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Industry 4.0 applications towards sustainability in hospitality: First waves in the guest room

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Abstract
Digitalization is positioned as an important element for the future of hospitality related services, especially since the onset of the COVID-19 pandemic (Gursoy & Chi, 2020; Shin & Kang, 2020). Historically, digitalization focused on amplifying returns by increasing revenue and operational efficiency. The hospitality industry utilizes resources intensely to function well; and when used properly, technological improvements can optimize the development of a sustainable business model. This manuscript explores the role of recent innovations in digitalization, such as Big Data, the Internet of Things (IoT), and artificial intelligence (AI) in enabling environmental sustainability in hotels. These innovations become transparent when a substantial portion of resource utilization is being consumed (Yu-Lun et al., 2019).

Keywords
AI, IoT, sustainability, industry 4.0, hotel room, hospitality

Revisions

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Industry 4.0 Applications Towards Sustainability in Hospitality: First Waves in the Guest Room

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Abstract

Digitalization is positioned as an important element for the future of hospitality related services, especially since the onset of the COVID-19 pandemic (Gursoy & Chi, 2020; Shin & Kang, 2020). Historically, digitalization focused on amplifying returns by increasing revenue and operational efficiency. The hospitality industry utilizes resources intensely to function well; and when used properly, technological improvements can optimize the development of a sustainable business model. This manuscript explores the role of recent innovations in digitalization, such as Big Data, the Internet of Things (IoT), and artificial intelligence (AI) in enabling environmental sustainability in hotels. These innovations become transparent when a substantial portion of resource utilization is being consumed (Yu-Lun et al., 2019).

Keywords: AI, IoT, sustainability, industry 4.0, hotel room, hospitality

Digitalization advances in large-scale data collection and analytics have frequently been equated to the fourth industrial revolution—frequently referred to as Industry 4.0 (Hermann et al., 2016). The purpose of this paper is to lay the groundwork for empirical research in this emerging convergence space of combined Industry 4.0 and sustainability in the hospitality arena.

To achieve this purpose, the authors identified use cases and prevailing in-room solutions that demonstrated the potential to advance the impact of digitalization on hospitality sustainability. The discussion includes the opportunity of deploying artificial intelligence (AI) to enhance sustainability through optimal resource utilization by harvesting, analyzing, and acting upon data collected from in-room devices, and pairing it with traditional data sources. Such an analytics effort builds on the role of the Internet of Things (IoT) as a data generator and environmental juncture.

This paper takes a conceptual approach and reviews cross-disciplinary literature to examine the emerging Industry 4.0 theme and its potential applications in the hospitality industry. The
convergence space between Industry 4.0, hospitality, and sustainability is relatively nascent. Hence, conceptual analysis was deemed as a best fit to clarify concepts and reveal assumptions and steps (Machado & Silva, 2007) with the objective of laying the groundwork for future empirical research by identifying relevant use cases.

The resulting sub-domains were identified and analyzed for prevalent use cases and practices, with a focus towards objectives related to resource conservation. Based on the evidence and the implicit relationship between the subject areas, the scope of the convergence space was identified and further explored. Figure 1 provides a visual illustration of this approach.

**Figure 1.** Industry 4.0 - Sustainability Convergence in the Hotel Guest Room

Consequently, many applications selected because they hold the promise of benefiting from this convergence were analyzed through constructive analysis—a conceptual methodology that addresses a lack of explicit relationships between concepts or components with the aim of arriving at new conceptual theories (Kosterec, 2016). Ahlstrom (2007) described a two-step process to achieve this aim. First, the concepts involved need to be correlated with the existing concepts in place. Second, the direction of intuition needs to be correlated to the current concepts in place.

This methodology highlighted several use cases enriched by applying the collection of Industry 4.0 subdomains across them. As a result, a conceptual framework was derived to prepare the groundwork for empirical or experimental validation. This framework provided a basis for practical utility.

**Literature Review**

The review of literature involved the core database searches on distinct themes and a subset of their combinations: Industry, 4.0 and its components (AI, Big Data, and IoT), hospitality, and sustainability. The prevalence of multiple and oftentimes overlapping semantics associated with these concepts called for a definition to align with the scope of this paper.
**Industry 4.0**

Steam powered mechanical production marked the infancy stages of the first industrial revolution in the 18th century. At the beginning of the 20th century, electricity-driven manufacturing was responsible for the second industrial revolution. In the 1970s, the third industrial revolution began; a consequence of the application of electronics and information technology (IT) at scale (Horvath & Szabo, 2019).

The fourth industrial revolution (Industry 4.0) is characterized by an ecosystem of Big Data, cyber-physical systems, IoT, Internet of Services, and smart manufacturing that connects actors, objects, and systems in real time (Hermann et al., 2016). Junior et al. (2018a) focused on the importance of the relationship between Industry 4.0 and environmental protection, and Li et al. (2020) sought to provide an enhanced understanding of the impact of Industry 4.0 technologies on environmental sustainability.

Among other attributes and advantages from Industry 4.0, Perales et al. (2018) highlighted energy efficiency as a key advantage for businesses to leverage. For hospitality, this observation was further extended by Youssef and Zeqiri’s (2022) assertion that Industry 4.0 could mitigate the environmental impact of the industry through more efficient usage of energy, conservation of water, and reduction in food waste, which provided the basis for the theme of this paper.

**Big Data**

One of the major trends of Industry 4.0 on the minds of industry technologists, Big Data eludes a universally accepted definition. Nonetheless, a common thread across descriptors of the definition includes the V words volume, velocity, followed by variety, variability, veracity, visualization, and value (Dijcks, 2013; Schroock et al., 2012)—all applicable in the hospitality context. The original three—volume, velocity, and variety—were used by Laney (2001) in the context of conventional data management issues, devoid of the adjective big, and subsequently morphed into the founding attributes of Big Data as the term gained traction in usage over a decade later (Kwon et al., 2014). Though an all-encompassing definition of Big Data as an enabler of a concept’s scientific development has remained elusive, De Mauro et al.’s (2015) elucidation captured the essence of the concept for the purpose of this paper: “Big Data represents the information assets characterized by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value” (p. 103).

While Mikalef et al. (2018) underscored the importance accorded to Big Data from a technical perspective, Mariani et al. (2018), in their review of Big Data applications in hospitality, inferred that research in this field appears to be fragmented in scope and narrow in the methodology area. Nevertheless, Kwon and Jung (2019) demonstrated that investment in Big Data platforms by businesses, irrespective of the sector and size, had a positive impact on their valuation. On the theme of convergence, Guilarte and Quintans’s (2019) literature review examining the impact of Big Data on environmental sustainability in tourism revealed that a large proportion of Big Data is user generated content (i.e., social media reviews). This paper, on the other hand, focuses on Big Data sourced from on-premises operations and devices.
**Internet of Things (IoT)**

IoT is another trending technology theme. The term may be defined as a network of sensors that interact with one another and at the same time with other compatible systems (Dorsemaine et al., 2015; Madakam et al., 2015). Verma and Shukla (2019) argued that, in the hospitality industry, IoT has taken several dimensions in the areas of safety, cost savings, and entertainment. The prevalent gap between a hotel’s sustainability readiness and its IoT readiness was brought into focus by Eskerod et al. (2019).

The physical aspect of IoT refers to digitally enabled interconnected devices that communicate autonomously among themselves using standard wireless protocols, thereby evolving from computers in networks to connected objects (Raiani, 2013). In other words, objects which in the past were not able to exchange information with each other—neither through electronic nor manual mechanisms—are now empowered to communicate to each other. This functionality can now empower *things* to act and make efficient decisions and to pass on useful data to the individuals that work with them.

These trends are visible in the consumer world where smart watches, advanced light bulbs, and fitness trackers directly communicate with the consumer’s smartphone. Thus, with the advancement in sensor and controller technology, IoT has already become part of the daily life of consumers (He et al., 2020). Additional potential for IoT use remains in the enterprise space where it can accelerate operational efficiency and customer service (De Camargo et al., 2018).

As such, major chains including Marriott International and Hilton Hotels & Resorts have launched their own IoT initiatives focused on providing novel guest experiences and increasing effectiveness in service delivery. For example, IoT initiatives include intrusion detection systems that will notify guests (via their smartphone) when a door or a window is not properly closed. Guests will also have control of the thermostat, water temperature, and other room amenities through their smartphones or via voice activated devices (Grass, 2017).

Industry estimates suggest robust growth in IoT adoption from an estimated 8.74 billion connected devices with a cumulative turnover of $389 billion in 2020 to 25.4 billion devices with a revenue stream of over a $1 trillion by 2030 (Holst, 2021). Naimat (2017) attributed this uptick in IoT-related activities to several growth drivers such as increased device connectivity through uniform IT platform adoption, higher infrastructure availability for data analytics, and additional revenue potential and reduced cost through optimization and scale.

**Artificial Intelligence (AI)**

While AI has many connotations across different disciplines and contexts (Wang, 2019), a comprehensive definition provided by Eitel-Porter (2018) positioned AI as a set of technologies covering the spectrum from machine learning (ML) to natural language processing and deep learning, allowing machines to mimic human behavior in sensing, understanding, acting, and learning. The ability of a computer to mimic human behavior constitutes the essence of AI. ML is a subset of AI that learns from its environment to perform pattern detection and predictive analytics tasks. Deep learning, in turn, is a subdomain of ML and refers to multiple layers of artificial neural networks that mimic human brain activity based on a set of algorithms. Natural language
processing, on the other hand, is the ability of a computer to cope with a natural human language. While AI as a domain of research has existed for over half a century, the confluence of growing computing power and the spurt in data generation has made practical applications viable. For more technical discussions and definitions outside the scope of this paper, see Kok et al. (2009).

As traditional hotel data assets are complemented by a growing volume of sensor-harvested data, the end-to-end automation of pattern recognition and predictive analytics associated with ML algorithms promise to be most suitable for application in the convergence space defined in Figure 1. ML algorithms can be broadly grouped into three families: (a) supervised learning, based on the relationships between given inputs and outputs for prediction and classification tasks, (b) unsupervised learning, based on the exploration of input data without the availability of any explicit output for the development of clustering and association rules, and (c) reinforcement learning, based on performance iteration, with the objective of maximizing rewards for correct actions (Chui et al., 2020; Granville, 2020).

In hospitality, ML applications have been discussed in the context of cost reduction, optimizing operations, productivity enhancement, and minimizing waste (Ivanov, 2019; Kuo et al., 2017; Samara et al., 2020). Use cases in revenue management have also received attention (Millauer & Vellekoop, 2019; Schwartz et al., 2021) and the growing adoption of AI-powered chatbots is a testimony to the prevalence of guest experience applications (Putri et al., 2019; Ukpabi et al., 2019). Some use cases are examples of robotic process automation (RPA) that eliminates repetitive processes using structured input and logic is important to underscore (Schmitz et al., 2019). If the sense, comprehend, act, learn aspect is absent, then knowing whether these use cases are truly ML-driven is moot.

**Sustainability**

Sustainability has three primary facets: economic growth, social inclusion, and environmental protection, collectively referred to as the triple bottom line model (Junior et al., 2018b). While Bujan et al. (2019) focused on its application in hospitality, Nadkarni et al. (2019) conceptualized the impact of the Big Data-IoT ecosystem on sustainability in the hospitality context. Whether out of a sense of responsibility or because of mounting social pressure, there is an upward trend in the adoption of environmentally sustainable practices by the hospitality industry (Balaji et al., 2019). In fact, Chen (2019) argued that there is an increasing relationship between a hotel’s brand competitiveness and its effort to reduce carbon emissions.

The scope of sustainability in this paper is limited to its environmental aspect. According to Gössling (2013), the travel and tourism sector is one of the main contributors of environmental pollution. Hospitality is a resource-intensive industry; its impact on natural resources is multi-dimensional, including such diverse areas as CO2 emissions, nutrition demand, water and electricity consumption, waste disposal, noise generation, construction activity, and land utilization (Jones et al., 2014; Shao et al., 2020). However, the far-reaching resource consumption of the hospitality industry creates an equally sizable potential to impact sustainability with efficient technology solutions. Available hotel guest room control technologies already achieve 12–24% HVAC energy savings and 16–22% lighting savings (King & Perry, 2017).
Case studies highlight the scope of such applications. For example, Shao et al. (2020) underscored the utility value of monitoring energy consumption and enabling optimization across the organization. They argued that proximity sensors located across a property can augment micro-locationing capability via the guest’s smartphone and to trigger the in-room ecosystem to prepare the guest room accordingly in guest in or guest out mode.

Gökalp & Eren (2013) provided an example for the optimization of resource consumption through an analysis of guest behavior. For example, integrating the thermostat into the network enables it to interact wirelessly with guest room door lock and receive the data on any entry or exit that may have taken place. Determining the guest’s presence also helps improve accuracy, such as enabling the thermostat to communicate wirelessly to the guest room lock and obtain detailed data on entry and exit events.

Smart metering is an IoT application that could also apply to the hospitality industry. Here, collecting and analyzing smart meter data in the IoT space can help make decisions regarding predicting electricity consumption and forecast relevant demand and supply. In developing a conceptual framework for optimal real-time diagnostics and monitoring of smart buildings, Li et al. (2019) used a hotel as a case in point, wherein energy consumption patterns in individual guest rooms were mined using an array of smart meters right up to device level, and unsupervised learning algorithms were applied to classify energy consumption patterns for a specific device. This approach is spatially and temporarily scalable for developing use cases focused on in-room sustainability.

While research has explored IoT-enabled sustainability efforts to reduce energy consumption and food waste (Wen et al., 2018), the potential of IoT ecosystems in water conservation—particularly the last mile usage—remains underexplored. Solutions are emerging that allow fine-tuned control of water outlets in the room through exchanging traditional mechanical components with digitally addressable intelligent devices (Falko & Kriechbaumer &., 2016). Operators can measure data with regards to the water consumption in the guest room; these measurements can be in terms of volume, timing, and temperature. The operators also could determine the maximum temperature and flow in the guest room for the travelers to use during their stay. This advanced intelligence can also be utilized by interacting with other devices such as door locks. For example, the system can now regulate the use of water at higher temperature and pressure for housekeeping purposes when housekeeping staff enters the room for cleaning purposes. However, such solutions have yet to find much practical application, and advancements in this area are particularly pressing as many destinations are water-distressed (Gabarda-Mallorquí et al., 2017). Such destinations suffer from the discrepancy between water consumption in hotels and in local residences. For example, overnight guests staying in a luxury hotel consume between 200 and almost 1000 liters of water a day, which in many parts of the world is substantially more than a local resident consumes in a day (Becken, 2014). The resource-intensive nature of the hospitality industry has triggered the industry to look at technology to improve sustainability, with investments in the IoT being one of the top use cases for such efforts (Naimat, 2017).

While the literature identifies broad opportunities for hospitality sustainability in each of the emerging Industry 4.0 areas, the review suggests the convergence space of these areas and hospitality sustainability, particularly with reference to the guest room, has not received the attention it deserves. The premise is that IoT usage generates Big Data as an enabler of AI-driven
insights that reduce resource consumption. Growth in IoT deployment directly impacts the Big Data Vs, as sensors and actuators interact via the Intra- or Internet, allowing data to be collected from a variety of sources (Braun et al., 2019). However, Shadroo and Rahmani (2018) pointed out that IoT generated Big Data are worthless if no knowledge is extracted through analysis. Towards this end, Hajheiheydari et al. (2019) proposed a framework for generating business value from IoT data using a three-pillar structure—IoT, Data Mining, and Value Proposition map. A hotel’s ability to better understand guest behavior and preferences by harvesting real-time IoT-generated data and to deploy AI to optimize energy consumption could address this gap in the context of sustainability (Kansakar et al., 2019).

While Buhalis and Leung (2018) proposed a macro level ecosystem model for a smart hotel to represent this convergence, this paper aimed to focus on a specific sub-area of the ecosystem. Energy and water are typically the second highest shared cost in hotel operating expenses, just behind salary overheads. Within the area of energy consumption, the largest single resource consuming domain in hotels is the guest room, with about a 50-50 share between electricity and water as evident in Figure 2 (Tuppen, 2014). Consequently, building on Buhalis and Leung’s (2018) work, a natural focus is hotel room-specific Industry 4.0 activities. Nadkarni et al. (2019) first made inroads in this direction by exploring Big Data-IoT use cases in hospitality that are sustainability-driven.

**Figure 2. Distribution of Utility Consumption in Hotel**

![Image of distribution pie chart](https://example.com/image.png)

*Source. Tuppen, 2014*

A critical concern in this regard is that resource consumption savings do not impact the guest experience. While the literature offers little insight on the impact of sensor-driven technologies for sustainability on the guest experience, the impacts of in-room technology and in-room
sustainability efforts have been investigated separately in prior research. Susskind (2014) ruled out any negative impact on guest satisfaction from in-room sustainability initiatives adopted by hotels. Further, studies on hotel in-room technologies have focused on guest satisfaction and preferences (Bilgihan et al., 2016; Cobanoglu et al., 2011). Consideration for the impact on the guest experience must be given when implementing technology-driven in-room sustainability efforts.

Discussion

A review of existing sustainability use cases within any of the single domains of the convergence space in Figure 1 reveals an overwhelming focus on IoT when it comes to early applications and successful case studies. The following section proposes potential extended sustainability-focused use cases derived from enhancing such applications with other Industry 4.0 technologies. These can be applicable for the hospitality in-room appliance ecosystem.

Based on these examples, several proposed applications can be derived to expand the scope of such IoT use cases into the full Industry 4.0 ecosystem, moving beyond the rule-based input—process—output driven approach towards self-sustaining systems leveraging ML-driven pattern recognition and the inclusion of broader data sources. This also presents related opportunities for new applications in the realms of guest relation and operational aspects. As there is little evidence of any active deployments of such approaches and associated research, four conceptual pathways for creating value proposals are presented to highlight potential use cases within the convergence space.

Figure 3 illustrates how the combination of Industry 4.0 domains beyond standalone IoT applications can enable use cases that provide enhanced greater value than prevalent approaches. Collecting IoT-driven sensor input, incorporating additional data sources into the Big Data mix, and applying ML-driven insight generation enables such prevalent applications to amplify their sustainability impact. This combination can touch several areas, such as optimized room resource consumption without negative guest impact by applying traditional data overlay over in-room IoT-driven workflows and analyzing customer behavior in the room to optimize resource demand management using established guest profile characteristics. Furthermore, the ability to link guest behavior directly to sustainable practices in the context of HVAC and water control allows incentivizing guest behavior either by charging for resource consumption (pay as you use) or by providing reduced rates, credits, or loyalty points for low consumption. In terms of operational efficiency, optimizing and automating procedures based on the combination of IoT devices and the traditional data map, as well as ML insights to increase accuracy and reduce waste, are additional opportunities to create sustainability value.

Conclusions

This paper’s key contribution is the exploration of the inevitable potential convergence space across Industry 4.0 and hospitality sustainability in the room. While such early efforts have started to emerge in industry, little research has been published in this space so far. Thus, from an academic perspective, this work lays the groundwork for empirical research leading to third-order causal knowledge required for theory development (Rossiter, 2002).
### Figure 3. Enhanced Value Use Cases From Industry 4.0 Applications

<table>
<thead>
<tr>
<th>Standalone Application</th>
<th>Industry 4.0</th>
<th>Current Sustainability Impact</th>
<th>Enhanced Convergence Use Case Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Guest behavioural data, i.e., check in times, meal times, past room appliance preference, demographic information</td>
<td><strong>Value</strong></td>
<td>Combine Presence or Utilization-based energy consumption optimisation across HVAC and electricity consumers with behavioural data for specific guests or guest groups, without compromising on guest comfort by timely re-activation of guest preferred settings</td>
</tr>
<tr>
<td>HVAC energy savings mechanisms using event driven input data (check in/out, motion, door events) to trigger energy saving algorithms</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Internet of Things Data</td>
<td>Door lock event patterns, motion patterns, check in/out events, appliance utilization</td>
<td><strong>Value</strong></td>
<td>Default water and thermostat appliance to optimal guest temperatures based on given circumstances. Reduce water consumption through reduced mixing and adjustment wastage by guest by defaulting to common requirement based on traditional data map</td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Explore guest room utilisation against guest demographic and behaviour patterns</td>
<td><strong>Value</strong></td>
<td>Incentivize guest behavior by either charging for energy consumption (&quot;pay as you use&quot;) or by providing reduced rates, credits, or loyalty points for low consumption. Development of consumption index against input variables</td>
</tr>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Use of guest history data to determine adjustments to default setting based on usage patterns</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Digital water control instead of analog mechanical flow and temperature adjustments</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Internet of Things Data</td>
<td>Digital control and measurement of water set point and flow rate selected by guests during stay through IoT</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Predict water temperature and flow required for basin/choke to apply default</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Link consumption data to guest profiles</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Measurement of guest energy and water consumption and incentivise below average consumption</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Internet of Things Data</td>
<td>Measurement of water consumption, air/water heating or cooling, fan operation, light/power use through meters</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Explore guest room utilisation against guest demographic and behaviour patterns</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td><strong>Big Data</strong>&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Room usage expectation data from reservations planning</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Internet of Things Data</td>
<td>Electronic value for water flow control in the room</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Explore guest room utilisation against guest demographic and behaviour patterns</td>
<td><strong>Value</strong></td>
<td><strong>Value</strong></td>
</tr>
</tbody>
</table>

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1. Nadkarni et al., 2017; Chahat et al., 2019
2. Kaur et al., 2019; Chang et al., 2019
3. Lee et al., 2018; Chang et al., 2019
4. Jain et al., 2020

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An example of scope for further research is to harvest data in a live environment from multiple sources including IoT to train ML algorithms for predicting guest behavior and preventive maintenance leading to optimized in-room resource consumption. The outcomes can test the robustness of frameworks such as Technology Acceptance Model 3 (Venkatesh & Bala, 2008), and the artifact model (Turber et al., 2014) and paving the way for new theoretical constructs where necessary. Nevertheless, this paper benefits the hospitality practice by presenting opportunities for expanding the hotel data map with IoT-driven attributes and by extending the prevalent smart hospitality architecture towards Industry 4.0.

Such an extension enables new applications for Industry 4.0 use cases based on IoT data that can drive sustainability, such as the ability to aggressively optimize resource consumption in the room without negative guest impact, linking sustainability objectives to guest behavior and profile characteristics. These use cases enable more effective ways to address waste and shift the hospitality business model from flat fees towards attributes of the shared economy through pay as you use or rebate for low energy usage incentives. Examples include presence detection sensors paired with advanced sensor algorithms to identify optimizations of resource consumption in unoccupied rooms, methods to predict required water temperature defaults and ranges in the room and digitally preset outlets accordingly to reduce consumption, and water consumption measurement tools that would allow incentive-driven guest behavior changes. While sustainability is a primary factor for such initiatives, this example also serves to encapsulate side effects in the domains of guest experience and operational efficiency. Furthermore, it drives marketing potential through possible corporate social responsibility activities.

There is a promising outlook towards the future trajectory of ML applications for in-room IoT harvested data from the perspective of value addition to sustainable operation, but practitioners face many hurdles. These range from privacy and security concerns to organizational and stakeholder knowledge issues, a mix of applicable technology standards, and a lack of attractiveness of the sector. Some concerns can be alleviated. For example, the passive nature of the IoT and the natural guest engagement created by many applications described can overcome hurdles related to data collection methods of traditional tourism, such as guest unwillingness and privacy concerns as outlined by Keller et al. (2016). With the increased use of smart networked devices as part of the IoT, security vulnerabilities have emerged; Hyponnen’s law states that anything smart is also vulnerable (Mikko & Nyman, 2017). Thus, the implementation of IoT devices must be accompanied by appropriate security policies to address the increased risk.

On the technology side, vendors are promoting means to accommodate the requirement to build unified technology platforms (Risbud, 2020). To this end, Metallidou et al. (2020) proposed an IoT ecosystem for smart hotels that complies with the privacy and security requirements stipulated in regulatory frameworks such as the General Data Protection Regulation. This paper contributes to such advances in information systems models that represent an opportunity for empirical substantiation of the identified use cases in terms of value generation towards sustainability—paving a roadmap for further research in this Industry 4.0—hospitality—sustainability convergence space.
Theoretical Implications

Regarding the ML techniques identified in the literature review, the use cases previously discussed lend themselves to the application of supervised and unsupervised learning algorithms with the ability to recognize patterns and make predictions using Big Data. Orriols-Puig et al. (2013) demonstrated the use of unsupervised learning in knowledge discovery to support managerial decision making in the context of complicated business problems. They found that in the hospitality context, the prevalence of volume, velocity, and variety in a hotel’s data assets opens opportunities for the application of unsupervised learning algorithms; such algorithms can extract patterns from unlabeled data, using knowledge discovery processes—a subdomain of data mining. Further, fuzzy association rule mining can facilitate the automatic discovery of associations between features without the need for a target variable or explicit labelling (Agrawal et al., 1993).

These clustering techniques have found applications in customer segmentation, recommender systems, and targeted marketing. Customers who bought this also bought that is a prominent example. Such unsupervised learning algorithms can be effectively deployed for gaining insights into on-premises resource consumption and behavioral patterns by hotel guests.

An alternative ML approach for use cases is to predict the values of a target variable by identifying the features from the combined pool of IoT and non-sensor data assets for training supervised learning models. Supervised learning has found a variety of applications in business, including predictive analytics, forecasting, customer retention, fraud detection, and process optimization, among others. For instance, in urban planning and sustainability, Vijai and Sivakumar (2016) proposed a framework for water conservation using IoT data in combination with other data sources which can serve as a template and example for deploying supervised ML algorithms for forecasting in-room water consumption based on guest profile, geographic location, and weather conditions—together with sensor harvested data on actual consumption patterns including volume, temperature, duration, and frequency acting as predictors.

Thus, deploying unsupervised and supervised ML algorithms that feed on Big Data for the in-room IoT use cases acts as a value multiplier for meeting sustainability goals. The contribution of these Industry 4.0 components acting in tandem to enhance value creation is represented in Figure 4. In contrast, prevalent applications sit at the bottom of the progressive pyramid model from pure collection of data to prescriptive feedback cycles, as suggested by Mousannif et al. (2016). Devoid of convergence, the output for each of the use cases can be achieved through conventional programming paradigms (data + program = output). However, for the in-room ecosystem to function as an optimized automated and hyper-personalized whole, ML (data + output = algorithm) is required.

While the provision of data and the collection of information only covers the base in the value generation pyramid, the concepts outlined in this paper aimed at elevating hospitality onto layers previously inaccessible. Nevertheless, there is little evidence of the hospitality industry transitioning from making decisions based on past data to moving up the pyramid towards predictive analytics-based decision making. Indeed, Hunke et al. (2017) observed that while there are a broad number of use cases driving the expected adoption, the primary drivers for adoption lie in the upper layers of the pyramid and have not yet reached maturity: predictive maintenance, self-optimizing production, and automated inventory management. This is reflective of the limited
value generation of Industry 4.0 in hospitality today. Considering the potential of these use cases, the question emerges as to why these opportunities are so far only getting limited traction in the industry.

**Figure 4. Value Generation Pyramid With Industry 4.0 Contribution Overlay**

For operationalizing such ML deployments at scale, having the appropriate data ecosystems is a pre-condition, given the dependence on data volume, velocity, and variety. The linkages of the Big Data-IoT-Analytics-Cloud (BIAC) ecosystem leads to what Bughin et al. (2010) termed distributed co-creation. This is a precursor to *things* (in the context of IoT) integrated with AI to the extent of making autonomous decisions (Scheibenreif & Sussin, 2015). Edge computing is a case in point for deriving value from such distributed co-creation, particularly in an in-room scenario. In this case, the computational load is handled at the device/sensor end rather than on the cloud, thereby reducing latency and, importantly, the energy consumption of cloud data centers (Varghese et al., 2016).

**Practical Implications**

What emerges from this study is the need for a comprehensive hospitality analytics architecture that breaks through data silos (both internal and external) providing a 360-degree view of the business to address on-premises sustainability issues proactively. To this end, building on existing work on data ecosystems at the property level, the in-room component is brought into focus to identify the challenges associated with silos. These silos pose an impediment for harvesting relevant data, the analysis of which can provide near real-time actionable insights for optimizing resource consumption.

A traditional data warehouse based on extract—transform—load principle architecture is inadequate due to its inability to handle unstructured data (Miloslavskaya & Tolstoy, 2016), and preventing meaningful deployment of the ML applications discussed previously. On the other hand, a data lake is a storage repository that is scalable and can store massive volumes of raw data in its original format until needed for processing. This extract—load—transform sequence happens
without compromising the native data structure (Laskowski, 2016). As Miloslavskaya & Tolstoy (2016) underscored, data lakes can ingest “logs and sensor data (e.g., from the Internet of Things), low level customer behavior (e.g., website click streams), social media, document collections of (e.g., email and customer files), geo-location trails, images, video and audio and another data useful for integrated analysis” (p. 303).

A data lake is therefore proposed as part of the solution to the problem of silos in hotels which can enable ML deployment at scale for achieving in-room sustainability targets along with deriving other business insights. This, by extension, will cumulatively impact the Industry 4.0 components and their collective impact on in-room sustainability is illustrated in Figure 5.

**Figure 5. Industry 4.0 Architecture for In-Room Use Cases Aimed at Sustainability**

In-room data harvested via IoT feeds into the property’s local network via low power transmission (e.g., Bluetooth, Zigbee) and Transmission Control Protocol/Internet Protocol. Edge computing handles relevant on device analytics after factoring for latency, scalability, and privacy in parallel to the IoT data feeding into a data lake together with non-IoT data sourced from multiple hotel systems. ML models are deployed on this Big Data environment on the cloud data lake to derive predictive and prescriptive insights and trigger autonomous actions that lead to tangible sustainability outcomes.
Limitations and Future Research

Several challenges remain to be addressed. In Nadkarni et al. (2019), the lack of industry standards and the interoperability challenges deterred the smooth implementation process resulting in a fragmented data landscape due to the IoT requiring device-to-device interface with communication paths as opposed to point-to-point server communication. Gamage et al. (2020) cited the disconnect between past guest engagement records and new customer acquisition and marketing efforts as an example of the data silos prevailing in the hospitality industry.

These examples suggest a fragmented landscape, wherein data sources are spread across disconnected islands represented by multiple systems such as PMS, POS, CRM, marketing and web analytics, and external repositories like social media platforms and third-party data. Piecemeal solutions by hotel operators in the name of brand standards have led to a variety of implementation frameworks, sometimes proprietary; and this limited scalability, ultimately impacts guest experiences (Wood, 2013). If data and communication protocol standards develop in the hotel industry, effective and efficient communication would be enabled to further link connectivity among applications (Buhalis & Leung, 2018).

These challenges are also poised to impact the utilization of IoT generated data. Elements around room usage and guest behavior in the room (particularly energy and water consumption) have yet to find a place in the hotel data architecture (Altexsoft, 2019). The extension of the social-mobile-analytic-cloud, or SMAC stack (Ackx, 2014), led to the social, mobile, analytics, cloud, Internet of Things (SMACIT) framework proposed by Nadkarni et al. (2019), which addresses this gap.

With reference to actual implementation of IoT in hotel systems, Kansakar et al. (2019) identified additional major challenges: interoperability, security and privacy, data management, and responsiveness. The lack of standardization, the exponential growth of data volume collected, and significant computing resources to the security protocols for guest interaction and responsiveness all contribute to the challenges of linking the hospitality ecosystem together. While a subset of the applications has been shown to have a localized impact through room-level data exchange, to truly harness their power, the information exchange must be addressed across systems, bringing IoT generated data points into a Big Data architecture to support ML applications in pattern recognition, and identifying opportunities to overlay IoT data with traditional sources found in Buhalis and Leung (2018).

References


Hermann, M., Pentek, D., & Otto, B. (2016, January 5-8). Design principles for industry 4.0 scenarios [Conference Presentation]. The 49th annual Hawaii international conference on system sciences, Hawaii, USA.


