Design Science Research for Digital Information Management System (DIMS) in Construction and Demolition Waste Management

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1 Introduction

The construction industry is intricately connected to economic growth, employing approximately 7% of the global workforce and contributing to 13% of the gross domestic product (GDP) [1]. This sector consumes vast amounts of raw materials annually. Worldwide statistics show that construction produces 30–40% of all solid waste, with an average of 35% ending up in landfills. Consequently, this situation presents a substantial environmental challenge for the construction sector worldwide [1]. Therefore, the industry must move from its linear economy (Take-Make-Waste) to the circular economy. The circular economy encompasses concepts like industrial ecosystems and symbioses, the 3R principle (reduce, reuse, recycle), circular material flows, zero emissions, and more [2]. In the realm of construction, the impact of cutting-edge digital tools and methodologies is becoming increasingly evident [3].

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M. Kioumarsi, B. Shafei (eds.), *The 1st International Conference on Net-Zero Built Environment*, Lecture Notes in Civil Engineering 237,
https://doi.org/10.1007/978-3-031-69626-8_156

Industry 4.0 technologies play a pivotal role in the journey toward Circular Economy (CE) [4]. By redefining waste management practices, the convergence of Industry 4.0 and CE holds immense promise for environmental, health, and societal gains. The European Commission [5] has pinpointed three key areas where Industry 4.0 decision support systems can bolster CE efforts: (1) facilitating circular production through resource flow tracking, (2) enhancing the resilience and adaptability of built assets in alignment with CE principles via robust material information management, and (3) driving innovation in data spaces and establishing the architecture and governance framework for intelligent applications. Simultaneously, as a new technological era unfolds, digital advancements are revolutionising national and global economies by expediting decision-making and enhancing core business processes [6]. The recent surge in novel technologies propels the built environment into a contemporary data-driven landscape characterised by five distinct phases: data acquisition, mobile data highways, data security, data analysis, and data realisation [7–9].

This chapter focuses on the design science research (DSR) strategy to develop a conceptual framework for a digital information management system (DIMS) to facilitate construction and demolition waste management.

2 Research Philosophy for Information Systems Through Design Science Research

Research and its conclusions may be deceptive or meaningless if philosophy is not given enough thought or comprehension [10]. This is supported by Dawood & Underwood [11], who state that the failure of a great deal of research arises from the researcher needing first to understand their own philosophical assumptions. On the other hand, understanding philosophical questions can help Information Systems (IS) researchers ensure that their work is insightful and comprehensive. It can also improve the quality of the real work [12]. Ontology, epistemology, and axiology are the philosophical groundings of design science in research [13, 14]. Ontology pertains to underlying beliefs concerning the fundamental nature of reality. Ontological assumptions aid the researcher in moulding the perspective through which research objects are seen and examined [15]. After gaining an understanding of the fundamental concept of reality (ontology), the researcher can then delve into exploring its nature (i.e. epistemology) [16]. Epistemology, as a foundational component of research philosophy, delves into the essence of knowledge. It is defined as 'the theory of knowledge' and places its emphasis on the procedure involved in constructing, understanding, and advancing knowledge [15]. According to Mardiana [17], there are three paradigms within the philosophy of IS research: positivism, interpretivism, and pragmatism.

Positivism and DSR in IS share a focus on research rigour and relevance [18, 19]. While positivist research emphasises hypothesis testing and quantitative methods, DSR incorporates interpretive and critical perspectives, allowing for a comprehensive understanding [19]. Therefore, interpretivism emerged in response to positivism's limitations, emphasising contextual variables and human experiences [20]. In DSR within IS, interpretivism complements positivism by emphasising the subjective experiences of individuals, acknowledging the complexity of human sense-making and the importance of context in studying IS [21]. However, pragmatism is also recognised as a paradigm for DSR in IS, emphasising practical solutions to real-world problems [22, 23]. Pragmatism supports the creation and evaluation of I.T. artefacts, aligning with DSR's goal to address organisational challenges and contribute to both theoretical knowledge and practical value [21, 24]. Pragmatism emerged as the preferred research philosophy for this study. This decision was based on its ability to blend elements of various philosophies, including qualitative and quantitative approaches, and its strong alignment with applied research and practical problem-solving. Given the goal of developing a DIMS that serves the RECONMATIC consortium and contributes to knowledge, pragmatism offers the flexibility to use a mix of methods, consider multiple stakeholder perspectives, and prioritise practical outcomes.

3 Design Science Research for Information Systems

DSR within the field of IS represents a research paradigm focused on developing and evaluating innovative I.T. artefacts designed to address practical, real-world issues. The foundational principle is that knowledge and comprehension of a problem domain and its solution are acquired through the construction and application of the designed artefact. [22].

Several authors, including Hevner and Chatterjee [22], Vaishnavi and William Jr Kuechler [13], and March and Smith [25], have collaborated to outline common approaches in DSR within IS. Their collective work focuses on the step-by-step process of DSR, covering problem identification, artefact design, artefact evaluation, and knowledge contribution Fig. 1. Moreover, they unanimously agree on the key outcomes of DSR. They emphasise the creation of practical elements like constructs, models, methods, and real-world applications, along with the continuous improvement of overarching theories. This shared perspective underscores a widespread consensus in academia regarding the importance of tangible contributions through constructs, models, methods, real-world applications, and refined theoretical frameworks within the realm of DSR.

Holmstrom et al. [26] assert that the initial stage in design science involves pinpointing the problem through 'diagnosing the primary research problem'. Johannesson [27] suggests that the foremost consideration for a design science researcher should be the realisation that 'something is not quite right with the world, and it has to be changed'. The output of this phase is a proposal, formal or informal, for a new research effort [13]. Furthermore, the second step, according to Voordijk [28] and Hevner et al. [22], is to create the 'technological rule' (artefact) that will solve the real-world issue. Designing and creating this artefact, according to

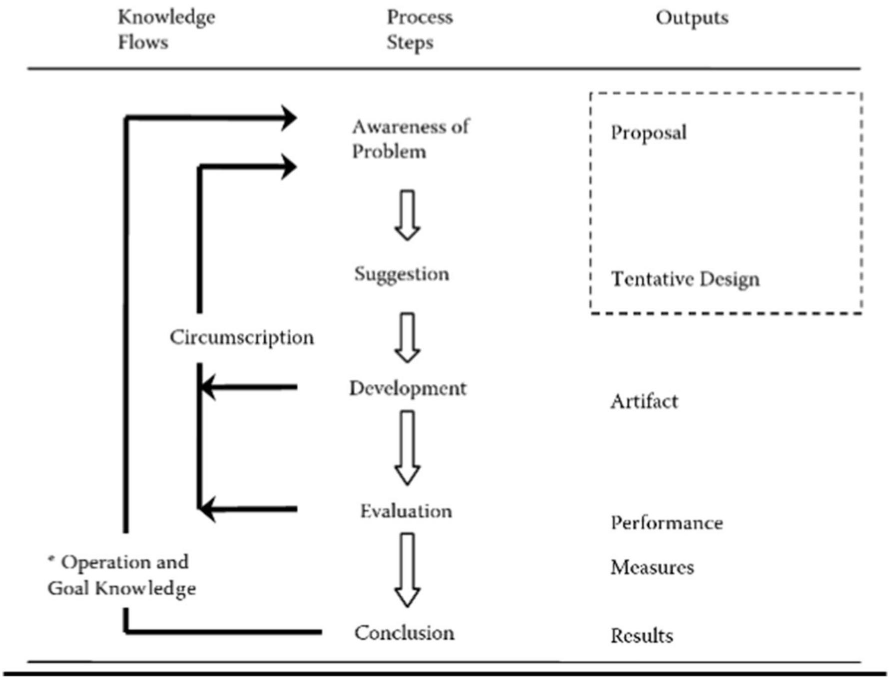

Fig. 1 The general methodology of design science research [13]

Hevner et al. [22], is the process of creating a solution concept (method or system) for a specific goal. This stage comes right after the proposal and is closely connected to it through the tentative design that is expanded upon and put into practice during the development stage [13]. Kehily and Underwood [29] state that the process of creating the artefact needs to be transparent for the solution to be meaningful from an academic perspective. This calls for an explanation of the choices made during the artefact's evolution and the development process. According to Hevner et al. [22], a design artefact's utility, quality and efficacy must be thoroughly demonstrated through well evaluation techniques. This is supported by Peffers et al. [30], who mentioned that these techniques are such as observation, analysis, experimentation, or testing, whereas Arthur [31] divided the evaluation into two components based on his belief that design science researchers have a greater chance of producing high-quality research outcomes if they employ a high-quality research process. The two components are (1) evaluating the quality of the process used and (2) evaluating the quality of the outcomes Fig. 2.

The evaluation results should provide evidence of the artefact's utility, quality, and efficacy. DSR in IS should also contribute to theoretical and practical knowledge of the problem and solution domains [30].

Finally, the last phase of DSR is the conclusion. As stated by Vaishnavi and William Jr Kuechler [13], this phase marks the culmination of a distinct research endeavour, typically resulting from satisficing, wherein discrepancies in the

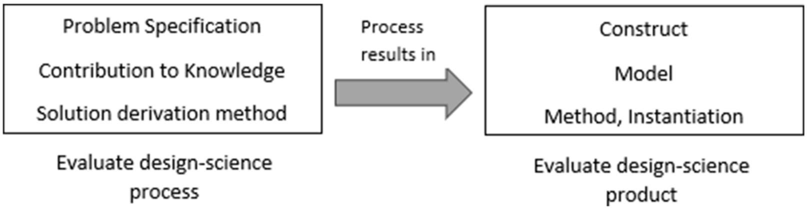

Fig. 2 Evaluating quality of DSR [31]

artefact's behaviour from the (repeatedly) revised hypothetical predictions are considered 'satisfactory'. Furthermore, Hevner et al. [22] emphasise the importance of presenting DSR effectively to both technology-oriented and management-oriented audiences.

4 DSR to Develop DIMS for CDWM

To address the challenges in CDWM, a comprehensive DIMS is being developed using the DSR method. Following DSR Fig. 3., the first phase is awareness of problem, the journey began with a critical review of the existing literature and the latest studies in CDWM, exploring the barriers and drivers in CDWM, the application of Industry 4.0 in CDWM, and the role of IS in the field to understand the problem. Through this critical examination, a noticeable gap emerged, concerning the integration of Industry 4.0 technologies to support the waste management, waste quantification, auditing and waste diversion in the C&D sector [31–33]. Specifically, this gap revolves around the absence of a comprehensive digital information management system that encompasses the entire project lifecycle, extending from inception to demolition or deconstruction phases. Furthermore, there is a notable lack of clarity regarding the roles and engagement of various stakeholders within these systems. Most of the information management systems reviewed in the existing literature, while promising in their potential, have exhibited shortcomings. One significant limitation is the absence of a secure and robust database infrastructure for effectively handling the vast datasets inherent in the integration of technologies like BIM and IoT or real-time data collection in BIM and Blockchain integration. Moreover, many systems have faltered in achieving real-time data collection, a critical feature to ensure the timely and accurate tracking of waste and materials in construction and demolition processes which will help analysing the material flow. In response to this gap, a proposal was formulated, suggesting the integration of BIM, IoT, and BC to enhance material flow analysis throughout the lifecycle of the project.

Looking towards the future, implementing the proposed solution will undergo a rigorous evaluation as part of the DSR process outlined by Arthur [34]. This process begins with a preliminary study to verify the identified problem's existence and

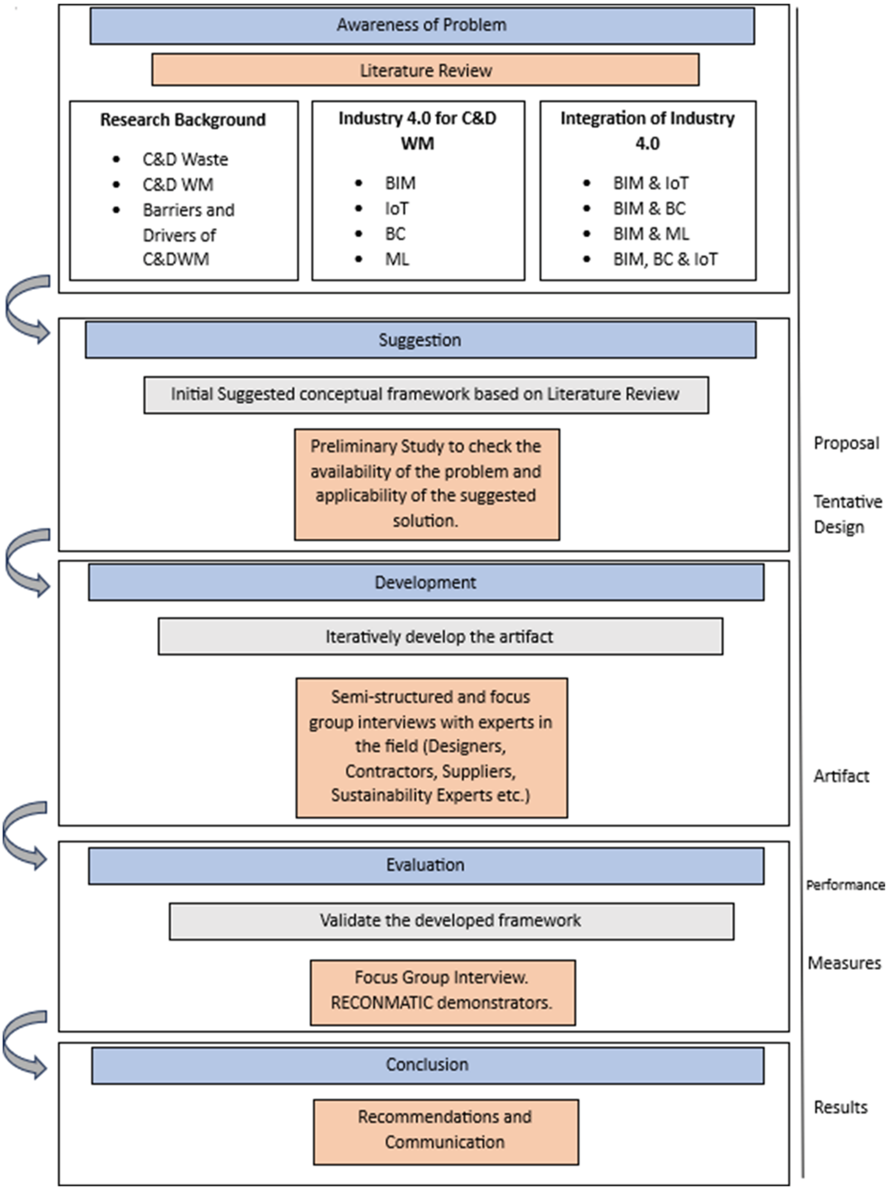

Fig. 3 Design science research process flow

assess the proposed solution's applicability. Two distinct groups will be targeted for this study through a questionnaire survey. RECONMATIC partners will be engaged to examine the problem's existence, the solution's applicability, and its support for RECONMATIC DEMONSTRATORS [35], and the wider industry's perspective will also be considered to check the problem's existence and the solution's applicability. Following data collection, the results from the preliminary study will undergo statistical analysis using SPSS to analyse the data and assess its reliability. Subsequently, the artefact will develop as a co-creation between the industry experts, involving semi-structured interviews with RECONMATIC partners and a focus group in a workshop with the wider industry. The framework will undergo iterative refinement by thematically analysing the qualitative data collected and then will be evaluated in the RECONMATIC annual meeting workshop, incorporating insights from RECONMATIC case studies. This will be done by following the Framework for Evaluation in DSR developed by Venable et al. (2016), by defining the explicit goals, choosing evaluation strategies determining properties that will be evaluated and designing the individual evaluation episodes [36]. Following this, the framework will progress to implementation, culminating in the development of the system architecture. This will be done by following the Togaf standard [37]. The outcomes and results of this endeavour will be disseminated through various channels, including journal papers, conferences, and the RECONMATIC website, solidifying its contribution to the field of CDWM, CE and Digital Technologies.

5 Conclusion

In conclusion, the aim of this research is to develop a comprehensive conceptual framework for a DIMS that incorporates Industry 4.0 technologies to enhance CDWM, encompassing the entire project lifecycle. This approach aligns seamlessly with the principles of DSR, where the central focus is on designing and exploring the use of an artifact to address a specific problem within a given context [38]. In DSR, researchers propose and develop an artifact to engage with a problem context, ultimately aiming to enhance elements within that context [38, 39]. This chapter has delved into the steps followed within the DSR strategy to develop this system as part of the Horizon Europe Project RECONMATIC.

Moreover, developing the DIMS presents challenges that blend academic standards with human interactions. Engaging stakeholders through interviews requires balancing diverse needs and opinions, often requiring negotiation to reach consensus. Whereas the development of the framework will be a co-creation between RECONMATIC Partners and the wider industry, this could also be a challenge since the RECONMATIC Partners would give their insights based on RECONMATIC project only. This potentially limits the scope of perspectives and experiences considered in the development process, posing a challenge in ensuring the inclusivity and comprehensiveness of the DIMS framework.

Thus far, the researcher has completed the problem detection phase, identifying key issues, including the lack of integration of Industry 4.0 covering the entire project lifecycle, a lack of understanding of stakeholder roles within these systems, and the absence of systems supporting material flow analysis. The researcher has proposed a framework that integrates BIM, IoT, and BC specifically to strategically manage information across the whole lifecycle of the project, supporting material flow analysis. This proposed solution will be followed by an evaluation of the identified problem and the suggested framework with RECONMATIC partners and the wider industry. Subsequently, the research will move on to the development of the artifact and, finally, its evaluation.

Funding This research was funded by Horizon Europe (grant agreement number 101058580, 2022) and by Innovate UK as part of the UK Guarantee programme for UK Horizon Europe participation (project number 10038579). Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the HORIZON-RIA. Neither the European Union, The UK nor the granting authority can be held responsible for them.

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