objectives of this study are twofold. The first is to evaluate the extent of current adoption and potential use of smart technologies and ICTs in SWM and the second is to outline the potential applications of such technologies in multiple processes of CDWM.

2. LITERATURE REVIEW

During the past few decades, several ICTs and other emerging smart technologies have been employed to improve the efficacy of SWM practices. Melare *et al*. (2017) observed a good distribution of the use of wide range of emerging smart and digital technologies such as Geo Technologies (e.g. GIS - Geographic Information System, GPS-Global Positioning System) Physical Computing and IoT (Internet of Things), RFID (Radio Frequency Identification), Cloud Computing, IP (Image Processing), CAD (Computer-Aided Design) and Databases in SWM during the past decade. The usage of these technologies varies depending on the application in different processes involved in SWM from waste generation to final destination. Melare *et al*. (2017) perceived that integration of ICTs in multiple processes of SWM could aid to achieve social, environmental and economic sustainability objectives while serving the community in a fast and efficient way with less impact to the environment (less pollution or greenhouse gas emissions) and at a lower cost. ICTs improve effective practices in terms of planning and management and help managers to make informed decisions on environmentally related issues (Melare *et al*., 2017).

In the context of the C&D sector, integration of embryonic digital technologies such as BIM (Building Information Modelling), Big data, GIS, GPS and RFID technologies in CDWM has been studied in some previous studies. However, the application of these technologies has not fully implemented in the sector (Jin *et al*., 2019). The construction industry is recognized as the second least industry in adopting the technologies and systems across the construction value chain (Agarwal *et al*., 2018). Some researchers have recognized that the lack of the use of advanced technologies in CDWM hinders the development of effective management practices in the construction sector. The issues identified with the lack of usage of advanced technologies in WM are lack of historical waste data, inconsistencies in waste data reporting, inaccuracy in waste estimation and lack of established platforms for promoting the circularity of recovered waste materials through reusing, repairing and recycling. In contrast, Melare *et al*. (2017) perceived that lack of historical data on waste collection management hinders the accurate planning and forecasting and hence directs to inaccurate decision making. Contributions of ICTs become substantial in handling the issues associated with increasing solid waste, which in turn has urged the need for the automation of waste data acquisition, identification, communication, storage, and analysis (Hannan *et al*., 2015).

The necessity for uniform historical waste data in implementing a successful WM system has been further emphasized by some researchers in the C&D waste stream. For instance, Zaman and Swapan (2016) highlighted the need for a uniform data capture platform to obtain more reliable and compatible data on waste estimation which could provide appropriate developmental directions for benchmarking of WM in the future. Wu *et al*. (2014) suggested that computer-aided technologies can be useful to record the C&D waste information for benchmarking and enhanced WM.

3. METHODOLOGY

A literature review-based approach surveyed both academic and applied publications to systematically review the adoption and potential use of ICTs and smart technologies in both SWM and CDWM. In the first stage, to limit the scope of the research, a keyword search in Scopus and Google Scholar were conducted. Several keywords were applied to find related publications. For example, for Scopus research engine, the following keywords were used: TITLE-ABS-KEY (ICTs) AND (Solid Waste AND Waste Management) AND (LIMIT-TO (DOC-TYPE, "Article")) AND LANGUAGE (English); TITLE-ABS-KEY (Construction AND Demolition Waste) AND (Waste Management AND ICTs) AND (LIMIT-TO (DOC-TYPE, "Article")) AND LANGUAGE (English). Besides, publicly available applied publications such as technical white papers, and other commercial web pages were reviewed to identify the use of ICTs and other smart technologies in commercial based SWM systems (online platforms) to which no peer-reviewed articles were found. Altogether 75 peer-reviewed articles, white papers, and commercial applications were reviewed to gain a broad understanding and evaluate the current and potential use of the ICTs and smart technologies in both SWM and CDWM streams. To understand and analyse the potential use of such technologies in CDWM, the current adoption of smart technologies in SWM was reviewed. Based on the existing adoption of smart technologies in SWM and CDWM, potential applications of such technologies were mapped out for CDWM which included the potential integration of ICTs and other smart technologies into the different processes of CDWM.

4. RESULTS AND DISCUSSION

In line with the review, a wide range of smart technologies have been adopted and proposed in SWM and the development of ICTs based WM systems are comparatively in the C&D sector. Table 1 presents a summary of the current status of the application of various types of spatial, identification, data communication and acquisition technologies in several processes of SWM and CDWM. In both streams, GIS has been the most widely used ICTs in combination with other technologies such as RFID, GPS among others.

Table 1: Different types of smart technologies applicable to SWM and CDWM

WM Process	Types of ICTs adopted		References
	SWM	**CDWM**	
Management of collection, route, and transportation	GPS, Imaging	GIS, GPS	Hannan *et al*. (2015); Li *et al*. (2005); Melare *et al*. (2017)
Site selection; planning; forecasting; management; estimation; optimisation	GIS, Remote Sensing, Imaging	Big data, BIM	Jin *et al*. (2019); Hannan *et al*. (2015); Melare *et al*. (2017)
Management and monitoring of containers	Sensors, Wireless network, Internet, RFID, GIS, GSM, GPRS		Melare *et al*. (2017)
Public administration and sustainable development	GIS	RFID, BIM	Melare *et al*. (2017); Iacovidou *et al*. (2018)
Determination of waste-disposal sites/illegal waste dumping sites	GIS, Remote Sensing, Image Processing	GIS	Melare *et al*. (2017); Hannan *et al*. (2015); Seror and Portnov (2018)
Waste Sorting	Robotics, RFID, Sensors, Imaging		Hannan *et al*. (2015)
Watch Matching	Artificial Intelligence		EME (2018)
Recycling of solid residues and management of electronic waste	GIS, RFID, Image Processing, IoT, Barcode		Hannan *et al*. (2015); Melare *et al*. (2017);
Waste material exchange	Resource Passport, Artificial Intelligence, Blockchain	PHP and Java Applet	EME (2018); Pun *et al*. (2007)

WM Process	**Types of ICTs adopted**		**References**
	SWM	**CDWM**	
Material information sharing	Blockchain		Licht *et al*. (2018)
Weight-based waste disposal payment	Blockchain, IoT		Lamichhane (2017)
Intelligent recycling; waste disposal; reduce landfill space; risk management	Barcode, RFID		Hannan *et al*. (2015)
Short and long-range communication	ZigBee, WI-FI, Bluetooth, VHFR, GSM/GPRS		Hannan *et al*. (2015)
Tracking and scheduling construction waste; stimulating reuse of construction components		RFID and Rule-based Reasoning	Zhang and Atkins (2015); Iacovidou *et al*. (2018)
Environmental impact assessment	Remote Sensing	GIS	Chen *et al*. (2018); Hannan *et al*. (2015);
Design review, 3D coordination, quantity take-off, and phase planning for managing waste		BIM	Kim *et al*. (2017); Chen *et al*. (2018); Won and Cheng (2017); Porwal and Hewage (2012); Cheng and Ma (2013)
Decision support in managing the waste generated from civil construction and demolition		GIS, Geo-referencing, Data input modules, and online analytical modules, Databases	Banias *et al*. (2011)
Demolition waste generation and performance comparison		GIS, Big data	Lu *et al*. (2015); Chen and Lu (2017); Chen *et al*. (2018)
Waste Estimating		Data input modules and online analytical modules	Paz and Lafayette (2016); Li and Zhang (2013); Pun *et al*. (2007)

GSM - Global System for Mobile Communication, GPRS - General Packet Radio Service, VHFR - Very High-Frequency Radio, EME -Excess Material Exchange

According to Akinade *et al*. (2018), existing CDWM tools such as waste management plan templates and guides, waste data collection and auditing tools, waste quantification tools, and environmental impact assessment tools have several issues. The identified issues associated with the above tools include insufficient and inconsistent data quality and waste reporting for waste management, inability to integrate with the design process and lack of interoperability with other software (Akinade *et al*., 2018). These problems have opened up the doors of opportunities to find solutions through the adoption of emerging spatial, identification, data communication, and acquisition technologies. Jin *et al*. (2019), recognised that more integrated approaches that adopt advanced technologies are useful to improve the C&D waste diversion and management practices. For example, Jin *et al*. (2019), have acknowledged that Big data and BIM are best-suited technologies by their inherent nature in facilitating to store and process a large amount of data that can be integrated to aid in the C&D waste quantification and waste control in overall project management. Therefore, it could be useful to review and understand the potential functions of smart technologies in the C&D sector. As such, the following sections briefly discuss the proposed applications and likely usage of some advanced technologies in different CDWM processes.

4.1 BIG DATA

The implementation of Big data in projects enables the collection of large amounts of exact data (from all data-generating devices or agents like BIM models or people), processes them at unprecedented speed and makes them accessible to all project participants thus saving substantial time and effort (McMalcolm, 2015). The issue of insufficient data quality has been addressed with the use of Big data in a study by Lu *et al*. (2015) in which Big data has been applied to compare the WM performance between the public and private sectors. Furthermore, Chen and Lu (2017) have used Big data analytics to examine the inter-relationships among waste generation and multiple factors such as demolition cost, demolition duration, and public-private nature of a building project by connecting several databases.

4.2 GIS AND GPS

GIS, alternatively, offers great benefits in data acquisition, storage, correlation, processing and analysis (Chen *et al*., 2018). In addition to the function which facilitates estimating the generated demolition waste, GIS can be used as an environmental impact assessment tool. For example, Mastrucci *et al*. (2017) applied GIS to build a bottom-up material stock model which integrates with the Life Cycle Assessment (LCA) to assess the environmental impact at the urban scale and integrates with GPS technology to provide real-time location of the material and its arrival time to the construction site (Li *et al*., 2005). In recent times, Seror and Portnov (2018) employed GIS to identify the dumping sites where C&D waste illegally dumped with potential risk.

4.3 RFID

RFID tags are another data collection technology that can be employed to track and trace construction materials and components, equipment, and tools as well as the construction workforce. RFID can stimulate the reuse of construction components and reduce their wastage (Iacovidou *et al*., 2018, Chen *et al*., 2018). According to Iacovidou *et al*. (2018), integrating RFID with BIM can help to develop sustainable resource management. While Zhang and Atkins (2015) proposed a framework that combines Rule-based Reasoning technology and RFID technology to track, schedule and intelligently handle incidents of waste movement.

4.4 BIM

BIM emerged from two technologies: space technology and data communication technology. It is commonly used in Architecture, Engineering and Construction (AEC) industries and can be effectively integrated with identification and data acquisition technologies such as GIS, RFID, GPS (Chen *et al*. 2018) and Big data (Bilal *et al*., 2015). The integration of these technologies with BIM offers many advantages in terms of facilitating location-based management, tracking of building materials and collecting remote data (Chen *et al*., 2018). BIM has been used in the building design stage to estimate the amount of demolition waste (Kim *et al*., 2017). According to Won and Cheng (2017), BIM offers great potential capacities in design review, 3D coordination, quantity take-off and phase planning for managing waste more efficiently throughout the project life cycle.

Cheng and Ma (2013) developed a BIM-based system for demolition and renovation waste estimation and planning. This developed model poses the capability to deal with the estimates of the detailed volume information of each element category and material type, total inert, and non-inert demolition and renovation waste volumes, demolition and renovation waste-disposal charging fees and the total number of pick-up trucks for demolition and renovation waste. Porwal and Hewage (2012) proposed a BIM-based analysis to minimise the waste rate of the structural reinforcement applicable for a two-storey reinforced concrete structure. Therefore, BIM-based systems/models and integration of other digital technologies with BIM can provide wide solutions to minimise waste generation and optimise materials use.

4.5 BLOCKCHAIN TECHNOLOGY

Blockchain is a decentralised transaction and data management technology (Wang *et al*., 2017). Blockchain technology creates a decentralised environment in which storage, operation, and control of the transactions do not rely on trusted third parties (Yli-Huumo *et al*., 2016) and hence, Blockchain can significantly reduce the transaction overhead (Ølnes *et al*., 2017). Though BIM and Big data can be used as data communication technologies, Blockchain is the only technology where decentralised databases of records allow participants in the network to directly interact via a peer-to-peer network for information sharing and transaction of payments (Turk and Klinc, 2017).

According to Wang *et al*. (2017), Blockchain can improve the records of onsite construction information such as construction logbooks, works performed and quantities of materials used with reliability and trustworthiness of the information recorded. Further, the distributed nature of blockchain and its distinct features including a high level of trust, transparency, immutability, and traceability could help to address the issues related to the quality of historical waste data, reporting, and data management. However, the application of Blockchain in the construction industry, in general, has been limited and lack of studies exploring the role of Blockchain found in the WM stream (Turk and Klinc, 2017). Blockchain can fundamentally change the traditional way of collecting, storing, replicating and tracing waste data at each movement of waste thus enabling the auditing of waste management performance while fulfilling waste-related compliances. As a transaction technology, it can facilitate the trading of C&D waste with improved operational efficiency, trust, and transparency by enabling the waste generators and waste consumers to connect without a trusted intermediary. The authors' ongoing research is aiming to develop a platform using Blockchain technology for C&D waste data management (to capture, report and trace) and trading of waste materials.

Having reviewed the potential features of identified technologies, Figure 1 provides a framework that outlines the possible applications of smart technologies, categorised under major four groups: Spatial, Identification, Data communication & Acquisition, and Data management & Transaction Technology. The framework contributes to the understanding of the potential capacities of each category of technologies in improving the process of WM in the construction sector.

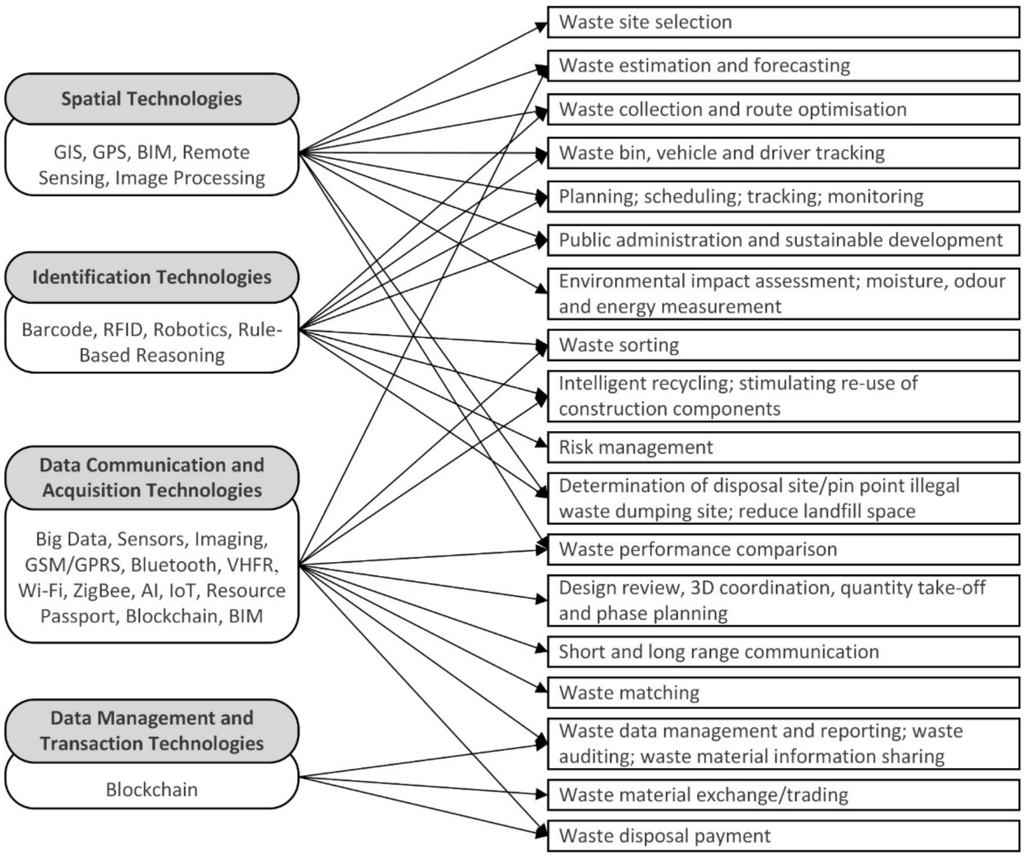

Figure 1: A framework for the potential use of different types of smart technologies in CDWM

This framework is useful to waste management practitioners/businesses, regulatory bodies and the government to understand the benefits of emerging technologies and to the development of effective strategies and future training programmes.

5. CONCLUSIONS

The integration of ICTs in various processes of WM has a positive impact on SWM and substantially contributes to sustainable development in emerging economies with economic benefits. This paper reviewed the current status and potential applications of innovative smart technologies in SWM and CDWM. A good distribution of a wide range of smart technologies and ICTs have been adopted in several processes of SWM while the adoption is still at the prototype stage with limitations in CDWM. However, it has been found that there is a lack of research on the integration of smart technologies to aid the waste data management, waste quantification, auditing and waste diversion in the

C&D sector. The framework which outlined the potential application of technologies contributes to the understanding of how smart technologies could play effective roles in improving waste management processes in the construction sector. More integrated approaches that adopt advanced technologies such as GIS, GPS, Big Data, BIM, RFID, IoT, and Blockchain could help to help to minimise the waste, reduce environmental impact, conserve resources and create new circular business models and global marketing opportunities in the C&D sector. This study also explored the features of Blockchain, as a viable data management and transaction technology which can facilitate waste data management and trading of waste with improved operational efficiency, trust, and transparency while enabling the waste generators and waste consumers to connect without a trusted intermediary. The authors' ongoing research is aiming to develop a C&D waste trading platform using Blockchain technology.

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