Simulating Trust and Interoperability in Hospitality Backends: An Agent-Based Approach Using Digital Confirmation Tokens

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Abstract

This paper introduces a novel agent-based simulation framework designed to evaluate the adoption and systemic impact of digital confirmation tokens in fragmented hospitality ecosystems. By modeling trust propagation, interoperability, and coordination dynamics among heterogeneous agents—including hotels, OTAs, and backend providers—the simulation offers a powerful methodological tool for exploring emergent behaviors in complex service environments. Calibrated with data from over 500 industry partners, the model achieved an average fidelity of 95%, validating its realism. The proposed 1AAS platform demonstrated exceptional scalability, supporting up to 10,000 agents and over one million message exchanges per round. This level of performance enables the exploration of coordination patterns at a scale previously unattainable in hospitality research. Results show that token-based workflows significantly improve backend coherence and automation, with booking success rates reaching 98% compared to 74–82% in current workflows. While the model emphasizes post-booking interactions, it opens new prospects for simulating upstream processes such as search and pricing—areas while traditional research methods struggle to capture complexity and scale. This work contributes both a methodological advancement and a practical tool for evaluating innovation in digitally mediated hospitality systems.

Key Words: Innovation, Simulation, Digital Tools, Trust, Hospitality, Decision-Making

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Introduction

As digital transformation reshapes the hospitality industry, seamless coordination across fragmented systems becomes a fundamental aspect of development. As the sector increasingly relies on complex, multi-stakeholder ecosystems, the necessity for trust, transparency, and interoperability in backend operations becomes paramount.

Hospitality operates within a fragmented technological landscape. Backend systems—such as booking engines, property management systems, and rate distribution platforms—are often siloed. This fragmentation is intensified by intermediaries introducing diverse data formats, protocols, and business logic. Consequently, fundamental operations like booking confirmations or room attribute sharing become error-prone. These inefficiencies reduce operational effectiveness and compromise guest experience consistency.

Industry analyses show that fragmentation inflates costs, weakens inventory control, and limits data visibility. Legacy systems like Global Distribution Systems (GDSs) and Virtual Credit Cards (VCCs) introduce transactional friction. Hotels and travel management companies (TMCs) struggle to synchronize content, rates, and payments, leading to delays, miscommunication, and compliance issues. These problems are compounded by the absence of standardized protocols and the lack of trust among loosely connected actors.

To address these issues, recent proposals have introduced digital confirmation tokens—NFT-like objects encapsulating booking metadata, compliance status, and transaction history. These tokens are not blockchain-native but emulate key NFT properties: uniqueness, traceability, and transparency. Embedded into backend workflows, they enable consistent propagation and verification of booking data across systems.

This paper presents an agent-based simulation to explore how digital confirmation tokens influence trust propagation and interoperability in fragmented hospitality ecosystems. By modeling hotels, OTAs, intermediaries, and compliance agents as autonomous entities, the simulation examines how token adoption affects system-wide behavior. This approach offers a novel methodological contribution by enabling the study of emergent dynamics—such as tipping points in adoption or trust network collapse—under varying conditions of token deployment and agent behavior.

The remainder of this paper is organized as follows: Section 2 reviews literature on interoperability, trust modeling, and agent-based simulation. Section 3 presents the conceptual framework. Section 4 details the simulation methodology. Section 5 reports the results. Section 6 discusses implications for hospitality innovation. Section 7 concludes with key contributions and future research directions.

Literature Review

This literature review is structured around three interrelated strands. First, it identifies the current state and research gaps in simulation and modeling within hospitality and tourism. Second, it evaluates the applicability of agent-based modeling (ABM) for capturing complex, adaptive behaviors in hospitality systems. Third, it analyzes the challenges of assessing systemic innovation, focusing on distribution models, margin optimization, and policy experimentation.

Simulation and Modeling in Hospitality: Current Practices and Research Gaps

Simulation and modeling have emerged as crucial tools for comprehending the intricate systems that underpin tourism and hospitality. These industries are subject to seasonal trends, economic fluctuations, and diverse human behaviors—elements that traditional models frequently fail to adequately capture. Jacopo et al. (2020) explore how system dynamics and agent-based models

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(ABMs) can represent both large-scale and individual-level tourism behaviors, such as visitor movement and stakeholder interaction.

Werthner, Pröll, and Stangl (2022) show how simulation tools improve decision-making and planning in e-tourism through scenario testing and gamified environments. Zhang, Wu, and Zhang (2023) use spatial-temporal simulations to evaluate tourism resilience in urban clusters, highlighting the role of dynamic models in shaping sustainable policy. Benckendorff (2022) focuses on simulation's ability to model tourist behavior and predict environmental impacts, especially in high-density areas.

In parallel, a range of software systems—both open-source and proprietary—have been developed for hotel and hospitality management, such as HotelDruid and Oracle's Opera PMS (AhsanSN, 2021; Oracle, 2023). These systems simulate operational tasks like room allocation, billing, and reservations across multi-day timelines. However, while they mimic operational dynamics, they lack the generative or predictive capacity of research-grade simulation frameworks. Their existence nonetheless reflects a growing demand for systematized hospitality management that could benefit from integration with advanced modeling approaches.

"Foundational developments in smart hospitality systems, such as those proposed by Buhalis and Leung (2018), have emphasized the importance of simulation and data integration. They introduced a smart hospitality ecosystem that leverages cloud computing, sensors, and big data analytics to enhance interoperability and decision-making. These systems aim to unify internal and external data sources to support real-time scenario modeling and revenue optimization. This foundational work has structured the subsequent advancements discussed earlier and sets the stage for the next section on agent-based modeling."

Agent-Based Modeling (ABM) and Its Relevance for Hospitality

ABM is a simulation technique that models complex systems through the interactions of autonomous, heterogeneous agents. ABM allows for bottom-up emergence of system-level patterns from individual behavior, making it suitable for hospitality contexts where customers, staff, firms, and regulators interact in non-linear and adaptive ways. In tourism and hospitality, ABMs have been used to simulate visitor movements, service interactions, and market dynamics under varying scenarios of demand, policy, or disruption (Baggio, 2020). Their ability to incorporate heterogeneity, adaptation, and spatial dynamics makes ABM a powerful tool for understanding phenomena such as over-tourism, demand forecasting, and service optimization (He, 2021).

The growing complexity of digital hospitality ecosystems has also prompted the development of decentralized and autonomous models. For example, the DASH system (Decentralized Autonomous and Smart Hotel) integrates blockchain, IoT, and AI to create fully automated hotel environments (DASH, 2023). These models extend the ABM paradigm by embedding smart contracts and token-based coordination into agent interactions, offering a vision of hospitality systems that are not only adaptive but also self-regulating.

Evaluating Systemic Innovation in Hospitality: Distribution, Margins, and Policy

Evaluating systemic innovation in hospitality necessitates understanding the interplay among distribution models, margin optimization strategies, and innovation policies in complex environments. Kuhlmann and Rip (2018) advocate for systemic instruments, arguing that linear models are inadequate in multi-actor ecosystems like hospitality. Their foundational work sets the stage for subsequent studies, such as Gonzalez (2021), who adopts a systemic lens to reveal misalignments between distribution system operators and technology developers, showing how innovation may stall without coordination.

Within hospitality, the demand for robust innovation evaluation is growing. De Larrea et al. (2021) call for a systemic, integrative approach that transcends firm-level analysis to address industry-wide interdependencies. Lopez Mateos et al. (2022) note the underuse of field experiments despite their proven value in revenue strategy optimization.

From a policy standpoint, Hall and Williams (2014) highlight tensions between top-down policy and bottom-up implementation in tourism. Edler and Fagerberg (2023) stress the need for evaluation frameworks that go beyond outcomes to account for learning, feedback, and systemic change.

In margin optimization, Acemoglu and Restrepo (2023) introduce an equilibrium model illustrating how distribution innovations reshape value capture between producers and consumers—insights applicable to hotel-OTA dynamics and dynamic pricing.

Recent blockchain innovations contribute to this discourse. Multi-chain and interoperable platforms aim to enhance trust, privacy, and scalability in tourism services (Zhang et al., 2022). These technologies enable decentralized reservations, incentivized data sharing, and smart contract enforcement (Cobanoglu et al., 2023; Sharma et al., 2023), aligning with goals of transparency, automation, and resilience.

1A Agent Simulation platform(1AAS)

This section outlines the theoretical and structural foundation of the proposed simulation model, which explores how digital confirmation tokens influence trust propagation and interoperability in fragmented hospitality ecosystems. The platform integrates concepts from agent-based modeling (ABM), token-based coordination, and systemic innovation theory to define the key entities, relationships, and mechanisms operationalized in the simulation.

Agents and Roles in the Hospitality Ecosystem

The simulation environment includes a diverse set of agents representing key actors in the hospitality ecosystem—hotels, online travel agencies (OTAs), wholesalers, aggregators, and compliance validators. These agents reflect the sector's operational and strategic complexity, where interactions span booking, distribution, and regulatory domains. Future iterations may incorporate additional agents such as destination management organizations (DMOs), payment processors, customer service bots, and travelers. Each agent is defined by attributes such as trust thresholds, communication protocols, and adoption propensities. This enables the simulation to capture the emergent effects of decentralized decision-making and heterogeneous interactions within a fragmented digital infrastructure.

Digital Confirmation Tokens as Coordination Artifacts

The central element of the framework is the digital confirmation token—a structured, NFT-like object that encapsulates booking metadata, compliance status, and transaction history. Although these tokens are not blockchain-native, they emulate key NFT properties such as uniqueness, traceability, and transparency. Each token represents a single booking and evolves through a lifecycle of creation, validation, and mutation, reflecting changes in status or stakeholder interaction.

Functioning as both a data container and coordination artifact, the token standardizes how booking information is shared and verified across systems. It also acts as a trust signal, allowing agents to assess counterpart reliability based on token integrity and completeness. By embedding structured compliance metadata and maintaining an immutable event log, tokens reduce ambiguity, enhance auditability, and support decentralized coordination. While designed for future blockchain integration, their immediate value lies in enabling lightweight, interoperable workflows that can be incrementally adopted.

Trust Propagation and Interoperability Dynamics

In the simulation, trust and interoperability are modeled as co-evolving properties emerging from repeated agent interactions. Trust is a dynamic, agent-specific variable that adjusts based on perceived reliability and transparency of other agents. This perception is shaped by the quality of exchanged tokens—completeness, timeliness, and compliance status—as well as responsiveness to token-related queries and historical behavior. Each token has one main owner, who allows partial or total visibility of the embedded information based on the trust level they have in other agents. This is a low-level, fine-tuned parameter that can be specified agent by agent. However, some operations require the owner to share minimal information with other agents, defined as atomic operations.

Interoperability is defined as the ability of agents to seamlessly exchange, interpret, and act on token data without loss of meaning or function. It depends on schema compatibility, protocol alignment, and the density of token adoption across the network. Successful exchanges reinforce both trust and interoperability, while failed or delayed interactions degrade them. This feedback loop allows the simulation to explore how local behaviors and technical standards scale into systemic coordination or fragmentation.

The framework supports analysis of critical thresholds—such as the minimum viable adoption rate for self-sustaining interoperability—and identification of structural vulnerabilities where trust breakdowns may cascade through the network.

Systemic Innovation and Emergent Behavior

Grounded in systemic innovation theory, the framework recognizes that innovation outcomes in complex environments like hospitality are shaped not only by individual technologies or actors, but by their interdependencies. The hospitality ecosystem is modeled as a complex adaptive system, where digital confirmation tokens act as structural innovations capable of altering coordination logic across the network.

Rather than assuming linear cause-effect relationships, the model imposes an initial business graph that defines the initial business relationship states between agents. The evolution of this graph enables the observation of emergent behaviors—such as cascading trust failures, adoption tipping points, or spontaneous formation of interoperable clusters—arising from decentralized agent interactions. These patterns are not pre-programmed but result from micro-level decisions, feedback loops, and adaptation strategies.

By simulating these dynamics, the framework provides a richer understanding of how innovation diffuses, stabilizes, or fails within fragmented infrastructures. It also offers a platform for testing policy interventions, incentive structures, or governance mechanisms that could accelerate systemic alignment and resilience. In doing so, the model moves beyond traditional performance metrics and opens space for evaluating innovation in terms of its capacity to reconfigure relationships, reduce friction, and foster trust at scale.

Integrated Simulation Methodology for Digital Token Adoption in Hospitality

This section outlines the approach used to simulate the adoption and systemic impact of digital confirmation tokens in hospitality ecosystems. It incorporates agent-based simulation design, experimental scenario modeling, and technical implementation.

The simulation environment is populated by autonomous agents representing key stakeholders—sellers, hotels, online travel agencies (OTAs), intermediaries, and compliance validators—each governed by specific behavioral rules, decision thresholds, and communication protocols. Digital confirmation tokens, which encapsulate booking metadata, compliance status, and transaction history, are exchanged to coordinate actions and validate information. All scenarios start with a booking request from sellers, which propagates through the business graph. The request is successful if the initiator receives a booking confirmation. Agents operate within a dynamic relation graph, where trust evolves based on token exchange outcomes. Interoperability is defined by agents' ability to interpret token data, influenced by schema compatibility and protocol alignment. This setup enables the emergence of trust cascades, adoption tipping points, and interoperable clusters.

Three experimental scenarios are modeled: (1) a baseline without token infrastructure, relying on historical trust and informal communication; (2) partial adoption, where only some agents issue and validate tokens; and (3) full adoption, enabling end-to-end traceability and compliance. Each scenario is run multiple times to account for stochastic variability. Key performance indicators (KPIs) include trust scores, token validation rates, booking latency, and interoperable network density. Sensitivity analyses test robustness under varying assumptions about agent behavior, network structure, and token design.

The simulation is implemented using the 1AAS (Amadeus Agent Simulator) platform, a modular agent-based framework tailored for hospitality. It integrates four core Python libraries. Mesa provides the simulation engine, supporting agent logic and real-time visualization. NetworkX manages the evolving agent network. A custom in-memory messaging system replaces traditional MPI-based communication, enabling low-latency, asynchronous exchanges. A key innovation is the WordToken module, which governs structured token exchange, simulating contractual logic and enforcing transaction constraints.

Agents are fully autonomous, operating in an isolated environment governed by a dynamic relation graph. The architecture supports semantic message routing, contract-based communication, and community-level aggregation. Performance benchmarks show that 1AAS outperforms existing agent-based configurations, particularly in large-scale simulations with high agent heterogeneity and interaction density.

Results

This section presents the outcomes of the simulation experiments, structured around three core findings: model realism, platform scalability, and validation of the token-based coordination mechanism. Each result is grounded in empirical data from extensive simulation runs and benchmarked against real-world operational patterns observed across a diverse set of hospitality stakeholders.

Model Realism and Fidelity

To assess realism, the simulation was calibrated using operational data from approximately 500 industry partners—40% hotel operators, 30% OTAs, and 30% backend providers. Initial runs, based on default parameters and network configurations, achieved a fidelity rate of 82%, defined as the proportion of outcomes aligning with real-world booking and coordination patterns. Through iterative fine-tuning with selected partners, this rate improved to an average of 95%, with peak accuracy reaching 98% in specific configurations. These results demonstrate the model's ability to realistically capture trust propagation, booking confirmation, and compliance validation in fragmented hospitality ecosystems.

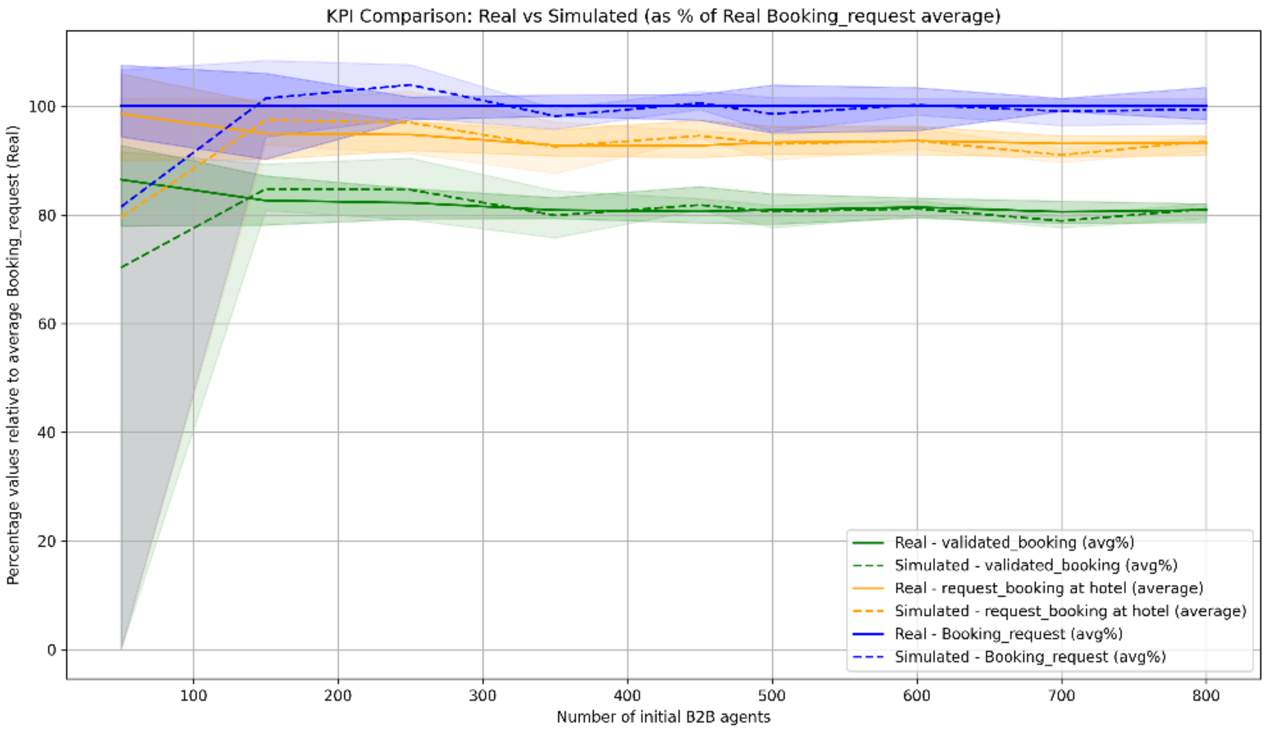

Figure 1: Calibration of the simulation model using real-world B2B Data. The graph illustrates how closely the simulated KPIs align with the real ones across different numbers of initial B2B agents. The visual overlap between the two series demonstrates the effectiveness of the calibration process and the model's ability to reproduce key behavioral patterns observed in the field.

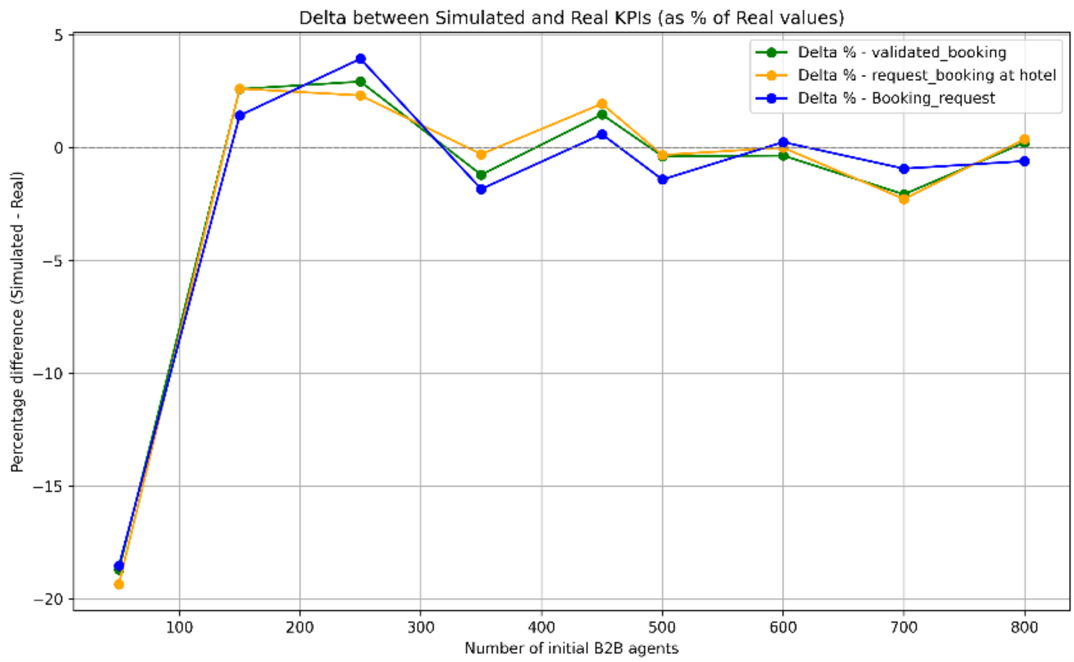

Figure 2:Systemic convergence of Simulated KPIs Toward Real-World Behavior This graph highlights the percentage difference (delta) between the simulated and real KPI values. A key observation is the emergence of a stable and systemic pattern as the number of simulated agents increases. Notably, the delta remains within ±5% for most configurations and tends to decrease with larger agent populations. This convergence suggests that the simulation model not only captures the average behavior but also begins to reflect the underlying systemic dynamics of the real-world environment. Such consistency reinforces the model's robustness and its potential for predictive and exploratory use in operational planning.

Scalability and Performance

A key objective was to evaluate the scalability of the 1AAS platform under high-load conditions. The system was tested with up to 10,000 concurrently active agents, simulating a realistic regional or global hospitality network. During peak rounds, the platform processed over 1 million token-based messages per iteration—including booking requests, confirmations, compliance checks, and trust updates. This throughput was achieved without distributed computing infrastructure, marking a significant advancement over traditional agent-based simulation frameworks. Benchmarks showed that 1AAS outperformed standard Mesa+MPI and Mesa+Python Messaging configurations in both speed and memory efficiency, confirming its suitability for large-scale, high-fidelity simulations. Scalability results will be formally disclosed in the final version of the paper, alongside the official launch of the product.

Validation of the Token-Based Coordination Mechanism

The final experiments validated the effectiveness of digital confirmation tokens in improving coordination and reducing friction. In the fully tokenized scenario, where all agents adopted token-based workflows, booking success rates—defined as transactions completed without human intervention—reached 98%. This marks a substantial improvement over the 74–82% success rates observed in simulations of current workflows. These results held across simulations modeling up to six months of business activity and involving 10,000 agents. The tokenized system also achieved full backend coherence, with no data mismatches or compliance violations, confirming its potential to streamline operations and enable scalable automation in complex hospitality networks. Results will be formally disclosed in the final version of the paper, alongside the official launch of the product.

Discussion

Although the simulation results exhibit robust performance in terms of realism, scalability, and coordination efficiency, several limitations must be acknowledged to contextualize the findings and inform future research..

First, the reliability of the outcomes depends on the quality of the underlying model. Regardless of the platform's sophistication, a poorly constructed or misaligned model can yield misleading results. Although the current model was calibrated using data from a diverse set of industry partners—achieving high fidelity—its accuracy remains contingent on assumptions embedded in agent behaviors, network structures, and token logic. Ongoing refinement and validation with real-world data are essential to maintain relevance and reliability.

Second, the current implementation focuses primarily on the post-booking phase of the hospitality workflow. The simulation begins at booking intention and does not include earlier stages such as search and pricing. These upstream processes are more complex and generate significantly higher volumes of interactions. For instance, message exchanges during search and pricing can far exceed those in booking and confirmation. While the model offers valuable insights into post-booking coordination, extending it to pre-booking dynamics would provide a more comprehensive view of the transaction lifecycle.

These limitations highlight key directions for future work. In particular, modeling the search and pricing phases could reveal new challenges and opportunities for token-based coordination—especially regarding scalability, latency, and trust formation. However, such extensions should be pursued only if supported by a compelling business case, given the added complexity and computational demands.

Conclusion

This paper presents a novel agent-based simulation framework designed to evaluate the adoption and systemic impact of digital confirmation tokens within fragmented hospitality ecosystems. By modeling trust propagation, interoperability, and coordination dynamics among heterogeneous agents, the simulation achieved high fidelity to real-world behaviors, with an average accuracy of 95% across diverse partner configurations. The results also confirmed the scalability of the 1AAS platform, which supported simulations involving up to 10,000 agents and over one million message exchanges per round—setting a new benchmark for non-distributed simulation environments.

Validation experiments showed that the proposed token-based coordination mechanism significantly improves operational coherence and automation. Booking flows completed without human intervention in 98% of cases, compared to 74–82% in current workflows. These findings highlight the potential of structured digital tokens to enhance trust, reduce friction, and streamline backend processes in the hospitality sector.

While the simulation offers valuable insights, its reliability depends on the quality of the underlying model. Additionally, the current implementation focuses on post-booking interactions, leaving upstream processes such as search and pricing for future exploration. Extending the model to include these phases could offer a more comprehensive understanding of systemic innovation, particularly if supported by a compelling business case.

In sum, this work contributes both a methodological advancement and a practical tool for evaluating innovation in complex service ecosystems. It opens the door to further research on tokenized coordination, trust modeling, and large-scale simulation in digitally mediated industries.

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