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RESEARCH ARTICLE

Sustainable Healthcare Management Practices and Hospital Performance: Exploring the Role of Green Operations and Digital Innovation

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ABSTRACT

The health care sector is responsible for generating 4–5% of the world's GHGs and hospitals are expected to enhance the quality and efficiency of services offered, and, above all, decrease their significant environmental impacts. There are two areas on which a way forward can be provided: green operations that includes energy and water efficiency, waste reduction and green procurement, and digital innovation including applicability of the Internet of Things for monitoring and analytics and electronic health records, telemedicine. But much of the research on these changes has focused on them individually and few studies have connected them to hospital performance. This paper introduces an integrated model concept that explores the relationship between sustainable healthcare management practices, green hospital operations as a relevant concept of sustainable management, and digital innovation, and how these strategies affect hospital performance. Based on the natural resource-based view, dynamic capabilities theory and the triple bottom line, and integrating concepts from the healthcare, operations management and information systems literature, seven propositions are developed. To boost not only green operations but also digital innovations, sustainable management practices are proposed. The proposals for both capabilities are based on improving performance at the environmental, operational–financial, and quality-of-care levels, while also aiming to mitigate management practices. The use of digital innovation is proposed as another enabling technology of the processes of greening, as well as to improve their impacts on performance. The paper offers construct definitions, a measurement instrument adapted from existing scales, and a partial least-squares structural equation modelling analysis plan to allow for empirical testing. This framework provides a model that can be tested, and also serves as a blueprint for hospital managers and policymakers for a green and digital integration.

Keywords: sustainable healthcare, green hospital, green operations, digital innovation, hospital performance, natural-resource-based view, PLS-SEM

INTRODUCTION

Hospitals aim to promote health, yet they are a major source of environmental damage. One of the estimates at the global level is that health care causes 4-5% of global GHG emissions, large effects on air pollution, water use and waste [1–3]. The impact of health-system emissions on public health has been observed in the United States, where improved health care needed to care for patients has been shown to compromise others' health [4]. Hospitals contain areas that require a much higher energy intensity than other sectors, for example, operating theatres. WHO has now called a health systems to become climate-resilient and low-carbon [6]. Some national systems, such as the National Health Service in England, have set out to measure and reduce their carbon footprint systematically [7].

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Hospitals are also increasingly expected to meet demand for quality, access, and efficiency. Globally, good health systems are at the heart of the Sustainable Development Goals [8], and health system managers are required to optimize individual patient experiences, population health outcomes, and cost control, known as the triple aim [9]. Thus, sustainability is not 'on the edges'. Hospital operating budgets include the costs of energy, water, waste and supply chain. Certain evidence exists that it is possible to save significant amounts of money over time by having a sustainable hospital [10].

Meanwhile, hospitals are undergoing an ongoing transformation toward digitization. Digitalization, such as Electronic health records (EHRs), telemedicine, connected medical devices, data analytics, artificial intelligence (AI), and related technologies, is transforming care delivery and health management [11,12]. COVID-19 has expedited this change, especially in the transition towards virtual care [13]. The use of digital technologies helps make care better and more efficient [14]. They can also support environmental goals, for instance, by reducing paper use, enabling smart monitoring of travel, and reducing energy consumption [15].

However, although these advances have occurred side by side, research has mostly addressed green practices and digital innovation implementation in hospitals separately. Few studies address their application in the service sector, with most focusing on manufacturing [16-18]. Typical health IT studies either examine clinical and/or financial outcomes but not environmental outcomes [14, 19]. Consequently, there is an inadequacy in terms of knowledge of three questions:

1. the real experience of participants related to 'sustainable healthcare management' and its perceptions of 'green operations' and 'digital innovation';
2. how these two work together to impact hospital performance; and
3. whether an improvement of the impact of 'green' operations is achieved through digital innovation.

This paper aims to answer these questions by creating a conceptual framework that is both integrated and comprehensive, which is rooted in the natural-resource-based view (NRBV) [10,11] and dynamic capabilities theory [20,21]. It serves in three ways. First, it pulls together evidence regarding Sustainable Healthcare Management, "Green" Operations, Digital Innovation and Hospital performance. Second, it suggests a framework of 7 testable propositions (assuming that there are some which are not included in these. Third, it offers a measurement instrument from a validated source to measure the framework and a structural equation modelling (SEM) analysis plan using partial least squares (PLS) to test the framework in hospitals.

2. Theoretical Background

2.1 Natural-resource-based view

The resource-based view (RBV) suggests that activities can provide resource-based sustained advantage if they are valued, rare, inimitable and non-substitutable [22]. Hart extended this opinion also to the natural environment. In the NRBV, pollution prevention, product stewardship and sustainable development turn into assets for competitiveness [20]. Porter and van der Linde also suggested that environmental initiatives and design can boost efficiency and encourage innovation, not just add costs [23]. For hospitals, the NRBV presumes that green operations are both a capability and a compliance requirement that can reduce expenses, enhance image, and contribute to the quality of care.

2.2 Dynamic capabilities

Dynamic capabilities are an organisation's ability to integrate, build and reconfigure internal and external competencies in response to changing environments [21]. Digital transformation is a clear example: it requires organisations to change their structures, processes and value creation in response to new technologies [24]. In hospitals, digital innovation can act as a dynamic capability. It enables managers to sense inefficiencies, such as unnecessary energy use or waste, and to reconfigure operations to address them.

2.3 Triple bottom line and hospital performance

The triple bottom line concept holds that organisations should be evaluated on their economic, social, and environmental performance [25]. For hospitals, this aligns with the multi-dimensional performance perspective in health services research. Donabedian's structure–process–outcome model links organisational structures and processes to clinical outcomes [26]. The balanced scorecard includes both financial and non-financial measures [27], and the triple aim includes experience of care, population health and cost [9]. In the present paper, therefore, hospital performance of a hospital is defined broadly to encompass all dimensions of the hospital environment, its operations, financial performance, and the quality of care provided.

3. Literature Review

3.1 Sustainable healthcare management practices

The managerial commitments and systems that integrate environmental and social sustainability and are embedded in the hospital governance are called sustainable healthcare management practices (SHMP). These involve leadership buy-in, sustainability policies, sustainability targets, environmental management systems, staff training, support and motivation, and relationships with suppliers and communities [6, 7]. The wider literature on green management consistently cites top-management support and internal environmental management as antecedents to green practice adoption [16,18].

3.2 Green activities in the hospitals.

Green operations practices (GOP) are the operational activities used to accomplish sustainability. They do include energy and water efficiency, renewable energy, reduction and separation of waste, green purchases, sustainable transportation and low-carbon clinical practice, including reduction of high-impact anaesthetic gases [1,5,6] in hospital settings. Research reported by manufacturing companies has demonstrated that implementing green supply chain and green operations can lead to better environment and sometimes economic performance [16,17]. Carbon-footprint studies in the health care sector demonstrate that energy, pharmaceuticals, medical devices and its overall supply chain are the most promising areas of reduction [4,7].

3.3 Digital innovation in hospitals.

Digital Innovation (DI) is a term used to describe the use of digital technologies and innovation, to change the processes and services within the hospital. These include the use of EHRs, telemedicine, IoT monitoring, smart building

management, data analytics, AI, and so forth [11,12,24]. EHR use has been widely adopted since the late 2000s [19], and health IT reviews have been overwhelmingly positive about its impact on quality, efficiency, and provider satisfaction [14]. Information systems can also contribute to environmental sustainability by tracking resource consumption, streamlining processes, and eliminating the need for physical tasks and activities [15].

3.4 Research gaps

Table 1 shows that the literature summarised therein suggests three gaps. First, green operations research is predominantly found in manufacturing, and its applicability to hospitals, where doctors may seem unable to make changes for patient safety reasons, has not been studied extensively. Second, studies in digital health tend not to use an environmental lens. Third, few frameworks examine the impact of the combination of management practices, green operations, and digital innovation on hospitals' multidimensional performance.

Table 1. Summary of key evidence underpinning the framework.

Theme	Key evidence	Implication for this study	Sources
Environmental footprint of health care	Health care contributes roughly 4–5% of global emissions; operating theatres and supply chains are major contributors	Hospitals are an important target for green operations	[1–3,5]
Health impact of health care emissions	Emissions from the health system cause measurable public-health damage	Environmental performance is part of the health mission	[4]
Decarbonisation programmes	National and WHO frameworks set out low-carbon, climate-resilient health systems	Management commitment and targets are antecedents	[6,7]
Economics of green hospitals	Sustainable hospital practices can reduce operating costs	Green operations may improve financial performance	[10,23]
Green operations and performance	Green supply chain practices improve environmental and, under conditions, economic performance in industry	Basis for P1 and P3; transfer to hospitals needed	[16–18]
Digital health and performance	Health IT shows predominantly positive effects on quality and efficiency	Basis for P2 and P4	[11,14,19]
IT for sustainability	Information systems can monitor and reduce resource use	Basis for P5 and P7	[15,24]

4. Conceptual Framework and Propositions

Figure 1 shows the proposed framework, and Table 2 defines the constructs. Sustainable healthcare management practices are the strategic antecedent. Green operations and digital

innovation are the operational and technological capabilities through which management intent is realised. Hospital performance is the outcome.

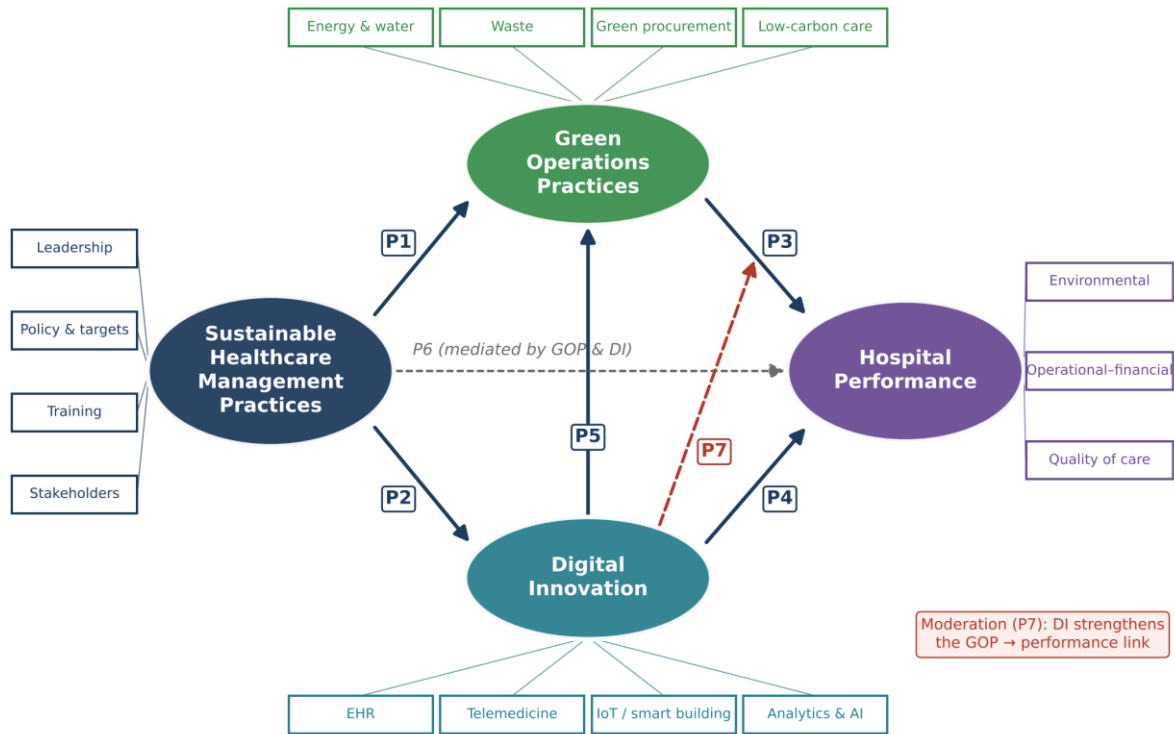


Figure 1. Proposed conceptual framework shown as a structural model. Ovals represent the latent constructs and rectangles their dimensions (Table 2). Solid arrows show direct relationships (P1–P5), the dotted arrow the indirect effect of

management practices on performance (P6), and the red dashed arrow the moderating effect of digital innovation (DI) on the relationship between green operations practices (GOP) and performance (P7). Developed by the authors from [20,21,25].

Table 2. Construct definitions.

Construct	Definition	Dimensions / examples	Theoretical anchor
Sustainable healthcare management practices (SHMP)	Managerial commitments and systems that embed environmental and social sustainability in hospital governance	Leadership commitment; policies and targets; environmental management system; training; stakeholder engagement	NRBV [20]
Green operations practices (GOP)	Operational actions that reduce the environmental impact of hospital activities	Energy and water efficiency; waste segregation and reduction; green procurement; low-carbon clinical practice	NRBV; green operations [16]
Digital innovation (DI)	Adoption and creative use of digital technologies to transform hospital processes and services	EHR; telemedicine; IoT and smart building systems; analytics and AI; paperless processes	Dynamic capabilities [21,24]
Hospital performance (HP)	Multi-dimensional outcomes of hospital activity	Environmental; operational–financial; quality of care and patient satisfaction	Triple bottom line; triple aim [9,25]

4.1 Management practices as antecedents

The NRBV indicates that environmental capabilities need to be created in a conscious manner via the organisational system and the management commitment [20]. Leadership commitment, sustainability policies and staff training provide direction, resources, and skills to hospitals to green operations and logistics. This management approach also supports investment in digital tools, improving visibility and control

over resource use [15, 24].

Proposition 1 (P1). Adopting green operations practices in hospitals is positively related a sustainable healthcare management practices.

Proposition 2 (P2). Digital innovation is positively related to sustainable healthcare management practices in hospitals.

4.2 Green operations and hospital performance are

positively related

Green operations are a direct diversion of impact on the environment. But they also save money: energy efficiency, waste reduction, and enhanced procurement lower resource consumption, which may be significant over a number of years [10,23]. POTENTIALS FOR PATIENT EXPERIENCE, STAFF MORALE AND REPUTATION: Cleaner environments, safer chemical management and an in-progress focus on sustainability may further enhance patient experience and staff morale and reputation [28].

Proposition 3 (P3). Green operations practices a positively associated with hospital performance (environmental, operational–financial, and quality of care).

4.3 Digitalisation and Hospital performance

Digital innovation can help better coordinate care, minimise errors and duplicate testing, decrease wait times, and support data management [12,14]. Telemedicine can expand access and reduce patient travel by connecting information. Proposition 4 (P4). There is a positive relationship between innovation in the digital world and the hospital's performance.

4.4 Digital innovation as an enabler of green operations -

To conduct effective green operations, digital technologies provide data and control. These include devices that smart-meter energy and water, IoT-based building management, e-waste tracking devices, electronic documentation instead of paperwork, and analytics to optimise supply chains [15]. From a dynamic capabilities perspective, digital innovation can enable hospitals to sense and act on environmental inefficiencies [21].

Proposition 5 (P5). Green operations practices, and digital innovation are positively related to each other.

4.6 Mediating and moderating roles

If the added value of management practices is primarily developing operational and technological capabilities, management practices' impact on performance should be reflected mainly in the extent of green operations and digital innovation.

- Proposition 6 (P6). Green operations practices and Digital innovation mediate this relationship.
- Due to the reinforcing nature, green and digital capabilities might also reinforce each other. Consider and optimize green operations digitally, as this is likely to yield greater benefits in hospitals.
- Proposition 7 (P7). Digital innovation positively moderates the relationship between GOPs and hospital performance, thus the relationship is stronger as the value of the digital innovation increases.

In fact, the effects of P5 and P7 can be described with a very simple typology (Figure 2). Hospitals with limited capabilities and limited footprint ("traditional") are in for high costs and footprint. Hospitals in which only one capability results were strong either in environmental savings that must be managed to realize, for example, by investments in air conditioning systems, or in process benefits that do not lead to environmental gains, for example, improved cost efficiency in the operating room (expansion only of the digital domains). Hospitals with both are expected to be the best in terms of overall performance ("green-digital leaders").

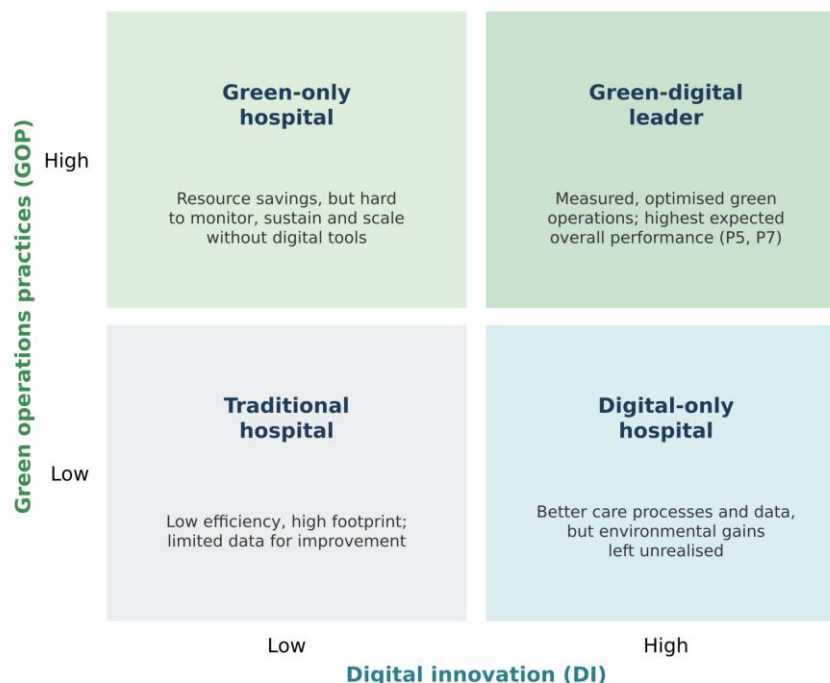


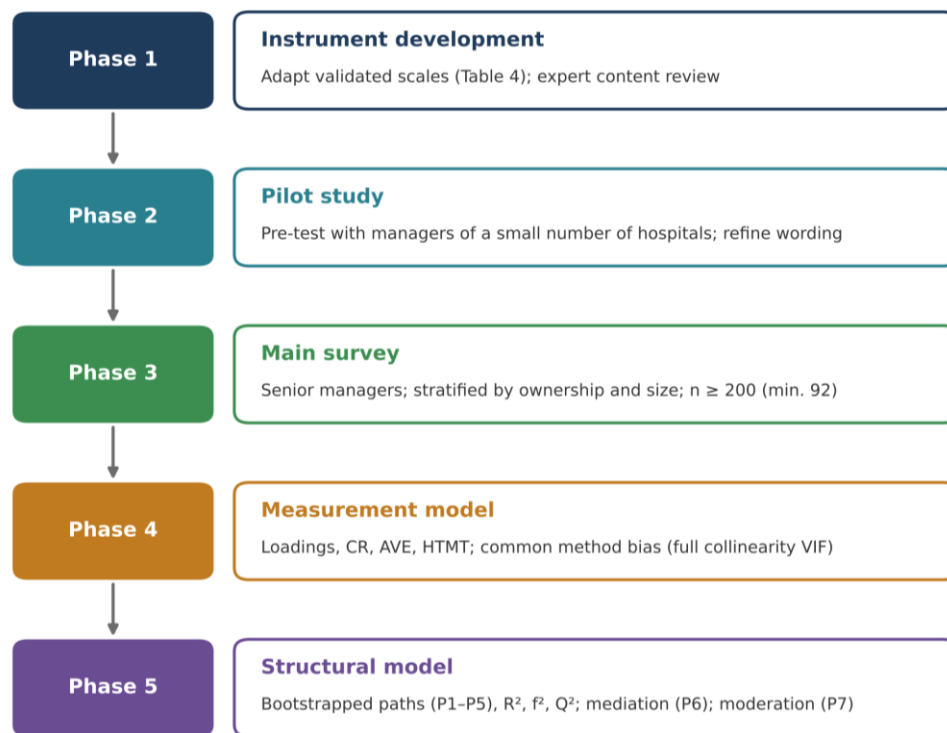
Figure 2. Green–digital typology of hospitals implied by propositions P5 and P7 (developed by the authors from [15,23]).

Table 3. Research propositions and their theoretical basis.

No.	Proposition	Type	Theoretical basis
P1	SHMP $\rightarrow$ GOP (+)	Direct	NRBV; top-management support [16,20]
P2	SHMP $\rightarrow$ DI (+)	Direct	Dynamic capabilities; digital transformation [21,24]
P3	GOP $\rightarrow$ HP (+)	Direct	NRBV; Porter hypothesis [20,23]
P4	DI $\rightarrow$ HP (+)	Direct	Health IT benefits [12,14]
P5	DI $\rightarrow$ GOP (+)	Direct	IS for sustainability [15]
P6	SHMP $\rightarrow$ GOP / DI $\rightarrow$ HP	Mediation	Resource orchestration through capabilities [21,22]
P7	DI $\times$ GOP $\rightarrow$ HP (+)	Moderation	Complementarity of green and digital capabilities [15]

5. Proposed Methodology for Empirical Validation

To support empirical testing, a research design is proposed (Figure 3).

**Figure 3.** Proposed five-phase research design for empirical validation of the framework [29,30].

5.1 Research Design And Sampling

A cross-sectional survey of hospitals, using the hospital as the unit of analysis, is recommended. Senior managers with familiarity with operations and strategy, including hospital administrators, operations/facility managers, quality managers and heads of IT, should be the respondents. Stratified sampling according to the number of beds and public and private ownership would enable a comparison between the different types of hospitals. With five predictors in the model (including the interaction term), the minimum sample size for a regression model with a medium effect size ($f^2 = 0.15$), based on G*Power with α of 0.05 and 80% power, is 92 [31]. No fewer than 200 useful responses are suggested to allow for subgroup

comparisons.

5.2 Measurement instrument

The multi-item, reflective constructs can be measured using 5-point Likert items (1 = strongly disagree, 5 = strongly agree) that are adapted from existing instruments (Table 4). Perceptual items may be used to measure the quality of hospital performance; objective indicators may be used if they are present. Examples include energy use per bed, waste per patient-day, average length of stay, bed occupancy, patient satisfaction scores, and operating margin. The instrument should be pre-tested and validated by experts or pilot-tested with a small group of hospitals prior to data collection.

Table 4. Proposed measurement instrument (five-point Likert scale; 1 = strongly disagree, 5 = strongly agree).

Construct	Code	Item	Adapted from
SHMP	SHMP1	Top management is committed to environmental sustainability in our hospital.	[16]
	SHMP2	Our hospital has a written sustainability policy with measurable targets.	[6]
	SHMP3	Staff receive regular training on environmentally responsible practices.	[18]
	SHMP4	We collaborate with suppliers and the community on sustainability goals.	[16]
GOP	GOP1	We actively reduce energy and water consumption in our facilities.	[6]
	GOP2	Clinical and general waste is segregated, reduced and safely disposed of.	[1]
	GOP3	Environmental criteria are used when purchasing products and services.	[16]
	GOP4	We adopt lower-carbon clinical practices where clinically appropriate.	[5]
DI	DI1	Our hospital uses an integrated electronic health record system.	[19]
	DI2	We provide telemedicine or virtual consultation services.	[13]
	DI3	Digital systems (e.g. smart meters, IoT) monitor resource use in our hospital.	[15]
	DI4	Data analytics or AI tools support clinical and managerial decisions.	[12]
HP	HP1	Our energy, water and waste intensity has decreased in recent years.	[7]
	HP2	Our operating costs have decreased relative to our activity level.	[10]
	HP3	Patient satisfaction has improved in recent years.	[9]
	HP4	Quality and safety indicators (e.g. errors, readmissions) have improved.	[26]

5.3 Data analysis plan

PLS-SEM is recommended because the model is prediction-oriented, includes mediation and moderation, and may be estimated with moderate sample sizes [29,30]. The analysis would proceed in four steps, with the thresholds given in Table 5:

1. assessment of the measurement model, covering indicator reliability, internal consistency, convergent validity [32] and discriminant validity using the heterotrait–monotrait ratio [33];
2. assessment of common method bias through procedural remedies and full collinearity variance inflation factors (VIFs) [34,35];
3. assessment of the structural model, covering path coefficients with bootstrapping (5,000 resamples), R^2 , f^2 and predictive relevance; and
4. testing of indirect effects by bootstrapping [36], and of the moderation in P7 by a two-stage interaction approach.

Table 5. Proposed PLS-SEM evaluation criteria and thresholds.

Stage	Criterion	Threshold	Source
Measurement model	Indicator loading	≥ 0.708	[29]
	Composite reliability / Cronbach's alpha	0.70–0.95	[29]
	Average variance extracted (AVE)	≥ 0.50	[32]
	Discriminant validity (HTMT)	< 0.85 (or < 0.90)	[33]
Common method bias	Full collinearity VIF	≤ 3.3	[34,35]
Structural model	Inner VIF	< 3	[29]

	Path significance	Bootstrapping, 5,000 resamples; $p < 0.05$	[30]
	R^2 / effect size f^2	R^2 0.25, 0.50, 0.75 weak/moderate/substantial; f^2 0.02, 0.15, 0.35	[29]
	Predictive relevance Q^2	> 0	[29]
Mediation (P6)	Indirect effect	Bootstrap confidence interval excluding zero	[36]
Sample size	Minimum n ($f^2 = 0.15$, power 0.80, 5 predictors)	92 (target ≥ 200)	[31]

6. Discussion

6.1 Theoretical implications

The framework makes three contributions to theory. First, it names NRBV to the extent that it is applied to manufacturing, to hospitals. It suggests that environmental skills in healthcare are also beneficial from a value-enhancing perspective beyond cost savings [20,23]. Second, it frames digital innovation as a dynamic capability that can both deliver direct performance and support green operations. It connects together two literatures that have, more or less, evolved separately: the health IT literature and the green management literature [14,15]. Third, it extends the triple bottom line and triple aim [9,25] to the realm of sustainability research in hospitals, as it was defined across environmental, operational, financial and quality dimensions.

6.2 Managerial and policy implications

6.3 Limitations and future research

As a conceptual paper, this study does not test the propositions empirically. Future research should validate the framework with survey data from hospitals in different countries and ownership types, ideally combining perceptual measures with objective environmental and operational indicators. Longitudinal designs would help establish causality and

capture the time lag between investment and performance. Further work could examine additional moderators, such as hospital size, ownership, regulatory pressure and funding, and specific digital technologies such as AI-based energy management.

7. Conclusion

Hospitals face a dual objective: enhancing care and efficiency while reducing their significant environmental impact. This paper aimed to develop an integrated framework linking sustainable health care management practices to hospital performance through green health care operations and digital innovation. We developed seven propositions based on the natural-resource-based view and dynamic capabilities theory. Proposals for green operations and Digital Innovation through management practices. Both capabilities are expected to improve hospital performance and mediate the impact of management practices. Digital innovation is also suggested to enhance green operations and their effects. To support empirical validation, a measurement instrument and a PLS-SEM analysis plan are provided. The framework provides a basis for researchers to test and can serve as a roadmap for managers to implement green and digital strategies in sustainable, high-performing hospitals.

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