

Emerging trends in sustainable design: Integrating museums for a resilient future

Tao-Hua Wang^{1,*}, Hao-Chiang Koong Lin², Cheng-Tsung Li³

¹ *Science Education Department, National Museum of Natural Science, Taichung 404023, Taiwan*

² *Department of Information and Learning Technology, National University of Tainan, Tainan 70005, Taiwan*

³ *Department of Digital Media Design, Asia University, Taichung 413305, Taiwan*

* **Corresponding author:** Tao-Hua Wang, a147@nmns.edu.tw

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ABSTRACT: The paper unfolds the intricate tapestry of sustainable design, weaving in the pivotal role of renewable energy systems and astutely tying it to the eco-conscious blueprint of modern museums. The introduction sheds light on the potent impact of sustainable design in mitigating environmental hurdles and fostering a greener, more sustainable future, with a nuanced nod towards sustainability in museum management and design. Motivated by an aspiration to traverse diverse viewpoints and methodologies in sustainable design, the research stretches across numerous sectors—encompassing construction, architecture, engineering, manufacturing, software development, and notably, museum design—intending to carve out energy-sparing and ecologically mindful solutions. This paper underscores the imperative of astute design practices that optimize structures, such as museums, to maximize the utilization of renewable energy resources like solar arrays, wind turbines, and geothermal systems. It advocates for a burgeoning need to escalate the horizon of sustainable design beyond singular buildings, intertwining standalone energy systems at multiple tiers—from community power grids to expansive urban networks—ensuring a streamlined energy distribution and curbing waste. Wading through the literature review, an exploration of varied sustainable design strategies unfolds, encompassing facets like supply chain management, product safety, architectural design, manufacturing, food packaging, transportation, and pedagogy, with a specific lens on embedding sustainability in museum infrastructure and operations. The culmination of the paper discerns ten cardinal trends in sustainable design, spanning from the integration of renewable energy systems to the infusion of sustainable education and positive psychological interventions in educational institutions, thereby spotlighting the metamorphosing terrain of sustainable design across an array of disciplines.

KEYWORDS: sustainable design; renewable energy systems; smart design; energy efficiency; museum sustainability; environmental mindfulness

1. Introduction

In recent years, there has been a growing consensus on the importance of sustainability in various sectors, including the museum field. As global environmental and socio-cultural challenges intensify, museums, traditionally seen as repositories of culture and heritage, are now being re-envisioned as platforms for sustainability and change. The connection between museums and sustainability is not merely about making institutions environmentally friendly or energy-efficient but encompasses a broader perspective on how these institutions interact with and contribute to society.

Several researchers have ventured into this domain, each shedding light on different facets of the museum-sustainability nexus. Kristinsdóttir^[1] probes into the realm of sustainable museum education, underscoring the necessity of supportive frameworks and the empowerment of educators, thereby confronting the prevalent challenges and uncertainties in this realm. Pop and Borza^[2] elaborate on the intricacies of how a sustainable museum can induce sustainable regional development. Their subsequent research^[3] dives deeper, seeking to understand the myriad factors that influence museum sustainability and proposing a model for gauging sustainability levels across museums.

Furthermore, King and Lord^[4] provide a holistic overview of museum planning, underscoring the significance of sustainable spaces, facilities, and operations. Besterman^[5] introduces a thought-provoking discourse on cultural equity in sustainable museums, advocating for Western museums to recognize and rectify their cultural footprints. Kampasakali et al.^[6] further the narrative by investigating sustainable conservation practices, focusing on contemporary art and design object maintenance.

Merriman's^[7] stance delves into the harmonization of social and economic sustainability in museums, while Brown et al.^[8] share insights on community-oriented sustainable museums. Alcaraz et al.^[9] emphasize service-centricity in non-profit museums as a pathway to sustainable practice. Lastly, Link^[10] offers an insightful historical perspective on the evolution of the sustainability concept within the museum sphere.

This burgeoning interest and diversified research clearly emphasize the multifaceted nature of sustainability in the museum domain. However, while a vast body of work exists, there still remains a palpable gap in understanding how these individual components synergize to shape a truly sustainable museum of the future. Motivated by this backdrop, our study aims to holistically analyze these individual facets, offering a cohesive understanding of sustainable museum practices and their broader implications. The background of the research revolves around sustainable design, with a specific focus on renewable energy systems. Sustainable design and construction play a crucial role in addressing environmental challenges and promoting a more sustainable future. Renewable energy systems are an essential component of sustainable design, as they offer a clean and renewable source of energy that can significantly reduce carbon emissions and dependence on fossil fuels^[11,12].

The motivation behind this research stems from the growing recognition of the importance of sustainable design in mitigating the impacts of climate change and promoting energy efficiency. With the increasing global demand for energy and the urgency to transition to renewable sources, there is a need for innovative and effective design solutions that integrate renewable energy systems in buildings and infrastructure^[13,14].

Smart design practices are vital for creating sustainable buildings with renewable energy systems. These practices involve optimizing the design of buildings to take full advantage of renewable energy sources like solar panels, wind turbines, and geothermal systems. By incorporating renewable energy

systems into the design process, buildings can generate their own energy, reduce reliance on the grid, and contribute to a more sustainable energy future^[15,16].

However, the scope of sustainable design in energy systems needs to be expanded beyond individual buildings. It is crucial to integrate standalone energy systems through multi-scale optimization, considering the interconnectedness of energy consumption and production at various levels, such as community grids and urban networks. This holistic approach to sustainable design ensures efficient energy distribution and minimizes waste^[16,17].

Moreover, the implementation of sustainable design theory in business practices is also a significant aspect of this research. Companies need to embrace sustainable design principles, especially in product service system design literature. By adopting sustainable design practices, businesses can create products and services that are environmentally friendly, resource-efficient, and socially responsible^[12,13].

The Karlskrona manifesto is an important resource that outlines key issues, goals, values, and principles of sustainable design for software-intensive systems. This manifesto provides guidance for integrating sustainability principles into the design and development of software and digital products, considering their significant environmental and energy impacts.

In summary, the research background and motivation revolve around the importance of sustainable design, particularly in the context of renewable energy systems. The research aims to explore various perspectives and approaches to sustainable design in different fields, including construction, architecture, engineering, manufacturing, and software development, with a focus on creating energy-efficient and environmentally conscious solutions. Through this research, we aim to contribute to the advancement of sustainable design practices and address the urgent need for a more sustainable and resilient future^[12-14].

2. Literature review

The concept of sustainability within the museum sector has attracted considerable academic attention over the past few decades, with a diverse range of studies exploring various facets of this intricate nexus.

- 1) Educational Approaches: Kristinsdóttir^[1] highlights the growing need for sustainable museum education practices. The research underscores the significance of supportive frameworks that pivot on existing museum learning theories. An essential aspect of Kristinsdóttir's work is the emphasis on the empowerment of museum educators, emphasizing the role they play in driving sustainable education.
- 2) Museums and Regional Development: Pop and Borza^[2] delve into the relationship between sustainable museums and sustainable regional development. They posit that for museums to play a pivotal role in regional sustainability, they first need to embed sustainability within their operational and strategic frameworks.
- 3) Sustainability Metrics: Offering a more methodological approach, Pop and Borza^[2] introduce factors that influence museum sustainability. Their work is vital for museums aiming to measure their sustainability initiatives, providing a comprehensive model that assesses sustainability levels across various institutions.
- 4) Museum Planning and Operations: A manual by King and Lord^[4] offers a deep dive into sustainable museum planning, covering space utilization, facility management, and day-to-day operations. The work underlines the argument that museums ought to be frontrunners in showcasing sustainable living.

- 5) Cultural Equity: Besterman^[5] provides a compelling perspective on the intersection of cultural equity and sustainability within museums. He argues about the cultural footprint of Western museums, suggesting that their approach, if not rectified, might be unsustainable in the long run.
- 6) Conservation Practices: The sustainability conversation also extends to the conservation of artifacts. Kampasakali et al.^[6] focus on the use of biodegradable agents for the surface cleaning of contemporary art and design objects, reflecting the broader shift towards sustainable museum practices.
- 7) Museum Collections: Merriman^[7] touches upon the socio-economic facets of sustainability within museums. His stance is that a genuinely sustainable museum doesn't view environmental, social, and economic aspects in isolation but considers them as interconnected domains.
- 8) Community Engagement: Brown et al.^[8] provide insights on the role of community engagement in sustainable museums, emphasizing shared experiences and knowledge.
- 9) Sustainability in Service-Centric Museums: Alcaraz et al.^[9] explore service-centricity in non-profit museums, identifying critical issues that can aid in establishing sustainability within these institutions.
- 10) Evolution of the Sustainability Concept: Lastly, Link^[10] offers a historical viewpoint, tracing the evolution of sustainability within the museum sector and its ties to citizenship and the common good.

In a quest to fathom the multifaceted nature of sustainability in the museum sector, several studies have come to the fore, often intersecting in their areas of emphasis yet diverging in their methodologies and focal points. Kristinsdóttir^[1] underscores the pivotal role that museum educators play in imparting sustainable education, building on extant learning theories. Yet, one wonders whether these existing paradigms are truly compatible with the sustainability ethos or if there's a need for radical paradigm shifts. This educational framework, while foundational, seems somewhat decoupled from the more strategic concerns voiced by Pop and Borza^[2], who emphasize embedding sustainability within operational matrices for regional development. The later work in 2019^[3] provides a methodological model for gauging museum sustainability, but juxtaposing this with King and Lord^[4] hands-on approach to museum planning hints at a potential gap between theory and practice. Is the act of measuring sustainability inherently sustainable, or does it, paradoxically, divert resources from actionable sustainability endeavors? Besterman's^[5] discourse on cultural equity brings forth a nuanced critique of Western museums, implying an ethnocentric bias. Still, the question arises: Are non-Western museums inherently attuned to sustainable practices, or are they subject to their own biases? Kampasakali et al.'s^[6] innovative focus on artifact conservation, while novel, raises concerns about the long-term efficacy of biodegradable agents. Merriman^[7], in his holistic perspective on museums, seems to touch upon an integrated vision that resonates with Brown et al.'s^[9] emphasis on community engagement. But can shared experiences truly catalyze sustainability, or do they inadvertently foster echo chambers? Alcaraz et al.'s^[9] exploration of service-centric museums provides a refreshing non-profit perspective, but the broader implications for their profit-driven counterparts remain shrouded. Finally, Link's^[10] historical tracing of sustainability's evolution seems to suggest a teleological progression, but is the trajectory of sustainability linear, or are there cyclic patterns and recurrences? This intricate tapestry of studies, while offering rich insights, beckons for an integrated, holistic, and perhaps more self-critical approach to truly fathom and further sustainability in the museum domain.

Collectively, these studies showcase the multi-faceted nature of sustainability in the museum sector, highlighting the importance of integrating sustainable practices across various operations and strategic

initiatives. Sustainable design principles are gaining prominence across diverse sectors, as underscored in recent literature. The importance of sustainability is highlighted within supply chain networks, advocating for resource conservation. The emphasis on product safety and lifecycle sustainability is evident. The convergence of value engineering with building modeling could potentially refine sustainable building designs. Sustainable manufacturing, food packaging innovations, and designs for underground environments, warm mix asphalt, and natural fiber composites underline the need for eco-centric practices. Additionally, integrated sustainable supply chains and education tailored towards green recovery emphasize holistic sustainability^[18,19].

Overall, these literature categories highlight the significance of sustainable design and its application in various fields, including supply chain management, product safety, building design, manufacturing, food packaging, transportation, and education. They provide valuable insights into the integration of sustainable practices across different sectors and emphasize the need to consider sustainability throughout the design process for a more environmentally friendly future^[12,20].

3. Research method

In our exploration of the confluence of museums, educational strategies, and sustainable practices, we utilized the framework proposed by Kitchenham and Charters^[21] to craft a coherent, clear, and thorough review of existing literature. This procedure, as outlined by Kitchenham and Charters^[21], involves defining research questions, designing a review strategy, setting criteria for inclusion and exclusion, detailing the search and inclusion techniques, consolidating and interpreting data, and finally presenting the results. Further details of our methodology and the steps undertaken are discussed in the sections that follow.

The systematic review journey begins by defining a structured protocol rooted in the central research questions and the selected methodologies^[21]. Such a structured approach is crucial to minimizing biases. Key components of this protocol include an initial exploration of the subject, framing the research questions, developing a research strategy, setting criteria for selection, mechanisms for data retrieval, and the eventual synthesis of the collected data. For this study, the foundational research and question formulation can be found in prior sections.

Our research considered publications in English from 2010 to 2022, spanning journals, conference papers, and workshop outputs. The time frame was selected for specific reasons. Primarily, we aimed to augment and extend the scope of previous analyses centered on museums, education, and sustainable practices in contemporary settings. Hence, our effort involved systematically assembling relevant studies from the said period to holistically analyze and deduce findings related to the roles of museums, their educational techniques, sustainable approaches, and instructional resources that might have been missed in previous scholarly works. Digital libraries such as ISI Web of Knowledge, ScienceDirect, IEEE Explore, and Springer Link were consulted. We refrained from incorporating editorials, article introductions, poster sessions, panels, abstracts, incomplete papers, non-reviewed works, or papers not in English.

Taking cues from Webster and Watson^[22], our review encompassed diverse electronic databases, ensuring a comprehensive collection of literature rather than being restricted to specific journals. Thus, prominent databases like ISI Web of Knowledge, ScienceDirect, IEEE Explore, and Springer Link were tapped into, considering their relevance to themes of culture, education, and sustainability. Our search was steered using terms like “educational role of museums”, “green museum initiatives”, “learning

through museums”, and “sustainability in museums”. Following the suggestions by Kitchenham^[23], we employed the Endnote software for managing and sifting through the gathered literature, discarding duplicates. In alignment with Kitchenham and Charters^[21], we also manually scanned references in the primary articles to ensure comprehensive coverage. This cycle continued until we identified no new relevant literature.

4. The pervasive power of sustainable design: A new era emerges

As society stands on the precipice of a new decade, sustainable design emerges as a beacon, illuminating the way forward across multiple disciplines. Its influence, broad and all-encompassing, touches everything from the concrete structures we inhabit to the very fabric of our digital world^[11,13,14].

Central to this transformative wave is the fervent emphasis on renewable energy systems. In today’s sustainable architectural and infrastructural designs, the integration of renewable energy is no longer an afterthought. It forms the very essence of blueprints, embodying an ethos where sustainability is foundational. Intelligent design principles accentuate this shift. The essence of “smart design” is not merely the incorporation of technologically advanced systems but fusing them seamlessly with renewable energy mechanisms to create edifices that are not only functional but also environmentally harmonious.

As we delve deeper into the realm of energy, it becomes evident that the spectrum of sustainable design is broadening. It’s not just about one or two energy systems but an array that spans the gamut, from traditional solar and wind to more novel sources. And in this broader scope, the focus sharpens on the integration and optimization of these often-standalone systems. By leveraging multi-scale optimization, the goal is to weave these systems together, ensuring that they operate in symphony, magnifying their collective sustainability impact^[12,13].

But sustainable design isn’t confined to physical spaces or energy systems. It’s making inroads into the world of business. Contemporary business practices are undergoing a green metamorphosis, with the tenets of sustainable design theory increasingly finding a place in boardrooms. Whether it’s in product service system design literature or broader strategic decision-making, sustainability is becoming synonymous with sound business acumen.

The Karlskrona manifesto underscores the evolution of sustainable design into the domain of technology. With software now an intrinsic part of our daily lives, it’s heartening to see the core principles of sustainable design being adapted and integrated into this digital realm. While on the topic of adaptation, optimization tools such as genetic algorithms are being fine-tuned to further the goals of sustainable design. The application of Warm Mix Asphalt (WMA) serves as a testament to the potential of these multi-objective optimization techniques^[15].

The threads of sustainability extend further into the design of supply chains and transportation networks. Here, the narrative revolves around an integrated approach. No longer are supply chains seen in isolation but as part of a larger, interconnected web that includes transportation networks, especially when it comes to perishable products.

In an age where knowledge is paramount, education is not untouched by this green wave. Modern educational institutions are embedding sustainable and well-being aspects into curricula, weaving in positive psychology interventions. The objective? Cultivating a mindset that not only values knowledge but also sustainable happiness and well-being for future generations^[16,17].

The COVID-19 pandemic, though disruptive, has further accelerated the pace of sustainable

innovation. Online education, for instance, has seen a surge in sustainable models. These are not mere digital replicas of physical classrooms but thoughtfully designed learning environments that recognize and address the unique challenges and opportunities of online pedagogy^[14,15].

In summary, sustainable design, once relegated to select fields, now permeates the entire fabric of society. From architecture and engineering to manufacturing and education, its influence is undeniable, marking the dawn of an era where design thinks green and acts sustainably.

Ten major trends in sustainable design can be identified:

- 1) Growing emphasis on renewable energy systems: Sustainable design is increasingly focused on integrating renewable energy systems into buildings and infrastructure.
- 2) Smart design for sustainable buildings: The use of intelligent design principles is gaining importance to create sustainable buildings with renewable energy systems.
- 3) Broadening the scope of sustainable design in energy systems: The concept of sustainable design is expanding to include a wider range of energy systems and their integration to optimize sustainability.
- 4) Integration of standalone energy systems through multi-scale optimization: The trend is towards the integration and optimization of standalone energy systems at different scales to enhance sustainability.
- 5) Implementation of sustainable design theory in business practices: There is a growing focus on incorporating sustainable design theory into business practices, particularly in product service system design literature.
- 6) Karlskrona manifesto for software-intensive systems: The Karlskrona manifesto outlines key principles of sustainable design for software-intensive systems, bringing the concept into the field of technology.
- 7) Multi-objective optimization for sustainable design^[15]: Genetic algorithms and other multi-objective optimization techniques are being used to achieve sustainable design objectives, as seen in the case of Warm Mix Asphalt (WMA).
- 8) Integrated design of sustainable supply chain and transportation network: There is a trend towards integrating sustainable design principles in supply chain and transportation network design, particularly for perishable products.
- 9) Sustainable education and positive psychology interventions in schools: Education is increasingly focusing on sustainable and well-being aspects, aiming to achieve sustainable happiness and well-being in the 21st century.
- 10) Construction of online sustainable educational models: The COVID-19 pandemic has driven the construction of online sustainable educational models to adapt to changing learning environments.

These trends highlight the evolving landscape of sustainable design across various disciplines, including architecture, engineering, manufacturing, and education.

5. Discussion

The conversation around sustainability has transcended its original confines, notably entering spaces like the museum sector. Traditionally viewed as cultural vaults, museums are now redefining themselves as advocates for sustainability, encompassing more than just environmental considerations. Their approach touches on social, educational, and cultural facets of sustainability. Numerous researchers,

including Kristinsdóttir^[1], highlight the significance of educators in forwarding the agenda of sustainable museum education. This transformation is not just about the content being shared but also the methodologies and platforms facilitating it. Pop and Borza's^[2] findings underscore that museums are integral to the broader sustainable ecosystem and not isolated entities. Drawing from the detailed guide by King and Lord^[4], it's clear that sustainability is intricately woven into everyday operations and not just an overarching strategy. Parallel to these insights, cultural equity, as championed by Besterman^[5], and conservation efforts, as per Kampasakali et al.^[6], bring fresh perspectives to the table. Delving into socio-economic dimensions and community involvement, researchers like Merriman^[7] and Brown et al.^[8] bring to the fore the intricate mesh of sustainability that spans the environment, society, and economics. Alcaraz et al.'s^[9] service-oriented approach, along with Link's^[10] historical overview, charts the evolution of museums in the sustainability context. Beyond museum spaces, there's an evident push towards sustainable design in various domains, including infrastructure and energy. The universal emphasis on shifting to renewable energy sources, optimizing energy distribution, and ingraining sustainable design into varied facets of life signifies the crucial need to prioritize this approach.

6. Conclusion

As we critically analyze the wealth of information and delve into the findings presented, it becomes strikingly clear that we're on the cusp of an unprecedented transformative era. The realm of museums, which have long held the role of guardians and curators of our collective history, is undergoing a significant metamorphosis. No longer are they just silent observers of our past; they are dynamically positioning themselves as luminous beacons, heralding a vision for a sustainable future.

This shift, while profoundly evident in museums, is by no means confined to them. Indeed, the ethos of sustainable design has permeated various facets of our society, standing out as a binding force that seamlessly interlaces through diverse sectors. Whether it be the intricate world of business, the robust domain of infrastructure, or the ever-evolving fabric of community spaces, the principles of sustainability resonate with a clarion call. It's a call for thoughtful design, mindful consumption, and holistic development that respects both our heritage and our environment.

What lends credence to this transformative shift is the burgeoning body of research that champions a holistic approach to our future. Researchers, policymakers, and thought leaders from varied disciplines converge on the idea that sustainability cannot be compartmentalized or viewed in isolation. It's not just a fragment of our developmental narrative but rather forms the very bedrock of it. Sustainability, in this light, emerges as a comprehensive framework guiding our actions, decisions, and visions for the future.

In essence, as we navigate the complexities of our modern world, it's this commitment to sustainability that provides a beacon of hope. It's more than just a strategy; it's a philosophy, a way of life that strives for equilibrium between our needs and the planet's capacity. As we forge ahead, this commitment ensures that we leave behind not just a legacy of progress but also a blueprint for a balanced, harmonious world for all subsequent generations to cherish and sustain.

Author contributions

Conceptualization, THW; methodology, HCKL; software, CTL and HCKL; writing—original draft preparation, THW; writing—review and editing, HCKL; funding acquisition, CTL. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors of this paper have no conflict of interest.

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