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Utilizing Manufacturing Digital Twins for Sustainability Reporting

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Abstract. The advance of digital technologies and the societal imperative to achieve sustainability exposes new pathways for businesses. The environmental and social impacts of industrial operations are well known and there are increasing demands to report impact through voluntary and mandatory corporate stakeholder reporting. The extensive live operations reporting is disconnected from corporate reports built retrospectively from aggregate enterprise data. This paper argues that the disconnect between operations and corporate reporting is a missed opportunity hindered by data integration, absence of frameworks to guide adoption and the missed value that comes from integrated reporting. By considering digital twin data and those of reporting standards such as from the EU's Corporate Sustainability Reporting Directive, the two could be mapped. Once mapped, a digital twin could be created to generate reporting data and enable improvement evaluation. This paper uses literature and expert interviews to report the requirements for linking digital twins to sustainability reporting. In turn it proposes a framework to guide data mapping and model configuration to use to evaluate the business level impact of operational changes. A discussion on the utility of the framework precedes the conclusion with directions for future research.

Keywords: Digital twins · sustainability reporting · manufacturing systems

1 Introduction

The impact of manufacturing is growing [1] and affecting ecosystems [2]. New practice implementations are needed [3]. To address the sustainability imperative [4], digital twins are promoted to address the evaluation of new environmental practices [5] as well as the long-standing productivity focus. As a core technology of Industry 4.0 [6], they can model efficiency, environmental and possibly social improvement scenarios. Digital twins, based on simulation, can capture the dynamic, time-varying interactions between materials and other resource flows through the stages of production system [7]. However, there are gaps in addressing environmental and social sustainability challenges using digital twins in operations [8] and the wider supply chain [9].

Communicating company activity voluntarily against selected Sustainable Development Goals (SDGs) [10] has become commonplace for organizations. Mandatory

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reporting requirements are being established, e.g. EU Corporate Sustainability Reporting Directive (CSRD). Until recently, they have been voluntary [11] with no single international standard [12].

Despite manufacturing operations having a significant role in a company's impact and that manufacturing has utilized extensive measurement for centuries, there is a disconnect between manufacturing operations and compulsory sustainability reporting. Irrespective of the use of digital twins, granular, frequent manufacturing reporting is not the source of sustainability reporting data. Instead, aggregate data is drawn from site meters, billing, etc. This represents a knowledge gap and an industrial opportunity.

Mandatory sustainability reporting standards have granularity that could be mapped to digital twin outputs and wider sources. The benefits would be twofold. First, corporate stakeholder reporting could be efficiently rolled up from operational metrics for traceability. This could be done regularly rather than annually. Second, operations improvement could be driven by business scenarios triggered by the desire to improve reportable corporate performance. The objective of this research is therefore to establish if and how digital twins can bridge between operations and sustainability reporting.

In this paper, we first examine the literature on digital twins and compulsory sustainability reporting and the potential for links between them. Based on a mixed methodology we then conduct empirical data collection with experts from across industry to consider the findings from the literature and the prevailing visions in manufacturing. Next, we develop a framework that combines the operations and simulation modeling domain with the domain of corporate sustainability reporting. We consider the applicability to a SME in the UK that has advanced thinking and practices in the sustainability arena. Finally, we discuss the findings, conclude and propose research.

2 Literature

Digital twins [6] have been used for sustainability related analysis such as energy [5] but in general are limited in their scope [8] and other techniques have been used to engage in broader environmental and social analysis [13].

There is a weakness in using digital twins for sustainability performance tracking [14] perhaps because environmental benefits are often being consequential rather than the prime focus [15]. With external reporting pressures requiring a manufacturing response [16] there is potential for digital twins to be implemented to respond to corporate, stakeholder-facing imperatives.

Stakeholder accountability necessitates effective measuring, monitoring and reporting for reasons of societal awareness and associated demand for insight and transparency [17] as well as industry expectations and emerging legislation. Against a backdrop of stakeholder dissatisfaction [17] standards are developing.

Such reporting standards span the breadth of environmental, social and economic metrics [18] and include ISO standards, UN Global Compact, Global Reporting Initiative (GRI), Task Force on Climate-related Financial Disclosures (TCFD), Task Force on Nature-related Financial Disclosures (TNFD). One such standard is the European Sustainability Reporting Standard (ESRS) (based on CSRD) framework that incorporates cross-cutting standards (1–2), and specific (topical) standards for environment (E1–E5), social (S1–S4) and general (G1). The five environmental standards (E1–E5) of Climate change, Pollution, Water and marine resources, Biodiversity and ecosystems and Resource use and circular economy are the focus of this paper.

3 Approach

Figure 1 presents the research approach used. Step 1 was the literature review to establish knowledge available in the academic literature on digital twins (DTs) and sustainability performance reporting (SPR). This sought to confirm the guiding research objective and formed the basis for subsequent interviews and framework development. The interviews in Step 2 were conducted to refine the established knowledge from the literature by incorporating the prevailing thinking and practice from industry. It served to confirm the validity of the research endeavor in case academic publications were not indicative of current practice. Interviewee questions posed included: frameworks or guidance they used, the scale and scope of analysis they considered, criteria for including/excluding data, their data sources, how unavailable data is addressed, how they consider manufacturing and sustainability together and whether they were aware of any companies working on such integration. Step 3 used literature and empirical evidence gained from industry to develop a conceptual framework to guide a process to align digital manufacturing with sustainability reporting standards. Finally, Step 4 was the high-level illustration of the framework application based on a UK company.

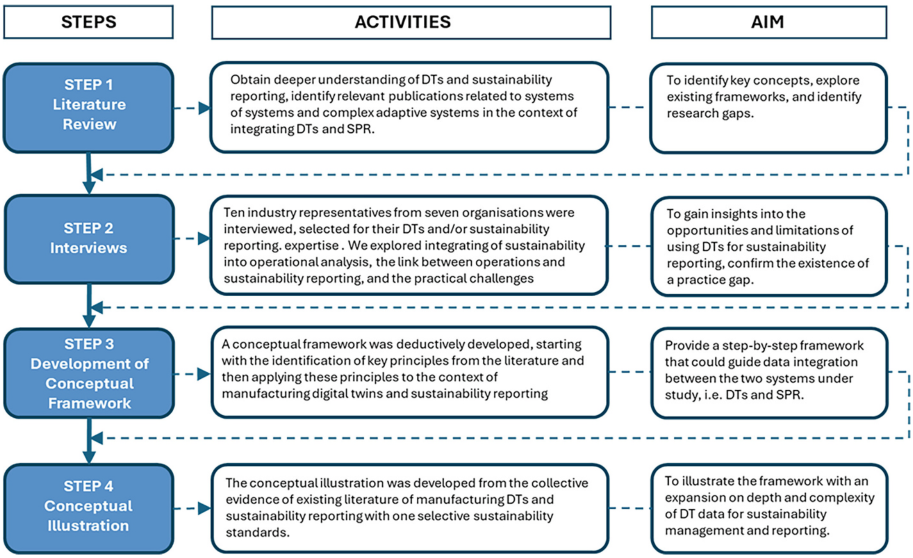

Fig. 1. The research approach used.

4 Results

4.1 Interview Insights

Table 1 summarizes the 10 interviewees from seven companies. All companies were operating in the manufacturing industry, i.e. each consultancy directly served manufacturing companies. Between one and three interviewees took part from each company. Each interviewee was invited for their depth of expertise in one of the three domains (indicated by the table text) of simulation modeling/digital twins, sustainability or manufacturing. All had depth of knowledge of sustainability or manufacturing (indicated by the table shading) even if their dominant role was in modeling. All were at least mid-career stage so had significant experience.

Table 1. Summary of the company type and main expertise of each interviewee.

#	Type \ Expertise	Digital twins	Sustainability	Manufacturing
1	Consultancy *sustainability*		Director	
2	Consultancy *sustainability*	Consultant	Consultant	
3	Consultancy *simulation*	Consultant	Consultant	Bus. development
4	Consultancy *simulation*	Director		
5	Consultancy *digital*		Innovation lead	
6	Manufacturer *automotive*		Director	
7	Manufacturer *aerospace*			Manager

All interviewees confirmed the disconnect between operations and external sustainability reporting. They cited a mismatch between high frequency manufacturing operations reporting and annual sustainability reporting. Many technical challenges were cited related to data in terms of sourcing (e.g. availability, quality, consistency, volume), use (e.g. aggregation of different sources for each metric) or breadth (e.g. technical, workforce, circularity, supply chain, etc.) For decision-making challenges, the mismatch between the cost and efficiency focus of digital twins versus the wider sustainability-driven focus at corporate level was identified. The lack of guiding processes or frameworks was seen as a barrier. Despite this, interviewees recognized the potential of digital twin enabled operations analysis to support progress beyond compliance and the exploit the utility of multi-scale strategic sustainability decision making.

4.2 Framework Development

The development of a conceptual framework to bring the sustainability reporting and the manufacturing domains together took a data flow view through standard approaches to sourcing for both domains. Figure 2 illustrates the data flows used in each of the two domains split across input and output categories. Each side/domain in the figure shows (once scope has been established) the flow of data from what is available and recorded to its use in performance reporting. In the planning stage of simulation methodologies, the performance reporting requirement drives the information collection plan and in turn the sourcing of the data items from the available inventory of data.

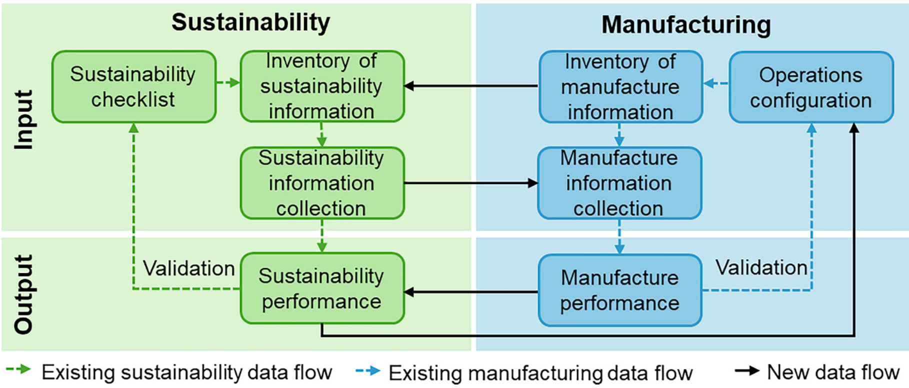

Fig. 2. Foundation of the information flows in sustainability reporting and manufacturing domains and their interlinking

Using Fig. 2 as the conceptual data flow representation, a conceptual framework was developed to operationalize the integration between the two domains shown in Fig. 3.

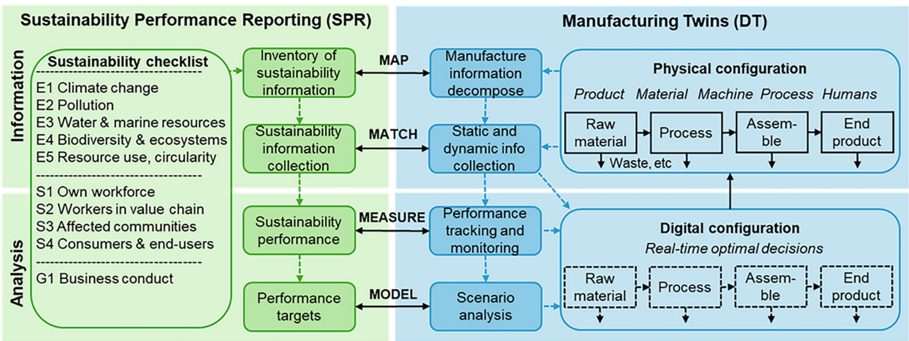

Fig. 3. Conceptual framework to operationalize the integration between sustainability performance reporting (SPR) with the manufacturing digital twin (DT).

The left-hand side of the figure is drawn from the standard steps within the selected EU standard, the European Sustainability Reporting Standard (ESRS) based on CSRD. This is mirrored on the right-hand side by the typical representations in the manufacturing domain. In the top right is a generic production process for the provision of information and this is mirrored in the bottom right by a corresponding digital twin for the analysis. Four steps of mapping, matching, measuring and modeling are used to align data collection, analysis and reporting between the two domains. For example, energy consumption in the manufacturing system is mapped and matched to the sustainability reporting requirements, i.e. to ESRS E1 Climate change. For example, manufacturing water consumption is matched to ESRS E3 Water and marine resources.

4.3 Framework Illustration

Figure 4 illustrates the application to a UK consumer products company with strong sustainability credentials. It was selected as all operations are completed on one site from which the company reports. Analysis of the sustainability reports and underlying calculations enabled the sustainability inventory, data collection and sustainability performance (KPIs) to be established. Operations sources raw materials, blends, packages into consumer retail containers and moves these to finished goods stores ready for dispatch. These were captured again for information sources, data and production metrics.

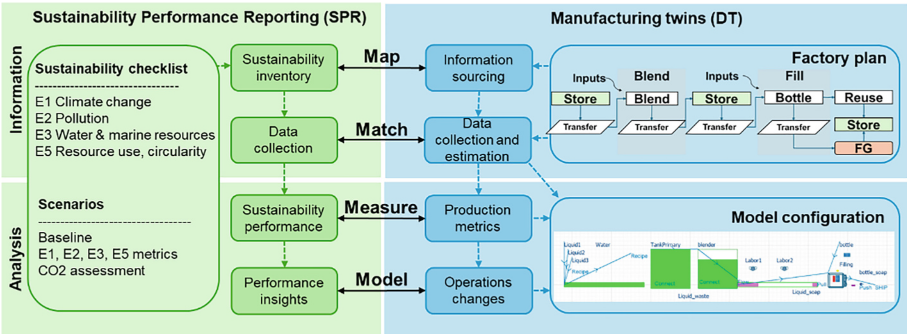

Fig. 4. Application of framework to consumer products company.

The focus was on the dominant revenue stream; bulk packaging and other products were ignored for simplicity. The ESRS focus was on categories E1, E2, E3 and E5 according to company needs. The model created in the Witness simulation software used available data to align with the sustainability KPIs. This was at a granular decision-making level that could be aggregated for annual reporting. The work demonstrated the ability to model manufacturing data that aligned with data categories needed for performance reporting.

5 Discussion

This research has sought to connect operations, enabled by digital twins, with a recognized sustainability reporting standard by creating an integrated mapping framework. It takes the language and standards from manufacturing and corporate reporting standards and guides the process of mapping, matching, measuring and modeling.

The research objective was to examine the bridge between operations and standard sustainability reporting, i.e. how granular operations reporting can support aggregate external reporting. The difference being the dynamic, granular data used from day-to-day production operation rather than aggregate sourcing from meter readings, billing, etc. Akin to dynamic Lifecycle Analysis (LCA), this has the advantage of granular insight for decision making but is variable according to prevailing conditions rather than the average, annualized reporting. The question of when to 'roll-up' the operations reporting to corporate level for effective decision making needs investigation.

The language of operations analysis and corporate reporting is suggestive of a one-way process in which improvements are inspired, investigated and implemented in operations and realized at corporate level. It is difficult to work from corporate external stakeholder reporting to inspire operational changes given the inability to breakdown the aggregate reporting data. However, if corporate reporting is built up from digital twin data it then becomes possible to inspire and investigate from a corporate reporting start point and use digital twins to game different improvement scenarios.

6 Conclusion

This exploration into the feasibility of connecting manufacturing operations, in particular, digital twins with compulsory sustainability reporting has demonstrated value and potential. Motivated by the significant environmental impact of operations and the imperatives on external sustainability reporting, this research established an academic and practice-oriented baseline before developing and demonstrating a framework.

From a theoretical perspective, no work exists nor do frameworks or supporting guidance exist in other fields. From a practice perspective, although the value of the connection was seen, there are no industrial instances of such connections from interviewing leaders in the simulation, manufacturing and sustainability fields.

This paper identified the untapped synergies between digital twin data and that of compulsory sustainability reporting. By aligning existing ways to build simulation models with those of a sustainability standard, a novel framework is proposed to enable operations data to be linked with sustainability reports. Our contribution is the previously unseen demonstration of how to connect day-to-day operations data with previously only annualized reporting that did not use operations data. This gives potential for operations data to feed into frequent assembly of sustainability reports and for the review of sustainability reports to drive focused operations practice change.

This work extends practice change from operational to strategic through the demonstration of corporate level improvements. The work shows potential for bridging between operations and sustainability domains and presented a means to achieve this. Future research lies in extending the digital twin scope beyond main shop floor operations, reviewing whether this bridging of enterprise activities improves decision making and understanding whether there are changes to decision maker behavior as a result.

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