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Internet of Things (IoT) Applications for Sustainable Building Maintenance: Benefits and Adoption Factors as Perceived by Building Practitioners in Rivers State

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Abstract

The integration of Internet of Things (IoT) technologies into building maintenance and facility management represents a transformative opportunity for improving operational efficiency, reducing costs, and advancing sustainability in the built environment. However, the extent to which this potential is being realised in developing country contexts, particularly within Nigeria's construction and facility management sector, remains empirically underexplored. This study investigated IoT applications for sustainable building maintenance and facility management, with three specific objectives: to ascertain the awareness of IoT technologies among building technology practitioners in Rivers State, to examine the perceived benefits of IoT-enabled maintenance systems, and to determine the factors constraining the adoption of IoT technologies in building management. A descriptive survey research design was adopted. Data were collected from 42 registered members of the Nigerian Institute of Building (NIOB), Rivers State Chapter, using a structured questionnaire. Descriptive statistics were employed to analyse the data. Findings revealed that awareness of IoT technologies applicable to building maintenance and facility management was moderate among building practitioners in Rivers State, indicating that the sector is engaging with the IoT ecosystem despite documented structural challenges. Perceived benefits of IoT-enabled maintenance systems were also moderate, suggesting that while respondents recognised some operational and sustainability advantages, these perceptions were not yet sufficiently strong to drive widespread uptake. Inadequate infrastructure and insufficient funding were identified as the principal factors constraining IoT adoption in building management. The study concludes that the Nigerian construction and facility management sector lags behind global trends in IoT adoption, and recommends targeted capacity building for building practitioners, increased investment in digital infrastructure, and the formulation of enabling policy frameworks to accelerate the uptake of IoT technologies for sustainable building maintenance and facility management.

Keywords: *building maintenance, facility management, Internet of Things, IoT adoption, sustainable buildings, Nigeria.*

Introduction

The global built environment is undergoing a profound digital transformation, with the Internet of Things (IoT) emerging as one of its most consequential enabling technologies. IoT refers to a network of interconnected physical devices embedded with sensors, actuators, software, and communication protocols that enable the collection, exchange, and analysis of real-time data across physical and digital environments (Atzori et al., 2020). In the context of building maintenance and facility management, IoT applications enable predictive maintenance scheduling, remote monitoring of building systems, energy optimisation, and occupant safety management functions that collectively advance both operational efficiency and environmental sustainability (Fang et al., 2020; Jia et al., 2019).

The sustainability imperative has intensified interest in IoT-enabled building management globally. Buildings account for approximately 40% of global energy consumption and a comparable share of carbon emissions (International Energy Agency, 2023), making the optimisation of building operations through data-driven IoT systems a critical lever for meeting national and international sustainability commitments. IoT-enabled maintenance systems can monitor real-time energy usage, detect equipment failures before they escalate, and facilitate predictive maintenance schedules that reduce both reactive repair costs and environmental waste (Hosseini et al., 2021; Meng et al., 2022). Smart building platforms integrating IoT sensors with building information modelling (BIM) and artificial intelligence analytics have demonstrated substantial reductions in energy consumption and maintenance costs in high-income country contexts.

In developing country contexts such as Nigeria, however, the adoption of IoT for building maintenance and facility management remains at an early stage, constrained by a complex interplay of infrastructure gaps, funding limitations, regulatory deficiencies, and skill shortages (Abioye et al., 2021; Adabre et al., 2020). The Nigerian construction sector, which includes building maintenance and facility management as critical sub-sectors, faces systemic challenges including irregular electricity supply, limited broadband penetration, and a shortage of professionals trained in digital building technologies. These structural conditions create a distinctive adoption environment that differs markedly from the contexts in which most IoT building management research has been conducted.

Building practitioners engineers, architects, quantity surveyors, and facility managers registered with professional bodies such as the Nigerian Institute of Building (NIOB) constitute the primary professional cohort responsible for advancing IoT integration in Nigeria's built environment. Their perceptions of IoT technologies, including awareness, perceived benefits, and perceived adoption barriers, are critical determinants of whether IoT-enabled building maintenance will be operationalised within Nigerian building management practice (Amoako-Attah & B-Jahromi, 2022; Oyedele et al., 2021). The NIOB Rivers State Chapter, as a professional regulatory body for building practitioners in the region, provides an appropriate and accessible study population for empirically examining these perceptions.

Despite the recognised importance of building practitioners' IoT perceptions, no empirical study has specifically examined IoT awareness, perceived benefits, and adoption barriers within the NIOB Rivers State Chapter population. This gap constitutes a significant limitation in the Nigerian building technology literature, particularly given Rivers State's status as a major economic hub with a substantial building and construction sector driven by oil industry infrastructure and urban development demands. This study therefore investigated IoT applications for sustainable building maintenance and the benefits and adoption factors as perceived by building practitioners in Rivers State, to generate context-specific evidence that can inform professional development, institutional investment, and policy formulation.

Purpose of the Study

The purpose of this study was to investigate IoT applications for sustainable building maintenance and facility management, with specific attention to the awareness of IoT technologies, perceived benefits of IoT-enabled maintenance systems, and factors constraining IoT adoption, as perceived by building technology practitioners in Rivers State. The following specific objectives guided the study:

1. Ascertain the awareness of IoT technologies applicable to building maintenance and facility management among building technology practitioners in Rivers State.
2. Determine the perceived benefits of IoT-enabled maintenance systems among building technology practitioners in Rivers State.
3. Find out the factors constraining IoT adoption in building management by building technology practitioners in Rivers State.

Research Questions

The study was guided by the following research questions:

1. What is the level of awareness of IoT technologies applicable to building maintenance and facility management among building technology practitioners in Rivers State?
2. What are the perceived benefits of IoT-enabled maintenance systems among building technology practitioners in Rivers State?
3. What are the factors constraining the adoption of IoT technologies in building management as perceived by building technology practitioners in Rivers State?

Theoretical Framework and Literature Review

Internet of Things in the Built Environment

The Internet of Things represents a technological paradigm in which physical objects are equipped with sensing, computing, and communication capabilities that enable autonomous data collection and machine-to-machine interaction (Atzori et al., 2020). In the built environment, IoT architectures typically comprise three functional layers: a perception layer consisting of sensors, actuators, and edge devices that collect building performance data; a network layer that transmits data through wireless protocols such as Wi-Fi, Zigbee, LoRaWAN, or cellular networks; and an application layer where data are processed, analysed, and acted upon through facility management software platforms (Jia et al., 2019; Fang et al., 2020).

Applications of IoT in building maintenance and facility management span a broad range of functions. Predictive maintenance systems use vibration, temperature, and current sensors to monitor the health of mechanical and electrical systems in real time, enabling maintenance interventions before equipment failure occurs (Hosseini et al., 2021). Smart energy management systems employ IoT-connected meters, occupancy sensors, and lighting controls to optimise energy consumption across building systems (Meng et al., 2022). Water quality and leakage monitoring systems using IoT sensors detect plumbing anomalies and reduce water wastage. Indoor air quality monitoring systems provide real-time data on $CO2$ levels, humidity, and particulate matter, supporting occupant health and comfort management. Security and access management systems integrating IoT sensors with artificial intelligence enable dynamic threat detection and access control. The integration of these IoT applications with BIM platforms and AI-driven analytics constitutes the core of what is increasingly termed the smart building ecosystem (Xu et al., 2021).

Awareness of IoT Technologies among Building Practitioners

Professional awareness of IoT technologies is a foundational prerequisite for adoption, as practitioners cannot adopt what they do not know exists or understand. Research across diverse geographic contexts indicates that awareness of IoT in the construction and building management sector varies considerably by professional role, educational background, institutional exposure, and national digital infrastructure context (Abioye et al., 2021; Amoako-Attah & B-Jahromi, 2022). Oyedele et al. (2021) conducted a systematic review of technology adoption in construction and found that awareness of specific IoT applications as distinct from general knowledge of 'smart buildings' was limited even among professionals in relatively advanced digital construction environments.

In the Nigerian context, Abioye et al. (2021) investigated digital technology awareness among construction professionals in Lagos and found that while broad awareness of terms such as 'smart building' and 'IoT' was moderate, familiarity with specific IoT applications for building maintenance, such as predictive maintenance platforms and energy management IoT systems, was considerably lower. This distinction between general and specific awareness has important implications for professional development programme design, suggesting that awareness-building initiatives must move beyond conceptual orientation to develop practical, application-specific knowledge. Oladapo et al. (2022) similarly found that building professionals in Southwest Nigeria demonstrated higher awareness of IoT technologies associated with security systems than with energy management or predictive maintenance, likely reflecting differential exposure through consumer applications.

Perceived Benefits of IoT-Enabled Maintenance Systems

The literature consistently identifies a range of tangible and intangible benefits associated with IoT-enabled building maintenance, though practitioner perceptions of these benefits in developing country contexts are often more modest than the objective evidence from high-income deployments would suggest. Fang et al. (2020) documented cost reductions of 15–25% in maintenance expenditure attributable to IoT-enabled predictive maintenance in a study of commercial buildings in Asia, while Hosseini et al. (2021) reported 20–30% reductions in energy consumption in smart building case studies in Europe and North America.

Among building practitioners in African contexts, Adabre et al. (2020) found that perceived operational efficiency gains, rather than environmental sustainability benefits, were the primary benefit perception driving positive attitudes toward IoT building technologies. Meng et al. (2022) noted that practitioners tended to most strongly endorse IoT benefits that were proximate to their specific professional domain facility managers emphasising maintenance cost reductions and building engineers emphasising structural health monitoring capabilities. Oyedele et al. (2021) observed that sustainability-related IoT benefits such as energy optimisation and carbon reduction were perceived as less concrete and less personally motivating than direct cost and efficiency benefits, particularly in contexts where sustainability regulation is weak.

Factors Constraining IoT Adoption in Building Management

Despite the documented benefits, IoT adoption in building maintenance faces substantial barriers, particularly in developing country contexts. Abioye et al. (2021) identified inadequate ICT infrastructure including unreliable internet connectivity and power supply instability as the primary structural constraint to IoT adoption in the Nigerian construction sector. The energy reliability issue is particularly acute for IoT systems that depend on continuous power for sensor operation and data transmission. Oladapo et al. (2022) highlighted insufficient institutional funding as a critical barrier, noting that the capital expenditure required for IoT sensor networks, connectivity infrastructure, and platform subscriptions often exceeded available budgets in both public and private building management contexts.

Skill and capacity deficiencies constitute a third major adoption barrier. Xu et al. (2021) noted that IoT building management systems require practitioners to develop competencies in data interpretation, platform navigation, and IoT system maintenance that are not typically included in conventional building technology or engineering curricula. The absence of standardised professional development pathways for IoT competency development in the Nigerian construction sector exacerbates this capacity deficit (Abioye et al., 2021). Regulatory and policy gaps, including the absence of national standards for IoT building systems and inadequate incentive frameworks for smart building investment, have also been identified as significant systemic barriers (Amoako-Attah & B-Jahromi, 2022; Oladapo et al., 2022).

Methodology

Research Design

This study adopted a descriptive survey research design, which was appropriate for systematically documenting the perceptions, awareness levels, and adoption-related beliefs of building technology practitioners regarding IoT technologies, without experimental manipulation of study variables. Descriptive survey designs are well-established in construction technology adoption research and provide reliable data on practitioner beliefs and attitudes within defined professional populations (Creswell & Creswell, 2018; Yin, 2018).

Population

The population of the study comprised all registered members of the Nigerian Institute of Building (NIOB), Rivers State Chapter, with a total membership of 42 building practitioners at the time of the study. The NIOB Rivers State Chapter is the professionally regulated association of building professionals in the state, and its membership includes building engineers, facility managers, project managers, and construction consultants engaged in building maintenance and facility management practice. Given the manageable population size and the need for comprehensive data coverage, total enumeration was adopted, whereby all 42 members constituted the study sample, consistent with established conventions for small population survey studies (Asika, 2019).

Instrument

Data were collected using a researcher-developed structured questionnaire titled Internet of Things Adoption Survey for Building Practitioners (IOTASBP), structured in three sections corresponding to the three research objectives. Section A measured awareness of specific IoT technologies applicable to building maintenance (10 items), Section B assessed perceived benefits of IoT-enabled maintenance systems (10 items), and Section C examined factors constraining IoT adoption (8 items). All sections used a four-point Likert-type response scale. Items were developed from a review of the IoT and building management literature and adapted from validated instruments used in prior IoT adoption studies in the construction sector (Abioye et al., 2021; Oladapo et al., 2022).

Content validity was established through expert review by two specialists in building technology and one in construction technology adoption research. Reliability was assessed through a pilot study involving ten building practitioners in Bayelsa State (not included in the main study), yielding Cronbach's alpha coefficients of 0.83 for IoT awareness, 0.80 for perceived benefits, and 0.78 for adoption constraints, all meeting the recommended threshold of 0.70 (Nunnally & Bernstein, 1994).

Data Collection and Analysis

All 42 questionnaires were personally administered and retrieved within two weeks, yielding a response rate of 100%. Data were analysed using descriptive statistics (mean and standard deviation). A mean criterion of 2.50 was adopted as the benchmark; items with means at or above 2.50 were considered endorsed (positive perception or significant constraint), while items below 2.50 were considered not endorsed. All analyses were conducted using SPSS version 27.

Results

Research Question 1: What is the level of awareness of IoT technologies applicable to building maintenance and facility management among building technology practitioners in Rivers State?

Table 1: Descriptive Statistics for IoT Technology Awareness (N = 42)

S/N	IoT Technology	Mean	SD	Remark
1	Smart sensors for building energy monitoring	2.81	0.74	Aware
2	IoT-enabled security and access control systems	2.95	0.68	Aware
3	Predictive maintenance platforms using IoT sensors	2.45	0.91	Not Aware
4	Smart water management and leak detection systems	2.62	0.85	Aware
5	Indoor air quality monitoring devices	2.55	0.88	Aware
6	Building automation and HVAC IoT controls	2.50	0.92	Aware
7	Structural health monitoring using IoT sensors	2.38	0.97	Not Aware
8	Smart lighting control systems	2.71	0.80	Aware
9	Remote facility monitoring platforms (cloud-based)	2.43	0.95	Not Aware
10	IoT-enabled waste management systems	2.29	1.01	Not Aware
	Grand Mean	**2.57**	**0.87**	**Moderate**

Table 1 reveals that building practitioners in Rivers State demonstrated a moderate overall awareness of IoT technologies applicable to building maintenance, with a grand mean of 2.57. Six of the ten technology items recorded means above the 2.50 criterion. IoT-enabled security and access control systems recorded the highest awareness (M = 2.95, SD = 0.68), consistent with the widespread deployment of IoT-based security devices in the Nigerian commercial and residential building sector. Smart sensors for energy monitoring also recorded high awareness (M = 2.81, SD = 0.74). In contrast, IoT-enabled waste management systems (M = 2.29), remote facility monitoring platforms (M = 2.43), and structural health monitoring systems (M = 2.38) were below the criterion threshold, indicating limited practitioner awareness of these more specialised applications.

Research Question 2: What are the perceived benefits of IoT-enabled maintenance systems among building technology practitioners in Rivers State?

Table 2: Descriptive Statistics for Perceived Benefits of IoT-Enabled Maintenance Systems (N = 42)

S/N	Perceived Benefit	Mean	SD	Remark
1	IoT reduces building maintenance costs through early fault detection	2.81	0.79	Agree
2	IoT improves energy efficiency in building systems	2.76	0.83	Agree
3	IoT enhances occupant safety and comfort	2.71	0.87	Agree
4	IoT enables real-time monitoring of building performance	2.64	0.91	Agree
5	IoT reduces the environmental footprint of building operations	2.52	0.96	Agree
6	IoT enables predictive rather than reactive maintenance	2.57	0.90	Agree
7	IoT improves facility management data accuracy	2.60	0.88	Agree
8	IoT reduces emergency maintenance incidents	2.55	0.92	Agree
9	IoT enables remote building management without on-site presence	2.48	0.99	Not Agree
10	IoT enhances compliance with building sustainability standards	2.45	1.02	Not Agree
	Grand Mean	**2.61**	**0.91**	**Moderate**

Table 2 reveals a moderate overall perception of IoT benefits among building practitioners in Rivers State (Grand Mean = 2.61). Eight of the ten benefit items were endorsed above the criterion threshold. Perceived cost reduction through early fault detection recorded the highest mean (M = 2.81, SD = 0.79), indicating that operational cost savings are the most strongly perceived benefit. Energy efficiency improvement (M = 2.76) and occupant safety enhancement (M = 2.71) were also strongly endorsed. In contrast, remote building management capability (M = 2.48) and compliance with sustainability standards (M = 2.45) were below the criterion, suggesting that practitioners' benefit perceptions are more strongly oriented toward operational efficiency gains than toward regulatory compliance and sustainability outcomes. The moderate grand mean indicates that benefits are recognised but not sufficiently compelling to independently motivate adoption in the current structural context.

Research Question 3: What are the factors constraining the adoption of IoT technologies in building management as perceived by building technology practitioners in Rivers State?

Table 3: Descriptive Statistics for Factors Constraining IoT Adoption (N = 42)

S/N	Constraining Factor	Mean	SD	Remark
1	Inadequate internet and digital infrastructure	3.45	0.62	Significant
2	Insufficient funding for IoT system acquisition and deployment	3.38	0.68	Significant
3	Unreliable power supply affecting IoT device operation	3.52	0.59	Significant
4	Lack of trained personnel for IoT system installation and maintenance	3.21	0.74	Significant
5	High cost of IoT devices and platforms	3.29	0.71	Significant
6	Absence of national IoT building management standards and policy	3.10	0.80	Significant
7	Cybersecurity and data privacy concerns	2.90	0.88	Significant
8	Limited awareness of available IoT solutions among practitioners	3.00	0.85	Significant
	Grand Mean	**3.23**	**0.73**	**Significant**

Table 3 reveals that all eight constraining factors recorded means substantially above the 2.50 criterion, with a grand mean of 3.23, indicating that building practitioners in Rivers State strongly endorsed multiple barriers to IoT adoption. Unreliable power supply (M = 3.52, SD = 0.59) emerged as the most strongly endorsed constraint, reflecting the chronic electricity infrastructure deficit in the Nigerian context. Inadequate internet and digital infrastructure (M = 3.45) and insufficient funding (M = 3.38) were the second and third most strongly endorsed constraints respectively, consistent with the extant literature on IoT adoption barriers in developing country construction sectors (Abioye et al., 2021; Oladapo et al., 2022). High cost of IoT devices (M = 3.29), lack of trained personnel (M = 3.21), and absence of national IoT policy frameworks (M = 3.10) were all strongly endorsed, indicating that the barriers to adoption are structural, financial, human capital-related, and policy-driven simultaneously. Cybersecurity concerns, while the least strongly endorsed constraint, still recorded a mean of 2.90, suggesting emerging awareness of data protection challenges associated with IoT deployment.

Discussion of Findings

The finding that building practitioners in Rivers State demonstrated moderate awareness of IoT technologies for building maintenance (Grand Mean = 2.57) is consistent with findings from comparable studies in the African construction sector. Abioye et al. (2021) found moderate awareness of digital building technologies among construction professionals in Lagos, with consumer-facing IoT applications such as security systems generating higher awareness than specialised maintenance platforms a pattern replicated in the present study. The relatively high awareness of IoT security and access control systems (M = 2.95) in the current study likely reflects widespread deployment of these systems in Nigeria's commercial real estate sector, providing practitioners with experiential exposure that more specialised IoT applications have not yet generated. The low awareness of predictive maintenance platforms (M = 2.45), structural health monitoring (M = 2.38), and remote facility management tools (M = 2.43) indicates that practitioner knowledge of IoT is predominantly superficial and consumer-oriented, rather than deeply grounded in the technical, application-specific knowledge required for professional building maintenance practice. The result however negates the result by Okwelle and Nwineh (2025) who found low level of knowledge of IoTs among students and lecturers of technical and vocational education in tertiary institutions in Rivers State.

The moderate perception of IoT benefits (Grand Mean = 2.61) aligns with findings by Adabre et al. (2020), who found that construction practitioners in Sub-Saharan Africa acknowledged IoT's operational efficiency potential but expressed less certainty about its practical achievability in their local institutional and infrastructure context. The prominence of cost reduction (M = 2.81) and energy efficiency (M = 2.76) as the most strongly perceived benefits is consistent with Fang et al. (2020), who found that operational efficiency gains were the most motivating benefit category for practitioners when assessing building IoT technologies. The relatively lower perception of sustainability compliance benefits (M = 2.45) reflects the weak regulatory environment for sustainable building practice in Nigeria, where there are currently no enforceable national standards mandating IoT integration for sustainability compliance, reducing the perceived urgency of this benefit dimension (Oladapo et al., 2022; Amoako-Attah & B-Jahromi, 2022).

The finding that infrastructure constraints particularly unreliable power supply (M = 3.52) and inadequate internet connectivity (M = 3.45) emerged as the most significant adoption barriers is theoretically and practically significant. This result strongly confirms the findings of Abioye et al. (2021), who identified infrastructure deficits as the primary barrier to IoT adoption in the Nigerian construction sector, and aligns with broader evidence on the role of enabling conditions in technology adoption, as articulated in the UTAUT framework's facilitating conditions construct (Venkatesh et al., 2003). The severity of power supply unreliability as a barrier is particularly contextually resonant in Rivers State, where grid electricity supply is intermittent and IoT sensor networks require uninterrupted power to function reliably. Insufficient funding (M = 3.38) and high device costs (M = 3.29) further compound the adoption challenge, particularly for smaller building management firms and public sector facility managers with constrained capital budgets. Taken together, the findings paint a picture of multiple, mutually reinforcing structural barriers that collectively constitute a formidable adoption ecosystem challenge unlikely to be resolved by awareness campaigns or professional training alone.

The finding that limited practitioner awareness itself constitutes a significant adoption barrier (M = 3.00) creates a recursive dynamic in which low awareness limits uptake, and limited uptake reduces experiential knowledge generation that would otherwise build awareness a trap observed in other technology adoption contexts in developing economies (Xu et al., 2021; Oyedele et al., 2021). Breaking this cycle requires deliberate, systematic investment in professional capacity development, as well as deliberate policy instruments that reduce financial barriers and establish enabling infrastructure conditions for IoT deployment in the Nigerian building management sector.

Conclusions

Based on the findings of this study, the following conclusions are drawn. Building technology practitioners in Rivers State, as represented by NIOB Rivers State Chapter members, demonstrate a moderate level of awareness of IoT technologies applicable to building maintenance and facility management, with awareness concentrated in consumer-familiar applications such as security and energy monitoring systems, and considerably lower for specialised applications such as predictive maintenance platforms and structural health monitoring. Perceptions of IoT benefits are also moderate, with operational cost reduction and energy efficiency perceived as the most compelling advantages, while sustainability compliance and remote management benefits are less convincingly perceived. The factors constraining IoT adoption are strongly endorsed across multiple dimensions, with unreliable power supply, inadequate digital infrastructure, and insufficient funding constituting the three most significant barriers. The study concludes that the Nigerian building maintenance and facility management sector lags markedly behind global IoT adoption trends, with adoption constrained not by individual-level resistance but by systemic infrastructure and resource deficits that require coordinated institutional and policy responses.

Recommendations

Based on the findings and conclusions of the study, the following recommendations are made:

1. The Nigerian Institute of Building (NIOB) should design and implement targeted IoT capacity development programmes for its Rivers State Chapter members, focusing on application-specific IoT knowledge for building maintenance and facility management, to close the awareness gap particularly for predictive maintenance, structural

health monitoring, and remote facility management platforms.

2. The Federal Government of Nigeria and the Rivers State Government should increase investment in digital infrastructure, including broadband internet expansion and distributed power generation facilities (solar-backed micro-grids and battery storage systems), to address the critical enabling condition deficits that constitute the primary barriers to IoT adoption in the building management sector.
3. The Federal Ministry of Works and Housing, in collaboration with NIOB and other professional building bodies, should formulate and enforce national standards and a policy framework for IoT integration in building maintenance and facility management, incorporating incentive structures such as tax reliefs and public procurement preferences for IoT-enabled building management to stimulate private sector investment.
4. Building technology programme curricula at polytechnics and universities in Rivers State should be updated to incorporate IoT literacy modules covering relevant building management applications, data analytics, and IoT platform management, ensuring that future practitioners enter the workforce with foundational digital building technology competencies.
5. Further research should examine IoT adoption behaviours among specific sub-categories of building practitioners (engineers, facility managers, quantity surveyors), use longitudinal designs to track adoption trends over time, and investigate the moderating role of organisational size and type on IoT adoption barriers in the Nigerian building management sector.

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