UNVEILING THE SYNERGY: ECONOMIC AND ENVIRONMENTAL VALUE OF BUILDING MANAGEMENT SYSTEMS IN THE ERA OF DIGITAL SERVICE INNOVATION

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ABSTRACT

Purpose:
The paper aims to address the under-utilisation of Building Management System (BMS) data by proposing a model to assess both the economic and environmental value of improved data use in BMS, focusing on system monitoring and remote service, while guiding the transition to digital service offerings in building management.

Design/Methodology/Approach:
Through interviews with stakeholders in the emergency lighting sector, the application of a causal loop diagram and models described in the literature, the study develops a model based on the concepts of servitization and digital service innovation. It quantifies the value creation to customers, value capture for providers, and the environmental impact by considering the level of digitalisation of system monitoring and remote control.

Findings:
The model demonstrates how an increased level of digitalisation – through monitoring and remote control – can significantly improve service delivery, reduce operational costs, and improve environmental sustainability. It identifies a strategic shift from pay-per-service to subscription models as critical to maintaining provider revenues in the face of increased service efficiency and reduced manual intervention.

Originality/Value:
This study contributes a novel framework for quantifying the benefits of digital BMS, highlighting the potential for improved operational efficiency, cost savings and environmental benefits. It highlights the role of servitization and digital transformation in redefining value creation in building management and provides insights into the strategic deployment of digital services.

KEYWORDS: value creation, value quantification, value visualization, building management systems

1. INTRODUCTION

Building management systems (BMS) play a crucial role in monitoring, managing, and controlling building service systems, particularly mechanical and electrical systems. While early systems emerged in the 1960s, the introduction of user interfaces in the 1990s enabled data transmission and visualization for building operators (Brambley et al., 2005).

However, current data utilization practices often fall short of maximizing the value proposition of BMS. The decreasing cost of hardware (sensors, storage, processors) and standardized protocols have facilitated the rise of digital services (Burak Gunay et al., 2019). Research highlights the potential for data analysis to optimize energy consumption and detect faults, ensuring system performance (Brambley et al., 2005; Burak Gunay et al., 2019; Fernandes et al., 2018; Piette et al., 2001). Despite these advancements, opportunities remain for improvement in leveraging data in areas, such as systems monitoring and remote control.

The building management sector faces a growing labour shortage in the EU (Brucker Juricic et al., 2021). BMS data plays a vital role in this context by assisting with malfunction detection and information retrieval, reducing service technician response times (Bader & Oevermann, 2017). Furthermore, real-time, and remote access to BMS data allow for optimized technician routes and quicker problem resolution (Mori & Fujishima, 2013).

Despite the abundance of data stored in BMS, its effectiveness can be hampered by unnecessary text, irrelevant information, or insufficient details for actionable insights (Marocco & Garofolo, 2021). Improving data quality and visualization can significantly enhance building maintenance efficiency and lower operational costs. Additionally, remote access and control capabilities can further optimize service delivery by reducing travel time and on-site visits. Interviews with SMEs in Switzerland and Germany conducted for this study confirm the recognized benefits of monitoring and remote-control systems.

However, these companies are still focused on reactive and on-demand services, such as pay-per-service, rather than designing, pricing, and delivering data-driven services. Limited knowledge of how to unlock the full potential of digital BMS and quantify its economic benefits for both customers and providers is a major barrier. Providers are concerned that a shift to data-driven services could lead to fewer customer interactions (i.e. fewer billable services, less billable time, and less travel to customer sites for billable work) all of which are significant considerations that discourage them from developing digitally enabled services.

This paper proposes a model to comprehensively assess the economic and environmental value of data utilization within BMS. The model offers a framework for quantifying these benefits and promoting a more efficient, cost-effective & environmentally conscious use of data-driven building management services. It is thus designed to serve as a tool for building managers to support their decision to invest in BMS and to design an adequate service revenue model.

In the following sections, we first present the theoretical foundations of our model, followed by a detailed presentation of the model itself, including its design and methodology. We then highlight the practical application of the model through a case study in the emergency lighting industry, demonstrating its quantified benefits for provider, customer, and the environment. This progression from theory to practice highlights the model's role in driving digitalisation for operational efficiency and sustainability in building management systems.

2. THEORETICAL BACKGROUND

2.1 Servitization as a Strategic Transformation

Servitization, a pivotal shift from product-focused to service-centric business models, underscores the evolution towards cultivating enduring customer relationships through comprehensive service offerings. This transformation, vital in the realm of building management, advocates for integrating digital services – such as condition-based maintenance and remote control – within traditional product offerings. The concept, originating from the seminal work of Vandermerwe & Rada (1988) has gained momentum, emphasizing the creation of value beyond mere transactions to foster deeper customer engagement and loyalty (Grönroos, 2015; Nasiri et al., 2023).

2.2 Digital Service Innovation for Effective Building Management

The advent of digital service innovation stands as a cornerstone for the successful implementation of servitization in building management. Embedding digital technologies within Building Management Systems (BMS) paves the way for novel service offerings that not only elevate customer value but also engender a more profound engagement with building managers. Tools enabling real-time data visualization and remote diagnostics exemplify how digital capabilities can empower decision-making processes, thereby preventing equipment failures (Momeni et al., 2023; Rabetino et al., 2024).

2.3 Servitization and Environmental Sustainability

In an era where environmental stewardship is paramount, servitization emerges as a strategic pathway to align building management practices with sustainability goals. By leveraging data-driven insights for optimal resource use, servitization aligns with environmental mandates, propelling organizations towards compliance with stringent regulations. Notably, the regulatory landscape acts as a catalyst, propelling industries towards servitization to fulfil sustainability criteria, a notion echoed by recent studies (Zhang et al., 2024).

2.4 Overcoming Resistance: A Value-Centric Approach to Servitization

The essence of this transition lies in effectively articulating the value proposition (Grönroos, 2015) of servitization to building managers, which necessitates addressing challenges such as cultural inertia and resistance to change (Hamel, 1996; Kotter, 2012) and overcoming the prevalent product-centric mindset. Quantifying the economic and environmental benefits serves as a compelling argument (Karamitsos et al., 2020) for adopting a service-oriented approach.

2.5 Product-Service Systems (PSS): A Gateway to Economic and Environmental Sustainability

The building management systems and their management processes can be considered Product-service systems (PSS). PSS, embodying the integration of products and services, presents a viable strategy for addressing environmental concerns while balancing economic and social objectives. Despite the potential for greater resource efficiency, the environmental impact necessitates careful consideration during the design phase of PSS (Doni et al., 2019; Tukker, 2004). The classification into product-oriented, use-oriented, and result-oriented services provides a framework for understanding the shift towards outcome-based models, further enriched by the exploration of digital technologies like IoT and big data analytics as enablers of sustainable value creation (Bressanelli et al., 2018; Ding et al., 2023).

2.6 Modelling and Quantification of Environmental Value in Smart Services

Addressing the paucity of research on quantifying environmental value in smart services, this study draws upon the methodologies of Maliqi et al. (2024) and Meierhofer & Heitz (2023), integrating life cycle assessment with PSS. The proposed model emphasizes the use of modular designs and smart devices to enhance product longevity, resource efficiency, and circularity. A causal loop diagram serves as a foundational tool for understanding the system dynamics and value streams, facilitating the development of a calculation model to explore complex interactions within the ecosystem.

3. METHODOLOGY

3.1 Interviews

We conducted in-depth interviews with representatives of four key stakeholders in the emergency lighting sector: a manufacturer, a project provider, an electrical contractor, and a facilities management company. A common theme in these discussions was the current shortage of qualified service engineers in the market. This shortage is attributed to the physically demanding nature of the work and the industry's inability to compete with the higher salaries offered by other sectors, such as the solar industry. One company highlighted a particular interest in optimising the potential of their systems due to their customer base – cleaning contractors with additional responsibilities as facility managers, who often lack knowledge and experience of the systems.

When asked about the potential efficiencies that could be achieved through improved data monitoring and remote-control capabilities, respondents estimated time savings in the range of 30 to 80%. This suggests that there is significant perceived value in such PSS, despite their current under-utilisation. Motivated by these findings, we have developed a decision support tool to analyse key metrics such as workforce utilisation, value creation for customers, value capture for providers and the environmental impact in different scenarios. This tool aims to provide empirical support for strategic decision-making in the adoption of digital BMS solutions.

3.2 Ecosystem and Causal Loop Diagram

To build the foundation of our model, the complex system under examination was subjected to a thorough analysis. This involved identifying all the relevant actors, their key performance indicators (KPIs) and the links between them. These elements were systematically mapped using a causal loop diagram (see Figure 1). This diagram not only illustrates the relationships between the actors and their KPIs but also serves as a fundamental tool for the subsequent modelling process.

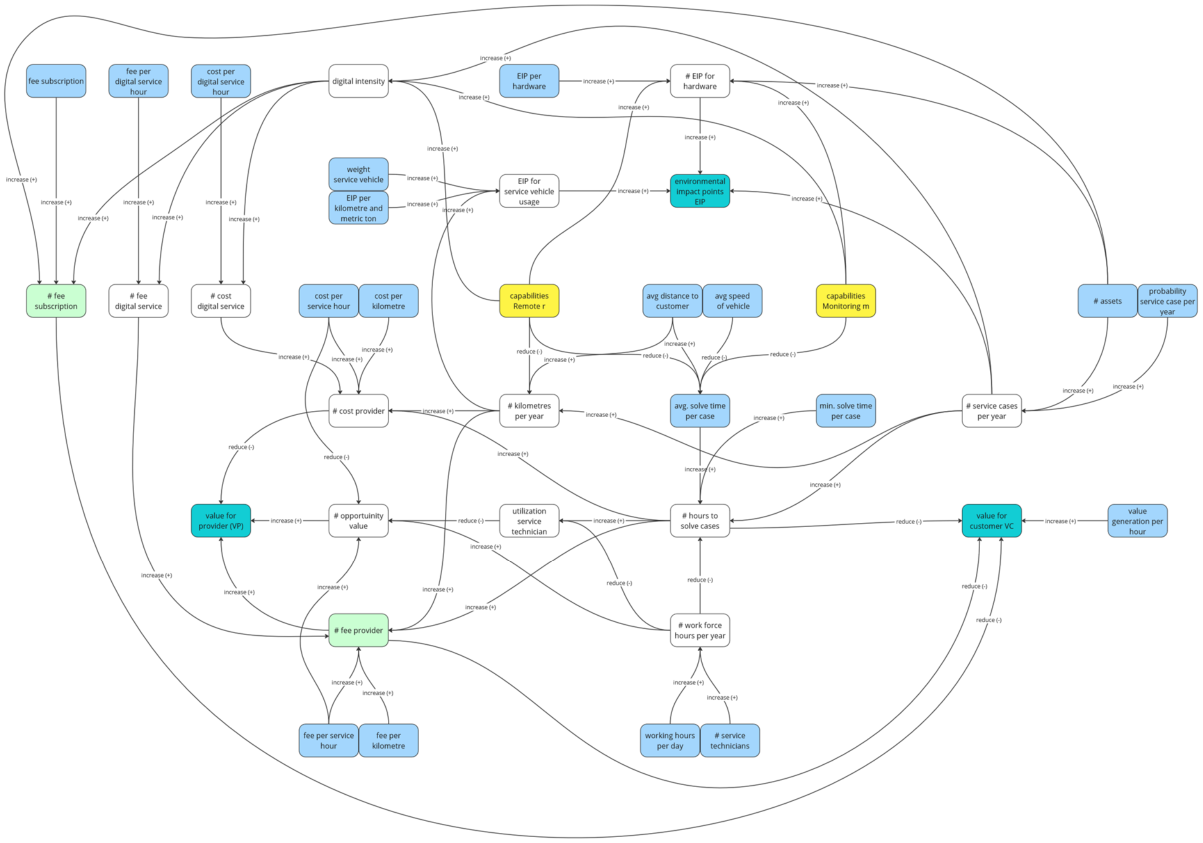

Figure 1: Casual Loop Diagram

3.3 Model

Our model has been developed using the existing literature on value calculation models (Meierhofer et al., 2021, 2022; Meierhofer & Heitz, 2023), which can quantify the value for the customer, the provider and the environment based on smart service configurations, considering the four phases of a customer life cycle. Rather than considering all four phases (initiate, expand, stabilize, terminate), our model focuses only on the phase stabilize, when the customer has already deployed and is using the product. Unlike the mentioned literature models, this model does not include services such as preventive maintenance or optimisation but only focuses on system monitoring and remote control.

This focus decision is based on the interviews, which we use as an assumption for the model because, according to their statements, the systems installed already can provide data on their operational status and can be controlled via an interface. We therefore focus this model on these low-cost services – picking the low-hanging fruit – and assume that it would be possible to equip all systems with monitoring and remote-control hardware at low or moderate cost. With just a few parameters from experience or business records, the model calculates the potential value to customers, providers, and the environment in different smart service configurations.

3.4 Monitoring and Remote Service

These different smart service configurations are modelled by their digitalisation level with the variables m (monitoring) and r (remote control), which can take on a value between 0 and 1, where 0 means that the digital service is not used and 1 means that the service is fully used, with gradual levels between 0 and 1. In addition, the variable r cannot be greater than 0 when $m = 0$, as remote control implies that monitoring is possible. The higher the value of m, the less time it takes to resolve the case, as monitoring means that more and higher quality data is available from the device for the technician to use, and the higher the value of r, the fewer kilometres it takes on average to travel to the customer and the less time it takes to resolve the case, as there is no travel time.

3.5 Value for Provider and Value for Customer

We calculate the mutual value creation between customer and provider as value creation for the customer V_{C} and value capture for the provider V_{P} (for details see (Meierhofer et al., 2022)), which are calculated based on the variables m and r.

The economic service value created for the customer by the supplier, denoted by V_{C}, depends on the uptime of the system. To calculate this value, the process starts with the calculation of the actual running hours, which is the difference between the estimated running hours E_{RHF} and the expected downtime E_{DT}. These calculated hours, expressed as $(E_{RHF} - E_{DT})$, are then multiplied by the monetary value that the customer generates per hour of operation, V_{G}. Finally, to derive the net economic value for the customer, the service fee F_{P} charged by the supplier is subtracted.

$$V_{\mathrm{C}}(m,r) = V_{\mathrm{G}} \cdot (E_{\mathrm{RHF}} - E_{\mathrm{DT}}) - F_{\mathrm{P}}(m,r)$$

We define V_{P} as the value captured by the provider through the provision of services. This value is given as the fee charged to the customer, $F_{\mathrm{P}}(m,r)$, minus the cost incurred by the provider to provide the service, $C_{\mathrm{P}}(m,r)$, adjusted by the inclusion of opportunity costs, C_{O}. The opportunity cost component, C_{O}, considers the potential value that could have been realised by maximising the utilisation of workforce to 100%.

$$V_{\mathrm{P}}(m,r) = F_{\mathrm{P}}(m,r) - C_{\mathrm{P}}(m,r) + C_{\mathrm{O}}$$

In determining the service charge, $F_{\mathrm{P}}(m,r)$, our model distinguishes between two scenarios: a) pay-per-service intervention and b) service intervention included in a recurring subscription charge.

In the traditional pay-per-service model (a), the customer is charged for each manual service action performed by the provider, such as an on-site visit or a manual remote intervention. The fee structure is based on a cost-plus approach that includes the costs incurred by the provider – typically labour costs for active working time, IT system and organization costs, including travel – plus a profit margin. Conversely, in the subscription model (b), the customer pays a periodic (often annual) subscription fee for the continued operation of the service, regardless of the manual intervention or technical effort required by the provider.

Enhanced level of digitalisation, characterised by the variables m and r, allows fewer and shorter manual interventions thanks to more precise fault diagnosis through system monitoring and advanced remote service capabilities. Consequently, in the model (a), which operates on a pay-per-service basis, this technological enhancement leads to a reduction in the service fees $F_{\mathrm{P}}(m,r)$ paid by the customer to the provider, thereby reducing V_{P} and increasing V_{C}. This shift suggests that a transition from model (a) to model (b) – from a transactional service fee to a subscription-based model – is essential to avoid value destruction for the provider. This transition is a major undertaking, requiring significant efforts in customer communication and change management. Our objective is to elucidate the quantitative impact of this transition on V_{P} and V_{C}, and thus provide analytical support for strategic decision-making regarding the optimal configuration of (a) and (b).

3.6 Environmental Impact

Our model uses the ecological scarcity method from Switzerland, refined by the Swiss Federal Office for the Environment (FOEN). This method covers a wide range of environmental impacts, including emissions and resource use. It is regularly updated to incorporate the latest scientific knowledge and standards, thus providing a more comprehensive assessment of environmental impacts. The key metric used is the Environmental Impact Point (EIP), which assesses the environmental impact of activities based on ecological scarcity.

Our model focuses on two environmental factors: the reduction in travel distance $EIP_{\mathrm{km}}(r)$ achievable through remote control r $(\text{scaling down with increasing } r)$, and the impact of hardware use $EIP_{\mathrm{hw}}(m,r)$, $(\text{scaling up with } m$ and $r)$. The combined environmental impact is described as:

$$EIP(m,r) = EIP_{\mathrm{km}}(r) + EIP_{\mathrm{hw}}(m,r)$$

The model can be customised for bespoke analysis, considering service frequency, travel distance and vehicle attributes.

4. FINDINGS

4.1 Case Emergency Lighting

This study examines a particular case within the emergency lighting sector in Switzerland and Germany, where buildings are typically equipped with centralised emergency lighting systems, that are connected to BMS. These systems, consisting of a control unit and batteries, provide lighting for emergency exits and escape routes in the event of a power failure. We investigate a company that not only sells these systems to property owners but also maintains them. The analysis includes the calculation of various KPIs such as workforce utilisation, system availability and added value for the provider and the customer, based on input parameters that reflect the company profile, the two scenarios (a) and (b) and the level of digitalisation. The aim is to assess the added value of increasing the level of digitalisation (m and r) for both the provider and the customer, the environmental impact, and the effect on the utilisation of the workforce.

4.2 Value for Customer, Value for Provider and the Dependence on Utilization

Figure 2 compares how value creation for the customer and value capture for the provider varies with the level of digitalisation m and r and the scenarios.

In the pay-per-service scenario (a), increasing digitalisation leads to a decrease in the value captured by the provider but an increase in the value created for the customer, as depicted towards the top left (magenta, M 1.00, R 1.00). This reflects the provider's reduced ability to charge due to increased efficiency, which reduces the cost to the customer.

Conversely, in the subscription scenario (b), further digitalisation reduces the provider's costs due to increased efficiency but allows the provider to maintain or increase subscription revenues, moving to the lower right (green, M 1.00, R 1.00). The customer gets a marginal improvement in service (in this emergency lighting case), but the cost of more sophisticated subscription models increases.

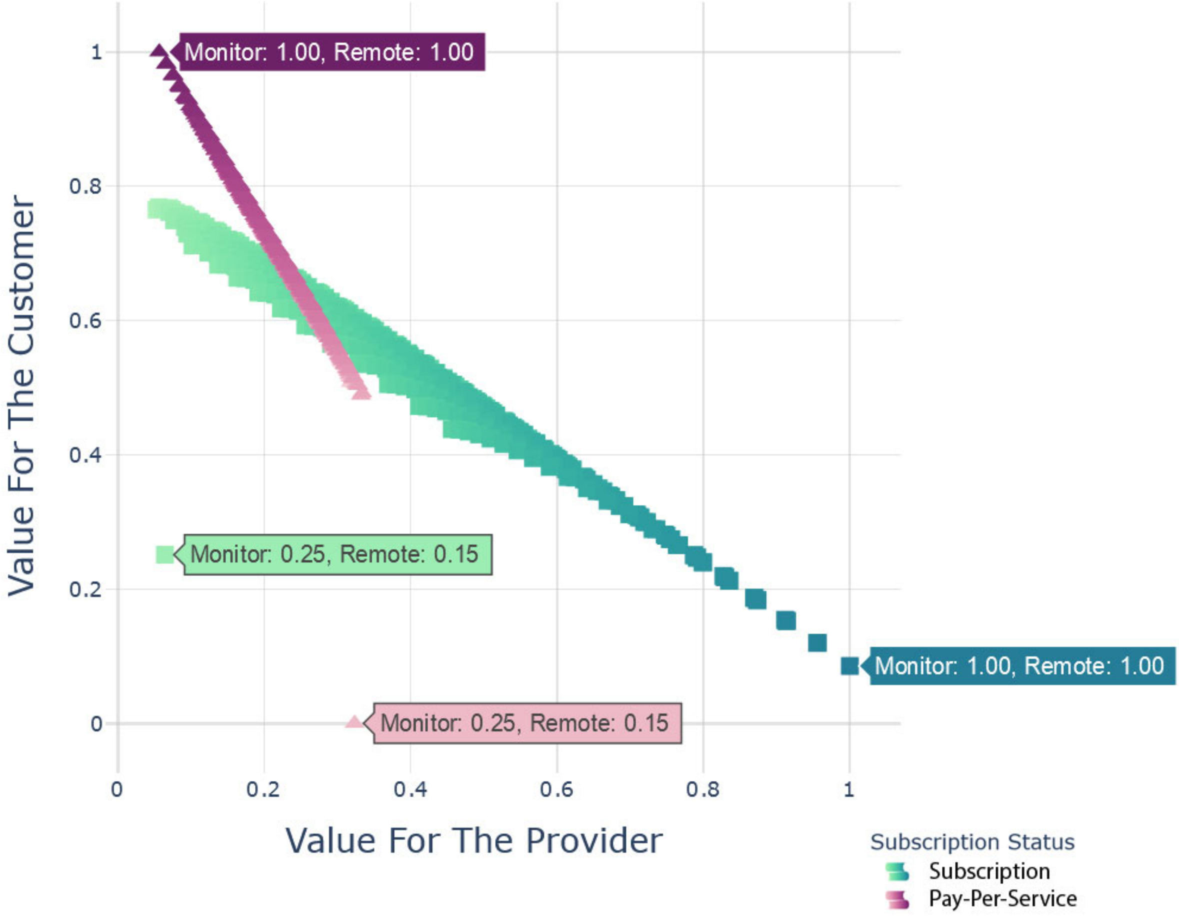

Figure 2: Value creation and capture constellations for the two scenarios pay-per-service (a) and subscription (b). The gradient from light to dark indicates increasing levels of digitalisation with darker shades indicating a higher cumulative level of monitoring and remote capabilities (higher value of $m + r$).

We assume that the provider is constrained by a fixed and limited number of human service technicians and faces the challenge of resource constraints. High workforce utilisation leads directly to increased waiting times for service interventions, resulting in longer time to repair and consequently longer downtime E_{DT}, thereby reducing value creation V_C. However, as digitalisation level m and r increases, it reduces workload and delays by lowering utilisation, mitigating the effects of resource scarcity, and improving V_C.

The model uses queuing theory to estimate workforce utilisation and repair times, which can be extremely high or theoretically infinite when utilisation approaches or exceeds 100%. Such scenarios represent a complete eradication of value for both customer and provider due to over-utilisation of the service. This phenomenon is illustrated in Figure 2, which highlights two critical points in the bottom left-hand corner (M 0.25, R 0.15 and M 0.25, R 0.15), indicating cases where utilisation is critically high but not yet at 100%. In addition, by calculating workforce utilisation, providers can examine which configurations are suitable for reducing workforce utilisation to counteract labour shortages.

4.3 Navigating Digital Transformation: Balancing Efficiency Gains with the Risk of Cannibalization

The concerns often expressed by companies in the context of digitalisation – particularly the fear that increased service automation, such as remote service or monitoring, will lead to a reduction in customer interactions and, consequently, billable services – are explicitly addressed in Figure 3. This consideration brings to the fore a critical dilemma: how should the pricing, and configuration of digital services and subscriptions be optimized in the era of digital transformation to avoid the threat of cannibalisation of its revenue stream?

Figure 3 depicts a threshold, represented by a horizontal plane in the three-dimensional graph, representing the current value for the provider in non-digital service scenarios. The intersection (black line) of this plane with the subscription surface illustrates the configuration of equivalent value capture by the provider, showcasing levels of digitalisation aligning with the value of the traditional pay-per-service model.

This visual aid is essential for providers to identify configurations of monitoring and remote services and to guide pricing strategies. The aim is to enable providers to achieve benefits comparable to those achieved before the integration of digital technologies. It acts as a key strategic tool, enabling operators to critically assess the impact of digitalisation on their service catalogue and pricing framework. The aim is to help providers maintain or improve their profitability as they integrate or transition to digital services.

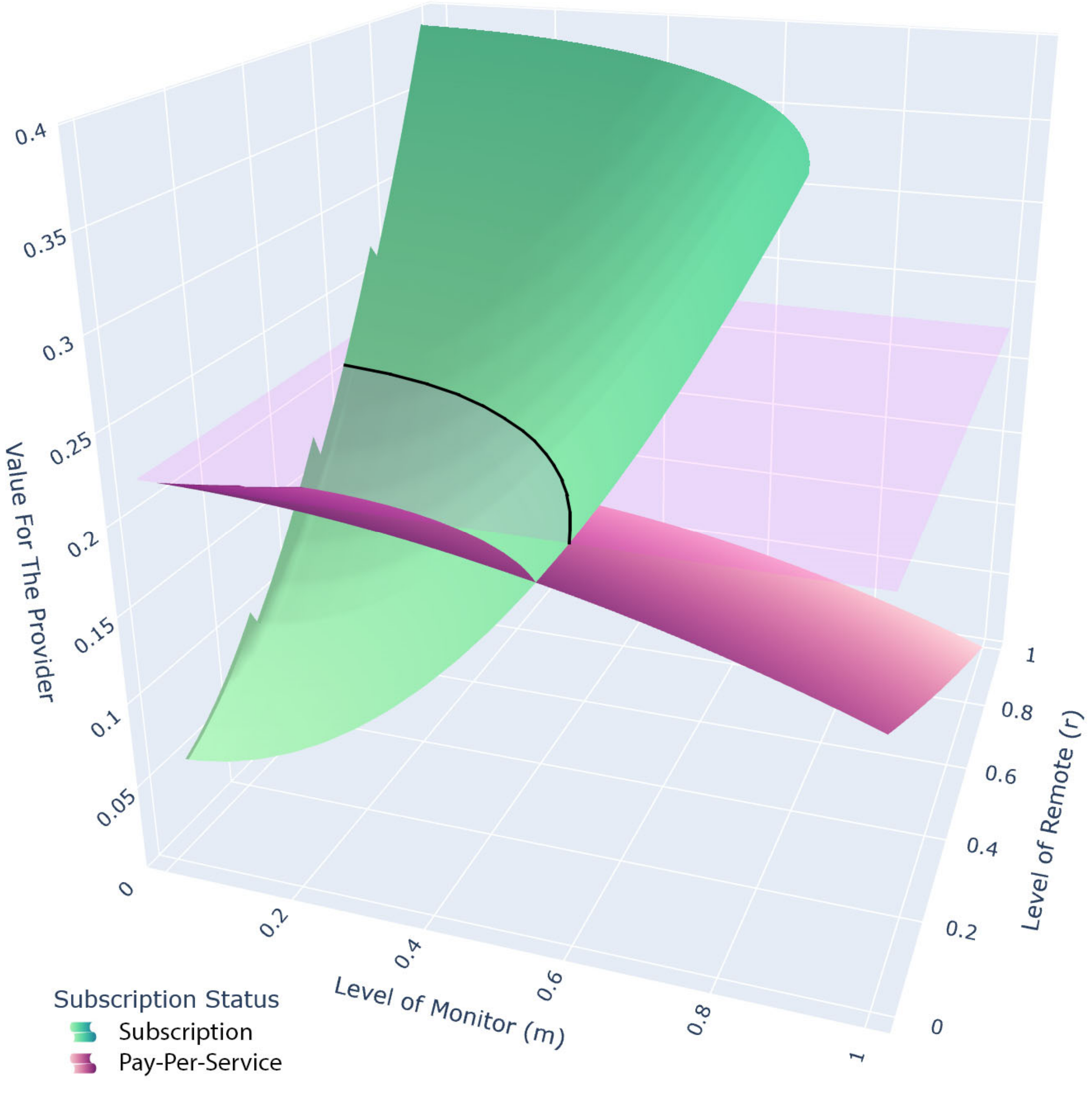

Figure 3: Value capture for the provider V_{P} for the two scenarios pay-per-service (a) and subscription (b), whereby the horizontal plane indicates the maximum value for the provider in the absence of digital services.

4.4 Environmental Impact Points

Figure 4 illustrates the environmental impact for upon varying levels of m and r. Two key dynamics are worth noting: firstly, the increasing environmental impact of using hardware with increasing m and r, for which we use the Raspberry Pi 4B is a representative example for our model for the sake of simplicity. Secondly, the influence of r significantly reduces the average distance travelled, thereby reducing the environmental impact of the service vehicle. The calculation of the vehicle was based on a 3.5-tonne van, with the EIP derived from the distance travelled. This analysis highlights the dual impact of digitisation – increasing financial value while delivering significant environmental benefits through reduced travel emissions, but at the cost of increased IT hardware impact.

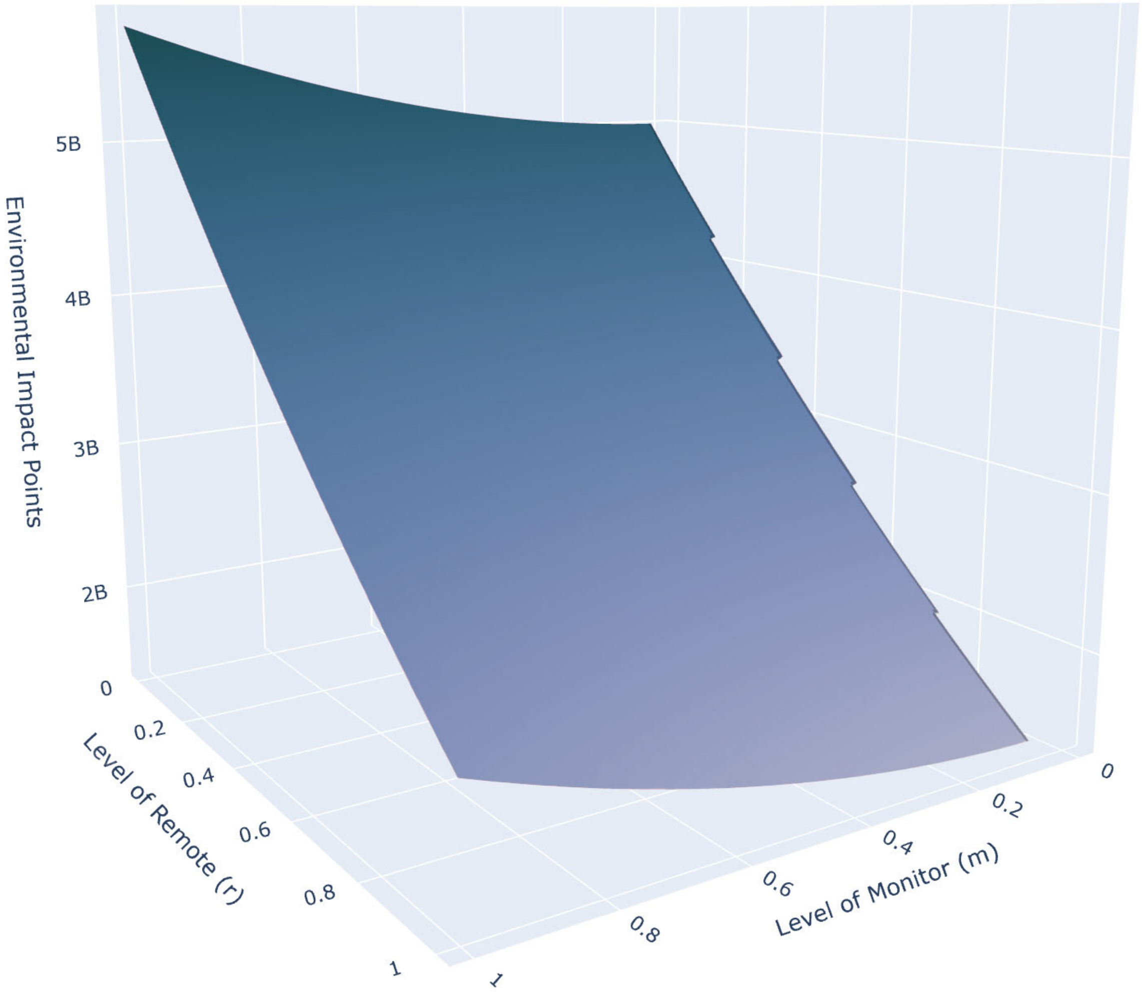

Figure 4: Surface showing the environmental impact points (EIP), depending on the digitalisation level m and r.

5. DISCUSSION & OUTLOOK

This study quantitatively highlights the impact of digitalisation in improving operational efficiency and environmental sustainability in building management through a comprehensive model that quantifies the economic and environmental value of BMS data usage. Applied to the emergency lighting sector, the model highlights the potential for digital services to optimise resource use and service delivery, distinguishing between subscription and pay-per-service scenarios to maximise value capture for the provider and value creation for the customer.

Looking to future developments, the adaptability of the model to comparable ecosystems beyond building management and its potential extension to include predictive maintenance and performance optimisation are promising avenues of research. This extension could provide deeper insights into the need for proactive system maintenance, further reducing costs and environmental impact.

The model also serves as a strategic tool for providers to navigate digital transformation, balancing efficiency gains with sustainable service models against the backdrop of environmental sustainability. This study contributes to both academic and practical understanding of the role of digitalisation in building management and suggests that future research could quantitatively explore the technological impact on service delivery models and the wider sustainability implications of digital transformation.

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