Journal of Building Engineering 6 (2016) 144–156

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Big data architecture for construction waste analytics (CWA): A conceptual framework

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ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form
1 March 2016
Accepted 4 March 2016
Available online 8 March 2016

Keywords:
Construction waste
Big data analytics
Building information modelling (BIM)
Design optimisation
Construction waste analytics
Waste prediction and minimisation

ABSTRACT

In recent times, construction industry is enduring pressure to take drastic steps to minimise waste. Waste intelligence advocates retrospective measures to manage waste after it is produced. Existing waste intelligence based waste management software are fundamentally limited and cannot facilitate stakeholders in controlling wasteful activities. Paradoxically, despite a great amount of effort, the waste being produced by the construction industry is escalating. This undesirable situation motivates a radical change from waste intelligence to waste analytics (in which waste is propose to be tackle proactively right at design through sophisticated big data technologies). This paper highlight that waste minimisation at design (a.k.a. designing-out waste) is data-driven and computationally intensive challenge.

The aim of this paper is to propose a Big Data architecture for construction waste analytics. To this end, existing literature on big data technologies is reviewed to identify the critical components of the proposed Big Data based waste analytics architecture. At the crux, graph-based components are used: in particular, a graph database (Neo4J) is adopted to store highly voluminous and diverse datasets. To complement, Spark, a highly resilient graph processing system, is employed. Provision for extensions through Building Information Modelling (BIM) are also considered for synergy and greater adoption. This symbiotic integration of technologies enables a vibrant environment for design exploration and optimisation to tackle construction waste.

The main contribution of this paper is that it presents, to the best of our knowledge, the first Big Data based architecture for construction waste analytics. The architecture is validated for exploratory analytics of 200,000 waste disposal records from 900 completed projects. It is revealed that existing waste management software classify the bulk of construction waste as mixed waste, which exposes poor waste data management. The findings of this paper will be of interest, more generally to researchers, who are seeking to develop big data based simulation tools in similar non-trivial applications.

1. Introduction

1.1. Construction waste—an overview

Rapid urbanisation and the appetite to build national infrastructure has escalated the construction activities globally. Notwithstanding the benefits, the adverse impact of construction activities on environment has serious implications worldwide [1]. Construction industry is noted for consuming bulk of rare natural resources and producing hefty amounts of construction and demolition (C&D) waste [2]. The construction industry is the UK's largest consumer of natural resources, using over 400 million tonnes of material per annum and is responsible for producing 120 million tonnes of construction, demolition and excavation waste yearly–around more than one third of all waste arising in the UK [3]. With the rising cost of construction projects and the growing environmental concerns, the construction industry is under immense pressure from government and environmental agencies to minimise construction waste and adopt more sustainable practices.

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http://dx.doi.org/10.1016/j.jobe.2016.03.002
2352-7102/

1.2. Waste intelligence—current state of waste management

Current waste management systems are based on what is called '*Waste Intelligence*' which is more about suggesting remedial measures to manage construction waste after it happens [4]. Waste intelligence based systems are mainly concerned about reports, dashboards, and queries on small amounts of current and past waste data [5]. These systems can efficiently answer close-ended questions such as project/site wise waste generated, progress towards defined waste targets, and understanding how a particular design strategy generates waste [6]. To answer such questions, these systems typically aggregate historical waste data or group it in some way (e.g. by RIBA stages, by material families, and so on). The end users are provided hindsight with limited insight on waste management activities.

1.3. Waste analytics—next generation of waste management

In contrast to the static Waste Intelligence approaches, the methodology of '*Waste Analytics*' proposes to deploy data-driven decision making at the design stage to significantly cut down on construction waste [3,7]. Evidence from literature [8–12] has shown that utilising waste minimising at the design stage is most promising; this is leading to the development of a consensus that waste minimisation through design (a.k.a. designing out waste) is the future of mainstream research in construction waste management [13]. Waste Analytics is mainly concerned with holistically designing out construction waste.

Specifically, Waste Analytics is the process of proactively analysing disaggregated and huge construction datasets to uncover latent trends or non-obvious correlations pertaining to design, procurement, materials, and supply-chain within the construction delivery process, which lead to construction waste during the actual construction stage. Waste Analytics, by comparison, investigates waste-related data in a more forward-looking and exploratory way [12]. Through analysing historical data, it enables the development of robust predictive models for construction waste estimation. Waste estimation models proactively inform about the amounts of waste arising from building design. Thus, designers optimise design accordingly for waste minimisation from myriad perspectives by asking more open-ended questions [5]. Rather than just aggregating data, it employs advanced analytical approaches (such as time series analysis) to forecast waste and prescribe best course of actions to pre-emptively minimise construction waste. It provides insight on current waste trend of the design and foresight to optimise design for designing out construction waste.

1.4. Big data for waste analytics

Big Data is the emerging capability to store and analyse large volumes of data scalably and reliably using a cluster of commodity servers [14,15]. There is tremendous interest in utilising the information in Big Data for analytics, not only to understand latent trends (exploratory analytics and descriptive analytics), but also for predictive & prescriptive analytics to forecast and shape future events [16]. Mostly, the advanced analytical techniques for Waste Analytics are supported by the Big Data technologies. Therefore, Big Data driven Waste Analytics is the next emerging trend that offers unprecedented opportunities to minimise construction waste through design. This synergistically integration of technologies (Big Data, Designing out Waste, and BIM) is a real game changer and promises the development of a resilient BIM based construction waste simulation tool to facilitate the designers in making right decisions to avoid construction waste in future construction projects.

Waste Analytics depends increasingly on high-performance computation and large-scale data storage. It requires large number of diverse datasets pertaining to building design, material properties, and construction domain knowledge for successfully carrying out the underpinning analytical tasks. Mostly, these datasets are highly complex, voluminous, heterogeneous, and incomplete [10,17,18]. Storing these datasets using traditional technologies and subjecting the data to real-time processing for sophisticated analytics is a very challenging proposition. This motivates the use of Big Data technologies to manage and analyse this data of unprecedented size.

1.5. Justification for research and contribution of this paper

There exists an obvious technological gap in existing literature on designing out construction waste. In particular, there is very little work on using Big Data techniques for construction waste minimisation. Developing a robust construction waste simulation tool, in particular, is the ultimate objective of this ongoing R&D effort. The intended tool will equip designers with well-informed and data-driven insights to optimise design for designing out waste through their BIM authoring software (such as Revit, MicroStation, etc.). To this end, this study proposes a Big Data architecture for construction waste analytics—an essential first step towards the development of a non-trivial construction waste simulation tool. The components, and relevant technologies, of the proposed architecture are conceived to store and analyse the emerging construction datasets of unprecedented size for real-time design exploration and optimisation. Since the architecture is supposed to support lifecycle stages of Waste Analytics, the paper contributes by detailing the Waste Analytics lifecycle as well. The term 'Architecture' in this text, is not used as architectural profession used in the construction industry, rather it is used as computer architecture that refers to the high-level structures of a software system.

The remainder of this paper is organised as follows: In the next section, the research methodology, focus of the paper and research objectives are discussed. Section 3 expounds the literature review where the emerging concept of designing out construction waste and the complexities surrounding its true implementation are described: this paper also discuss the strengths and weaknesses of competing Big Data platforms. Section 4 deliberates the waste analytics lifecycle and its relevance to designing out construction waste. Section 5 explains the proposed Big Data architecture for construction waste analytics. In Section 6, preliminary results are presented, and finally in Section 7, conclusions are provided along with a discussion for future work.

2. Methodology and focus of the paper

In this section, the twofold methodology adopted to carry out this research is discussed. An exhaustive literature review is initially conducted to propose the artefacts of intended waste analytics architecture and waste analytics lifecycle, which are later validated by employing them to perform the preliminary analysis over construction waste related data.

In order to propose a holistic Big Data architecture and waste analytics lifecycle, a thorough review of the extant literature on designing out construction waste, Big Data, and BIM has been carried out. In this regard, online databases of journals such as Journal of Big Data, Big Data Research, VLDB Journal, Automation in Construction, American Society of Civil Engineering (ASCE), Waste Management, and Resources, Conversation and Recycling are searched for research articles between 2000 and 2015. Recent reviews of research and books on Big Data Analytics are also