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FROM GRAVE-TO-CRADLE: QUALITY ASSURANCE SYSTEM FOR THE DEMOLITION WASTE MANAGEMENT

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ABSTRACT

The recent decade has witnessed significant demolition waste (DW) due to rapid urbanisation in many economies. Transforming from the traditional linear supply chains into a circular arrangement while thinking from 'grave-to-cradle' is a value-adding approach to managing DW effectively. Consequently, the concept of 'reverse logistics supply chains (RLSC)' has captured the attention of the construction industry. However, the poor quality of re-processed products has hindered the successful adoption of RLSC in the construction industry. Therefore, this study examines aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently. The study used a qualitative approach, including 20 semi-structured interviews with internal stakeholders of the RLSC of DW. The study empirically confirmed that the RLSC of DW should embrace an integrated system for QA, including four aspects: process, people, policy, and technology. Under process for QA, standard practices are to be undertaken separately during building dismantling and off-site waste processing stages. While people in RLSC are skilful, competent, licensed, supervised and monitored, internal and external organisational policies should also be available for QA. Besides, espousing traditional practices with innovative technologies is also imperative for QA in RLSC of DW. The study makes a significant contribution by empirically proving that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW. The developed quality assurance system provides useful insights for industry practitioners about the aspects that they should embrace in enforcing QA throughout the transformation from 'grave-to-cradle' in the construction industry.

Keywords: *Construction Industry; Demolition Waste (DW); Grave-to-Cradle; Quality Assurance System; Reverse Logistics Supply Chains (RLSC).*

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1. INTRODUCTION

The construction industry contributes to 40% of the aggregate waste produced globally, mainly due to construction and demolition activities (Jin et al., 2017). The volume of demolition waste (DW) produced on average is more than 70% of the total construction and demolition waste (CDW) (Ding et al., 2016). The DW encompasses a highly heterogeneous composition of inert and non-inert materials; thus, it exerts unfavourable environmental effects on the environment than the other types of waste if not otherwise properly managed (Hossain et al., 2017). Closing the loop of the construction supply chain by embracing well-planned and well-executed reverse logistics supply chains (RLSCs) would reduce the detrimental effects that have been caused due to the improper management of demolition waste (Brandão et al., 2021). In this study, the RLSC of DW is a process that moves materials and associated information from the dismantling of buildings to the new constructions to recapture the value of waste, which, if not disposed of at landfills (Hosseini et al., 2015). Given this, the organisations in the RLSC aim to divert waste from landfills to the forward supply chain by re-processing them into usable products which have demand from the secondary market (Shooshtarian et al., 2020). Therefore, producing quality re-processed products is a make-or-break factor that determines the successful adoption of RLSC in the construction industry.

However, the construction stakeholders had encountered quality issues in re-processed products, so they were reluctant to choose re-processed products over virgin products (Chileshe et al., 2016; Pushpamali et al., 2021). Previous studies indicated that the lack of technologies, physical resources, information, skills and competent workforce, rules and regulations, systematic procedures and benchmarking tools are the key reasons for the reduced quality of the re-processed products (Chileshe et al., 2019; Wijewickrama et al., 2021b). Product quality does not happen by chance; instead, it depends upon how well the quality is assured with the production process (Nikolaidis, 2012). In this regard, quality assurance (QA), a process-centred systematic approach to determining whether the final product meets the established requirements, plays an important role in the RLSC of DW.

According to Da Cruz et al. (2006), QA is crucial to prevent quality issues in products by assuring quality throughout the process rather than controlling it at the end. In light of this, QA is evolving with the notion of 'getting everything right first time every time' (p.23). Wijewickrama et al. (2021b) established through their systematic literature review (SLR) that an integrated system of people, process, policy, and technology is needed for QA in RLSC DW. However, this study demanded future research to validate the findings of their review by examining the empirical insights to develop a quality assurance system for RLSC of DW. Given this, the aim of this paper is thus to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study.

The original contribution of the study is that it empirically proved that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW. The developed quality assurance system provides useful insight for industry practitioners about the aspects that they should embrace in enforcing QA throughout the transformation from ‘grave-to-cradle’ in the construction industry. The remainder of the paper is organised as follows. The subsequent section is the literature review which is followed by the research methodology and results and discussion. The final section concludes by outlining the conclusions of the study.

2. LITERATURE REVIEW

The studies around RLSC in the construction industry were pioneered by Hosseini et al. (2013) and later extended by Hosseini et al. (2015). After these initial works, many empirical studies have been done in this area, especially focusing on identifying the advantages, barriers and challenges of adopting reverse logistics (e.g., Chileshe et al., 2016; Pushpamali et al., 2021). Throughout these studies, it is a recurrent fact that the poor quality of re-processed products is a significant impediment to the successful adoption of RLSC in the construction industry. For instance, Pushpamali et al. (2021) criticised a stigma attached to using re-processed products due to the perception of poor quality even if they are up to the expected standard requirements. Moving beyond this perception, Chileshe et al. (2016) pointed out that the practitioners in the construction industry have experienced quality issues in re-processed products in the real context due to poor quality control and compliance. Even though these studies have highlighted the issues related to the quality of re-processed products, none of these empirical studies has attempted to investigate how to improve their quality.

There is no solitary definition for 'quality'. Deming (1986) defined quality as producing a product or service to ensure customers' expectations. Later, Arditi and Gunaydin (1997) explained two distinct classifications of quality: product quality and process quality. The authors further described that product quality is the 'quality of elements directly related to the physical product itself' (p. 236), whilst process quality means the 'quality of the process that causes the product to be either acceptable or not' (p.236). Given this, Arditi and Gunaydin (1997) revealed that the product's quality depends upon the quality of the process used to produce it. Therefore, this concludes that ensuring process quality is paramount to producing quality output.

According to Keffane et al. (2021), QA is a process-centred approach that includes all the planned and systematic activities to fulfil the quality requirements of a product or service. It helps to achieve customer satisfaction via a continuous effort in improving product quality while identifying and eliminating the causes of quality issues during the production process. In this regard, QA is a proactive way of assuring quality throughout the process rather than controlling it at the end. Fox (2011) asserted that each task in the manufacturing process includes four elements: documentation required, the item being worked upon, the equipment being used to perform the task, and the person carrying out the work. The author further posited that all these four elements should be thoroughly considered for QA. Based on this proclamation, in the context of the RLSC of DW, Wijewickrama et al. (2021b) established that QA is a system integrated with four elements: process, people, policy, and technology. The authors highlighted that this quality assurance system includes practices and approaches that should be conducted by competent people using high-tech machines and equipment, complying with current legislation, regulations, standards, and guidelines. In this study, Wijewickrama et al. (2021b) developed a conceptual framework by reviewing the literature to build a foundation for QA in the RLSC of DW. However, there is still a lack of empirical research based on the investigations of the opinions of RLSC stakeholders, revealing the aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently. Consequently, the present study is a progression in fulfilling this gap in the literature.

3. RESEARCH METHODOLOGY

Busetto et al. (2020) stated that the qualitative approach advocates understanding and exposing the holistic view, including experiences and proclamations over a phenomenon under study. Therefore, this study aims to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study. With the exploratory nature of this inquiry, which demands a holistic understanding of QA in RLSC of DW, a qualitative interview-based approach was considered appropriate for data collection in the current study. A total of 20 semi-structured interviews were conducted with practitioners involved in building dismantling and off-site waste processing sectors in South Australia. The reason for conducting this study in South Australia is its leadership in waste management (Green Industries South Australia, 2020), with the highest contribution of 67% of CDW recycling in Australia (Zhao et al., 2022). Therefore, conducting this study in a context like South Australia advocates providing a valuable stream of knowledge regarding how QA is assured effectively and efficiently in RLSC to yield a higher percentage of waste recovery. Both purposive and snowball sampling techniques were used to recruit interviewees for the study. Due to the limited and unsupportive nature of the study's population, six participants were initially interviewed, and then they suggested the remaining 14 interviewees for the study. Table 1 outlines the profile of the interviewees.

Table 1: Profile of interviewees

Building dismantling and on-site processing			**Off-site waste processing**		
Interviewee (code)	**Designation**	**Experience (years)**	**Interviewee (code)**	**Designation**	**Experience (years)**
BD1	Managing Director	19	WP1	Business Development Manager	11
BD2	Managing Director	28	WP2	Accounts Manager	16
BD3	Managing Director	21	WP3	Occupational Health and Safety Manager	10
BD4	Quality Control and Sales Manager	18	WP4	Accounts Manager	8
BD5	Sales and Marketing Manager	18	WP5	Regional Manager	8
BD6	Director	14	WP6	Sales and Marketing Manager	15
BD7	Director	16	WP7	General Manager	11
BD8	Contracts Manager	19	WP8	Sales and Marketing Manager	10

Building dismantling and on-site processing			Off-site waste processing		
Interviewee (code)	Designation	Experience (years)	Interviewee (code)	Designation	Experience (years)
BD9	Managing Director	30	WP9	Sustainability Advisor	13
BD10	Operations Manager	10			
BD11	Managing Director	22			

The interviews were conducted from September 2020 to May 2021. The average duration of an interview was nearly 45-60 minutes, and the interviews were recorded with the interviewees' consent. The qualitative data collected from semi-structured interviews were analysed using the directed content analysis, which describes the themes of the study with support from the previous research that is incomplete and thus, demands further research (Hsieh & Shannon, 2005). This analysis consisted of three phases. First, the data was transcribed and scrutinised to identify preliminary themes known as open codes. Second, the developed open codes were combined, refined and categorised to form the axial codes, which were further refined in the third step to form the final themes of the study, which are known as selective codes.

4. RESULTS AND DISCUSSION

A summary of the findings of semi-structured interviews is presented in Figure 1. Accordingly, Figure 1 explains how process, people, policy and technology contribute to the QA in RLSC of DW. Each aspect of the quality assurance system is expansively discussed in the following sections.

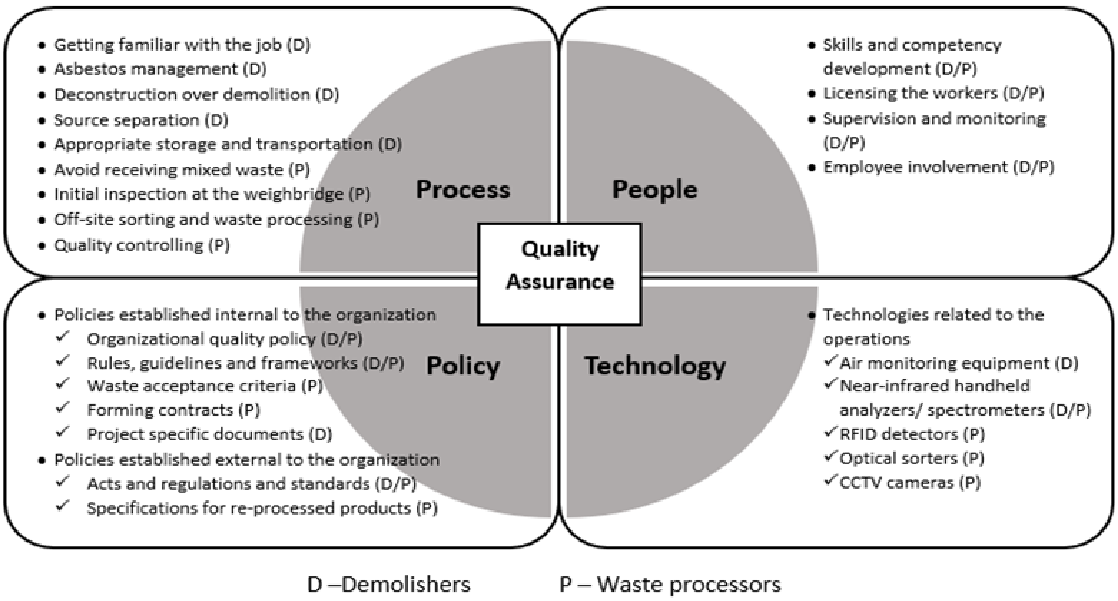

Figure 1: Quality assurance system for RLSCs of DW

4.1 PROCESS FOR QUALITY ASSURANCE

Corresponding with Wijewickrama et al. (2021b), the process for QA starts by getting familiar with the job before commencing dismantling. For this, demolishers visit the site and thoroughly investigate the status quo of the building to be demolished and get an in-depth understanding of the job scope. Similarly, collecting drawings and asbestos registers is also imperative to be familiar with the job. Asbestos management is a crucial QA practice undertaken during building dismantling and on-site processing (Zoraja et al., 2021). According to Interviewee BD3, the demolishers get samples and test them to confirm the presence of asbestos in the building. When carrying out the asbestos removal work, the licensed asbestos removalist should label the asbestos-contained waste appropriately and dispose of it as soon as practicable at a site authorised to accept it. The deconstruction of the building is also an important QA practice. Interviewee BD5 mentioned that instead of demolishing everything at once, considering deconstructing the building in sections helps prevent destroying components and materials that would otherwise be wasted in the end. The interviewees identified that source separation is an effective practice that reduces waste contamination, thence improving the quality of re-processed products. Interviewee BD1 highlighted that demolition sites have multiple bins or defined areas to separate each material on-site such as concrete, bricks, metal and timber.

> We always separate the concrete, bricks, timber, green waste, trees and rubbish. All the elements, stainless steel and all that separate. The ordinary sheet iron goes in with the iron waste, but stainless steel is separated, copper is separated, brass is separated, and lead is separated. We have separate piles, so we load up [all] piles separately and don't mix them (Interviewee BD1).

Most interviewees asserted that the appropriate storage and transportation of extracted materials to an off-site waste processing facility after demolition is a significant practice for QA in RLSC. Interviewee BD2 underlined that the most important concern here is to store and remove asbestos waste appropriately without allowing them to contaminate with other recovered waste. Interviewee BD10 stated that salvaged waste also should be uniformly stockpiled on the site to avoid contamination with each other. It is also important to take appropriate measures to minimise contamination or damage to salvaged materials during transportation.

The process quality of the waste processor primarily depends on the quality of waste that enters the material recovery facility (Chileshe et al., 2019). Conforming, Interviewee WP3 stated that as a large-scale waste processing company, they have a separate designation known as "Accounts Manager" who actively engages and ensure that the material recovery facility receives the sorted and uncontaminated waste, which complies with the waste acceptance criteria of the waste processor. The waste acceptance criteria are qualitative and quantitative criteria developed by waste processing companies and approved by the Environment Protection Authority to accept waste streams from demolishers (Wijewickrama et al., 2021a). After complying with the waste acceptance criteria, the demolisher needs to pay the gate fee (or tipping fee), which is the charge levied upon the waste accepted by the material recovery facility. Besides, Interviewee WP2 asserted that their company is forming contracts with some large-scale demolishers in SA. The interviewees revealed that when the waste loads are transferred to the weighbridge of the material recovery facility, the waste processor conducts an exhaustive examination to ensure that it is not contaminated. Interviewee WP1 pointed out that there are two full-time assigned roles as "customer service representative" and "spotter" to inspect the waste loads at the weighbridge. Interviewee WP2 mentioned that a few CCTV cameras are also fixed to inspect each load at the weighbridge. Interviewee WP1 divulged that if the waste load contains more than 5% of non-compliant materials, the waste load will not accept. Interviewee WP3 stated that even if the demolishers do source separation, the waste processor does off-site sorting again before introducing waste to the processing plant. After an exhaustive mechanical separation process, Interviewee WP3 revealed that his organisation ships all the ferrous metals to external specialists for further processing. The sorted inert fractions are recycled into rubbles, road-based materials, and clean, wet and mixed fill. The trommel fines, which arise as a by-product of trommel screening, are used as alternative daily cover material at landfills. The waste processors test re-processed products before dispatching them to the secondary market. Interviewee WP5 underpinned that their plant has an insitu-lab that advocates testing the re-processed products efficiently. Interviewee WP1 elucidated that in their organisation, they test the re-processed products against Department of Planning, Transport and Infrastructure (DIT) sampling specifications, and if products do not meet the standard requirements, they are not going to sell them.

> We have an Environ team who do some testing on products. And we also have a company called … who come in and test the stockpiles, which is independent. So that's a third party. So that no one can say that we rig the testing or whatever, we get a third party to come in twice a week. And then, those results get sent to the Environ team. And they're tested against DIT standards for the product (Interviewee WP1).

Interviewee WP3 stated that a group of specialists is assigned to do these tests in a waste processing organisation.

4.2 PEOPLE FOR QUALITY ASSURANCE

Even if the demolition is not a complicated operation, it demands workers with skills and expertise (Rameezdeen et al., 2015). Most interviewees mentioned that years of practical experience in the field are more important than the theoretical and explicit knowledge of workers engaged in demolition. Interviewee BD1 further highlighted that even after recruiting well-experienced workers for the company, the demolition companies conduct extensive training programs periodically for their workers as per the requirements in AS 4801:2001 (Occupational health and safety management systems). According to Work Health and Safety Regulations 2012, any worker assigned to remove asbestos should have either a Class A license (i.e., to remove all asbestos-containing materials, including friable asbestos materials) or a Class B license (i.e., to remove any amount of non-friable asbestos.). By getting Asbestos Removal License, the person conducting a business or undertaking (i.e., the employer of the business), on the one hand, is getting the assurance about his workers' safety as they are well informed to get protected from being exposed to the asbestos. On the other hand, the entire licensing process improves the knowledge of workers on managing asbestos safely, which is a significant practice in QA of demolisher's work (Wijewickrama et al., 2021a). Many interviewees raised the need for overseeing the execution of operations during the building dismantling and on-site processing. For instance, Interviewee BD1 stated that, as the company manager, he is on-site nearly every day instructing and directing his subordinates even if they are experienced and well-trained.

> We're a QA company; we've got procedures to abide by. When I go on the site, I fill out JHA (job hazard analysis) paperwork. I have the paperwork in place with their names on it, who's on site, who's doing what, and they all know what they've got to do by filling out paperwork, having the safety here, and generally making sure everything runs smoothly. (Interviewee BD1)

Despite advanced plant and machinery usage, human involvement plays a significant role in waste processing (Botello-Alvarez et al., 2018). Therefore, employing experienced labour and developing their skills and competencies throughout their job is vital for QA. For instance, Interviewee WP1 pointed out that most workers started with their company as waste pickers; thus, they possess expertise in the field due to long-term engagement in the same company. Also, waste processing companies always encourage workers to get relevant licenses for their jobs from authorised third-party organisations. In addition, in-house training programs are periodically scheduled to enhance the knowledge and skills of workers around contemporary techniques and technologies related to their work. Employee involvement and top management commitment are paramount toward QA during the off-site waste processing phase. Herein, Interviewee WP6 divulged that their company has a decentralised culture where the activities, particularly those regarding planning and decision-making, are delegated among many teams rather than a single one. Consequently, each employee in the organisation is responsible for their work; thus, it advocates for improving the quality of the job. Interviewee WP3 mentioned that his organisation has daily tool-box meetings, weekly QA meetings and monthly top management meetings. All these meetings promoted knowledge sharing among employees and a strong awareness of the issues and status-quo of the organisation. Given this, Interviewee WP3 revealed that top managers' influence and involvement in organisational performance are the key driving forces for his company to become competitive in the industry.

4.3 POLICY FOR QUALITY ASSURANCE

Demolishers and waste processors always work to deliver a quality service for clients through the highest performance standards, professionalism and customer service (Chileshe et al., 2019). To achieve this, most companies have obtained different third-party accreditations for quality management systems. For instance, Interviewee BD4 mentioned that his company's third-party accreditation to AS/NZS ISO 9001:2008 Quality Management Systems underlines its commitment to providing quality service while engaging with clients to understand their specific needs. The Interviewee BD4 further stated that a company-wide quality policy and, thereby, some supplementary documents (e.g., rules, guidelines and frameworks) had been established as part of this quality management system, considering it as a guide to continually improving the quality of their work.

> We've got ISO 9001:2008. Based on this, the company has a quality policy. To achieve this quality policy, the company has also developed a business management system manual, clear procedures outlining quality approach and operations, detailed quality work instructions, and customer satisfaction surveys. (Interviewee BD4)

From the waste processor's perspective, in addition to quality policy, they have developed waste acceptance criteria and formed contracts to minimise the risk of receiving mixed waste from demolishers. On the other hand, from the demolishers' perspective, project-specific documents are developed for the QA. For instance, Interviewee BD1 stated that they prepare a demolition management plan, asbestos removal control plan, safe work method statement, and sub-contracts for each project. Noteworthily, some of these documents are prepared due to stringent regulatory requirements (e.g., asbestos removal control plan), while the others are developed as per the organisational requirement to plan for the successful completion of the project.

In addition to the policies established within the organisations, there are externally developed policies that affect demolition and waste processing (Brandão et al., 2021). The Environment Protection Authority and SafeWork SA (i.e., state government agencies in South Australia) have developed acts, regulations and codes of practices that influence the QA in RLSC. For instance, Interviewee BD3 pointed out that the landfill levy, which is the most crucial influencer for QA of demolition (Wijewickrama et al., 2021a), is regulated through the Environmental Protection Regulation 2009. Furthermore, both Environment Protection Authority and SafeWork SA regulate asbestos management. Interviewee BD2 highlighted that SafeWork SA is responsible for administering asbestos removal as per the Work Health and Safety Act 2012 and the Work Health and Safety Regulations 2012 and provides important information for demolishers regarding managing and removing asbestos. Similarly, waste processors are also getting influenced by different acts, regulations and standards of regulatory bodies. For instance, Interviewee WP1 highlighted that the Environment Protection Act 1993 mandates that waste processing companies that receive more than 100 tons of waste during a year must have a license with Environment Protection Authority. Also, there are different specifications that DIT used to acknowledge waste processors of the quality requirements they expect from the re-processed products, such as national specifications, Austroads specifications and specifications used in other states. In addition, DIT has developed a master specification that communicates standard quality and/or performance requirements that the industry needs to achieve when supplying materials for infrastructure projects in South Australia.

4.4 TECHNOLOGY FOR QUALITY ASSURANCE

According to the interviewees, very few new technologies are used for QA during the dismantling and on-site processing stage, especially for asbestos management in a demolition project. Interviewee BD3 highlighted that since there are stringent regulatory requirements around asbestos management, they are setting up air monitoring over the demolition site at all times of asbestos removal operations. For this, they are using advanced static and positional air sampling instruments to take samples at fixed locations over an area during work on asbestos removal is taking place. Then the collected air monitoring samples are analysed by a NATA-accredited laboratory. Interviewee BD5 divulged that as a large-scale demolition company in SA, his company uses near-infrared handheld analysers to identify asbestos-containing materials in a building.

> Generally, a lab-based analysis would cost us more and be time-consuming. Therefore, to make our job easy and ensure the health and safety of the working environment, we are using a near-infrared analyser to identify asbestos rapidly

The Interviewee BD5 further mentioned that they plan to use a site proximity warning system in their future demolition projects. According to Interviewee BD5, this system uses radio frequency identification detectors to enhance site safety by avoiding accidents during the demolition process. It is a kind of early warning system for workers making them aware of risks at the site.

Waste processors also use different technologies for QA (Thatcher & Oliver, 2015). The authors further mentioned that waste processing is in-deed machine-oriented; thus, they always look for sophisticated technologies to improve the performance and quality of their work. Conforming, Interviewee WP1 stated that their waste processing plant uses optical sorters to sort commingled materials during the last stage of waste processing. These optical sorters help the material recovery facilities reduce their reliance on the workforce to sort various materials while making the entire process more efficient and effective. Furthermore, Interviewee WP1 mentioned that his company uses near-infrared spectrometers to detect asbestos in the waste loads before accepting them to the material recovery facility. Also, Interviewee WP4 divulged that his company uses CCTV cameras to observe waste loads more clearly at the weighbridge.

5. CONCLUSIONS

Quality assurance acts as a system in RLSC, which plays a significant role in producing quality output. The current study aims to examine aspects of the quality assurance system needed for RLSC to manage DW effectively and efficiently through an empirical study. The study used the qualitative approach, conducting 20 semi-structured interviews with internal stakeholders from building dismantling and on-site processing and off-site waste processing stages. The study confirmed that process, people, policy, and technology are the four aspects integrated to form the quality assurance system in the RLSC of DW. Herein, as the process, there should be well-compiled activities and practises for QA. In addition, an experienced, knowledgeable and competent workforce should be present to conduct these activities and practices by getting technical support from advanced and innovative technologies. Simultaneously, all these activities and practices should be undertaken within a guided framework complying with the extant laws, regulations, standards and internal organisational policies. With this, the study makes a significant contribution by empirically proving that an integrated system of process, people, policy and technology is needed for QA in RLSC of DW

The following significant implications are suggested. The developed quality assurance system would provide useful insights for industry practitioners in the RLSC about the aspects they should embrace in enforcing QA throughout the transformation from 'grave-to-cradle' in the construction industry. On the other hand, for the government and policymakers, identifying aspects of the quality assurance system would provide an opportunity to develop appropriate legislative strategies and coping mechanisms to promote QA in the RLSC. The study also encompasses a limitation which is acknowledged as follows. Given the study's exploratory nature, the results are not statistically generalisable. Therefore, this warrants a future research agenda where a more widespread investigation across the geographic regions.

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