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Ziyue Chen *, Lizhen Huang

Department of Manufacturing and Civil Engineering, NTNU, Norwegian University of Science and Technology, 2815 Gjøvik, Norway
Department of Manufacturing and Civil Engineering, NTNU, Norwegian University of Science and Technology, 2815 Gjøvik, Norway

ziyue.chen@ntnu.no

Abstract. Global warming attracts increasing public attention. However, in the past few decades, the contribution of construction to greenhouse gas emissions is around 40% of total emissions. The promotion of construction waste remanufacturing faces challenges. The application of digital twins in the remanufacturing of construction waste contributes to the tracking, recycling and management of construction waste. This article reviews the current research on construction waste remanufacturing and the application of Digital Twin in construction and remanufacturing, aiming at finding the current challenge of construction waste remanufacturing and the opportunity of Digital Twin to solve it. Then, the Digital Twin platform concept for construction waste remanufacturing is provided as a solution for the current challenges. Theoretically, this paper points out the shortcomings of the current research in construction waste remanufacturing based on literature review. Meanwhile, this article proposes the application of Digital Twin in construction waste remanufacturing, which expands the research scope of circular economy in construction. In fact, this research has driven the Digital Twin application in more industries. Besides, this research proposes a concept of potential solutions for the current challenges of construction waste in circular economy.

1. Introduction

Since the issue of global warming has drawn increasing public attention, in 1960s, the concept of circular economy was proposed [1]. However, in the past few decades, the contribution of the global construction to greenhouse gas emissions is approximately 40% of the total emissions [2]. The challenge of construction waste remanufacturing is the localization and corporate information communication of the industry chain.

The application of Digital Twin is expected to make a breakthrough by building connections among individuals in the industry chain. Digital Twin, academically, are digital copies of potential and actual physical assets (physical twins), processes, people, places, systems and equipment that can be used for various purposes [3]. It is applied for urban data capture and modelling in smart cities [4] and equipment detection and patient health record tracking and analysis in the medical industry [5]. In manufacturing industry, Digital Twin combines the Internet of Things, artificial intelligence, machine learning, and software analysis with spatial network diagrams [6] to create real-time digital simulation models. These models are updated and changed with changes in the physical copy. The Digital Twin mentioned in this paper are data-driven models and their applications in the remanufacturing industry. Digital Twin that is almost identical to the entity of the regional recycling industry could be

established, linking the physical and the digital remanufacturing industry of construction waste, and identifying dynamic changes in the industry through the analysis of the unified data [7].

Aiming at establishing the concept of Digital Twin platform for the connection among individuals during construction waste remanufacturing, this article first reviews the current literature on construction waste remanufacturing, aiming at analysing the challenges of current construction waste remanufacturing. Then, the main applications of Digital Twin in the construction industry and remanufacturing industry are summarized and the opportunity and challenges of Digital Twin in solving the construction waste remanufacturing problem are analysed. Finally, based on the basic framework of Digital Twin, this paper proposes the Digital Twin platform concept for construction waste remanufacturing process, trying to provide solutions for the problems existing in the remanufacturing of the construction waste.

The main contributions of this paper are mainly reflected in two aspects. Theoretically, based on the literature review of Digital Twin, construction and remanufacturing, this paper points out the shortcomings of the current research in the application and promotion of remanufacturing for construction waste. Meanwhile, this paper proposes the application of Digital Twin in construction waste remanufacturing, expanding the scope of research in remanufacturing in construction industry. Practically, this study drives Digital Twin in more industries and in a wider range of applications. Besides, this study proposes a concept for potential solutions to the current problems of construction waste in circular economy.

The following parts of this paper are as follows. The second section is the statement of methodology applied in this paper. The Third section is the current research on remanufacturing, Digital Twin and construction industry. The forth section is the discussion on the application of Digital Twin on the manufacturing for construction waste. The last section is concluding remarks and further research direction.

2. Methodology

According to the standard of systematic literature review, two research questions are defined to guide all subsequent steps, 1) What the main challenge of remanufacturing of construction waste currently is, and 2) Whether Digital Twin has a positive impact on the solution of challenge in the construction waste remanufacturing chain.

A search of published literature must be carefully planned to ensure that all important studies are covered. Therefore, we chose to conduct a systematic literature review from the perspectives of A) Digital Twin and Construction, B) Digital Twin and remanufacturing and C) Construction and remanufacturing, to collect the most extensive sample of papers in a reproducible and transparent way as is in **Figure.1**. Besides, D) The combination of Digital Twin, construction and remanufacturing is the focus of this article, while there is little relevant literature. Therefore, we will discuss it in the discussion section.

We selected 2 databases to search: Science Citation Index Expanded (SCI-EXPANDED) and Conference Proceedings Citation Index- Science (CPCI-S). Then, the full papers are searched based on the citation information. The SCI-EXPANDED and CPCI-S database contains journals and papers related to Digital Twin and its applications, as well as journals and papers related to remanufacturing and construction. In addition, through the "snowball" method [8], related papers in the field but were not captured by the research strategy are checked as well. Until March 2020, there is no time limit for the searches.

The following keywords are set based on the construction remanufacturing and Digital Twin, which are divided into three groups, and searched in the database mentioned above.

Group1: Digital Twin; Digitalization; Digital Twinning

Group2: Construction

Group3: Remanufacturing; Remanufacture

For research question 1, the keywords searched are the keywords in Group 2 and Group 3. 56 relevant research papers are selected for analysis.

For research question 2: The keywords are different combination of keywords in Group 2 and Group 1, and keywords in Group 2 and Group 3, and 46 papers are selected in total. Some Digital Twin and

manufacturing literature are added by snowballing, since there are few researches on Digital Twin based remanufacturing and construction, but more research on Digital Twin based manufacturing. Remanufacturing is like manufacturing on the aspect of Digital Twin application, so Digital Twin and manufacturing related literatures are collected to look for the potential of Digital Twin in construction remanufacturing.

All papers that meet the initial search criteria are moved to the reference management software. In the software, each paper has undergone three rounds of selection: first selection is title analysis, then abstract analysis, and finally full text analysis. The remaining papers are listed as data.

Figure 1. Framework.   **Figure 2.** Digital Twin for construction waste remanufacturing.
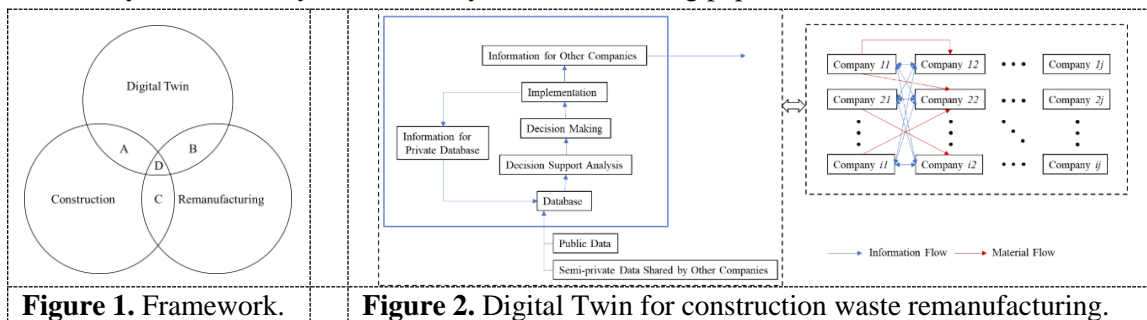
3. Results of Digital Twin in construction waste remanufacturing

3.1. Remanufacturing for construction waste

Based on the analysis of the literature related to construction waste remanufacturing, the following conclusions.

Proposition 1 The lack of data and the difficulty in exchanging information between subjects in the remanufacturing chain are the main challenges in the current remanufacturing of construction waste.

Among the literatures, there are 6 papers that analyse the factors might influence the remanufacturing of construction waste, such as data [9], technical [10], etc. The typical methods of the studies are qualitative analysis [11] and exploratory factor analysis [12] and the data is considered the main challenge of current construction waste remanufacturing [9].

However, there are few current studies on solving this data challenge [13]. Most of the current researches are based on case analysis on one or several types of construction waste. For example, Hertwich [14] proposed a life cycle analysis for the recovery of steel, aluminium and copper from construction waste. Cobut et al. [15] proposed a solution for the remanufacturing of hardwood waste in buildings based on case studies and evaluation models. However, these studies only solve the problem of remanufacturing from a technical perspective. In practice, multiple types of construction waste are often generated at the same time, and these research results are not practical enough to systematically solve the problem of stacking, transportation and remanufacturing of construction waste. It is worth noting that Doll and Tucker [16] quantify the amount of waste suitable for remanufacturing based on data mining and natural language algorithms. However, this study technically analyzed the amount of waste, but the research is not focused on data sharing mechanism. Therefore, how to realize the dynamic data collection and sharing on the construction waste remanufacturing industry chain is pivotal to promote the construction waste remanufacturing.

3.2. The application of Digital Twin in construction and remanufacturing

Because Digital Twins is currently rarely used in construction waste remanufacturing, this article analyzes the applications of digital twins in construction and remanufacturing, and a proposition is as follows.

Proposition 2 The application of Digital Twin in the construction industry is mainly in the design and maintenance stage, while is rarely used in the demolition stage.

The application of Digital Twin in the construction industry can be divided into the applications in design stage, maintenance and transformation and demolition according to the life cycle stage of a building [17-27].

24 literatures were about Digital Twin for design stage, which take place of over 50% of the total researches on Digital Twin for construction. These studies include simulations and visualization of Digital Twin [28], photovoltaic panel optimization for buildings [29], and underground infrastructure management frameworks [30][31]. Studies related to maintenance include bridge processing and detection frameworks [32], bridge maintenance decision systems [25], etc.

In the demolition stage, there are only three related researches。Kan and Anumba [33] proposed that Digital Twin is the network physics system itself. Popa et al. [34] proposed a recycling logistics design for glass panels based on Digital Twin in a Romanian case. Van Wegen [35] points out the pivotal role of Bentley System in the transition of the construction industry to the Digital Twin for building environment.

Proposition 3 There are few researches on Digital Twin for remanufacturing, and few specific models and frameworks to deal with the data and communication lacking challenges.

At present, Digital Twin's application in remanufacturing is mainly focused on manufacturing waste [36], while rare researches offer a solution for construction waste. Specifically, Wang and Wang [37] proposed a system framework for component-level remanufacturing based on Digital Twin for waste electrical and electronic equipment (WEEE). Scott-Emuakporl et al. [38] proposed a process and technology for component remanufacturing of aged gas turbines based on Digital Twin. Mandolla et al. [39] proposed the Digital Twin application framework for additive manufacturing of aircraft components. Gordon et al. [40] and Sun et al. [41] evaluate the performance of additive-made stainless steel based on Digital Twin.

4. Discussion on Digital Twin in construction waste remanufacturing

According to the challenge of current remanufacturing for construction waste and the shortcoming of current researches, it is believed that

Proposition 4 A concept based on Digital Twin, including data integration technology, information communication between departments and decision support model, contributes to the remanufacturing of construction waste.

According to the diagram in the left part of **Figure 2**, the enterprise database is the basis for decision support analysis. The database can be divided into two parts, external data and internal data. The external data mainly contains public data and semi-public data. The enterprise could use the decision analysis framework based on public data and imported data by themselves. This framework can include cost-benefit assessments, environmental benefit assessments, transportation routes, and construction planning. Decision and implementation based on the analysis is added to the company's internal database, which is private. Information that needs to be shared with all or some of the other companies on the platform will be submitted to the Digital Twin platform at this stage. As can be seen from the diagram in the right part of **Figure 2**, information communication can be carried out between every two companies on the construct remanufacturing industry network, but direct material flow between every two companies is not necessary.

Based on the above solutions, this paper proposes a concept for the various components for Digital Twin in construction industry. It mainly includes data integration, information communication, and integration of decision support models.

In the concept, data integration is the foundation. Only by implementing data integration and data exchange at the technical level, it is possible to consider the information exchange and decision support model construction and application between enterprises. Therefore, this paper proposes a data integration concept as shown in **Figure 3**.

This paper considers data warehouse technology as a feasible method to achieve data integration. Besides, the integration of geographic location information, by accessing GIS data into the enterprise's data warehouse, helps to continuously visualize enterprise information and certain public information, and provides data support for decision-making based on model calculation results. Secondly, in terms of information communication, it is necessary to establish a more complete data sharing platform and establish a certain incentive mechanism to promote the efficient flow of information in complex departmental structures. Besides, more attention should be paid to the security of data transmission, with blockchain as the support of data transmission.
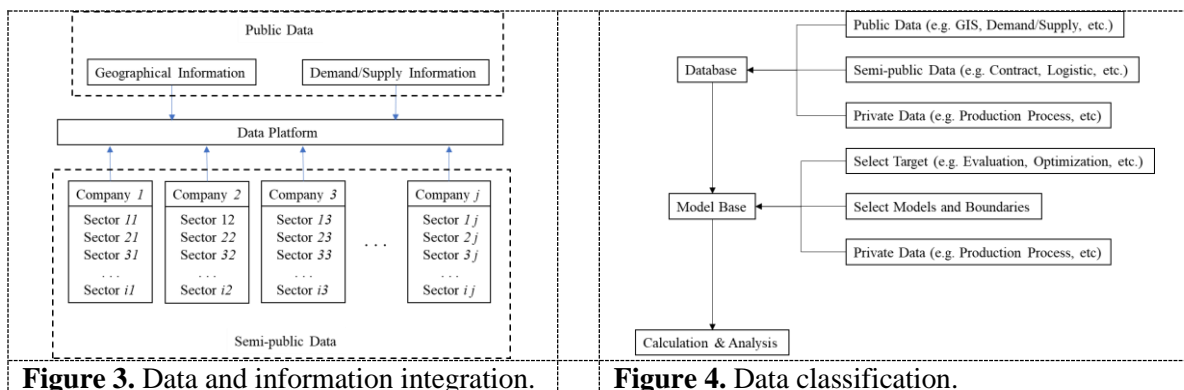
Figure 3. Data and information integration.   **Figure 4.** Data classification.

The integration of the decision support model in Digital Twin platform for construction, according to **Figure 4**, should be divided into basic information modules and analysis modules.

In the basic information module, public data, semi-public data and private data are collected on the same platform through data integration technology. In the data analysis module, this paper believes that multiple models should be classified according to the analysis objectives and integrated into the Digital Twin platform for construction as different toolkits. Enterprise technicians only need to determine the boundaries of the model and import data to optimize project progress and optimize project resources. This is beneficial to meet the different needs of enterprise data analysis. From a single enterprise perspective, different companies have different preferences and these preferences need to be considered in the model. From the perspective of the construct remanufacturing industry network, policymakers often need to balance the economic and environmental conditions of industrial parks. This trend should also be considered in the optimization model.

5. Concluding remarks

Currently, challenges on constructions are mainly data and information sharing, while there are rare studies on dealing with the challenges. The application of Digital Twin might provide a solution. This paper proposes the Digital Twin platform concept for building waste remanufacturing process, trying to provide a solution to the problems existing in the remanufacturing of the current construction waste. The implication of the research are as follows. First, establish a data integration platform based on data warehouse technology. Secondly, establish a certain incentive mechanism to promote the safe and efficient flow of information in complex departmental structures. Thirdly, this paper believes that multiple models should be classified according to the analysis objectives and integrated into the

Since data is currently the main obstacle to the promotion of Digital Twin applications, future research will be addressed on the technical issues of data integration. This is also the basis for decision support models and information sharing.

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