Eng. Sci., 2025, **35**, 1587

Engineered Science
DOI: https://dx.doi.org/10.30919/es1587

Artificial Intelligence-Driven Materiality: A Systematic Review and Perspective

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Abstract

Artificial intelligence (AI) and materiality are increasingly interdisciplinary domains of inquiry, fostering innovative research across fields for our society, such as engineering, philosophy, the arts, and sustainability. However, the review of such integrated aspects was not presented. This review examines existing literature and offer perspectives on the complex interdisciplinary themes between AI and materiality, including epistemic materiality, sociomateriality, creativity and design, and sustainable development. A systematic review of 60 recent articles was performed, following The population, intervention, comparison, and outcome (PICO) and preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The qualitative analysis of their keywords was also articulated. AI revolutionizes knowledge generation, enhances creative processes, and improves resource efficiency, offering opportunities for innovation while introducing ethical challenges such as algorithmic bias, accountability, and transparency. Also, AI profoundly affects epistemic and agential materiality, transforming knowledge creation, creative methodologies, and sustainable development initiatives. The paper highlights the implications and challenges, such as ethical concerns and technology-shifting barriers, as well as opportunities in integrating AI with material systems, ameliorating a smart and sustainable roadmap for future interdisciplinary research.

Keywords: Materiality; Artificial intelligence; Interdisciplinary; Perspective; Review.
Received: 18 April 2025; Revised: 29 May 2025; Accepted: 10 June 2025.
Article type: Review article.

1. Introduction

Artificial Intelligence (AI) possesses a long and complex historical background. Originally established in the 1950s, the discipline has experienced periods of enthusiasm and disillusionment, characterized by 'AI winters' subsequent to the proclamation of novel achievements.[1] While machine learning (ML) has been around for decades, the early 2010s witnessed a renewed interest in 'deep learning' approaches due to their exceptional performance in tasks like image classification, speech recognition, and machine translation.[2,3] Previous advances had challenges in transitioning to practical applications, but deep learning has been embraced across several sectors, especially by selected Big Tech firms like Apple, Google, and Meta, in both their offerings and as suppliers of computational infrastructure and services. Leveraging extensive training data and computing resources, ML and natural language processing (NLP) have emerged as fundamental tools for these entities. Simultaneously, the notion of materiality for society has become increasingly significant in academic discourse, especially within philosophy, social sciences, and engineering. Materiality, which includes both the visible and invisible components of physical things like systems, infrastructures, and products, interacts with AI in important and complicated ways.[4,5] This viewpoint highlights the dual aspect of AI as both a computational abstraction and a physically embedded entity.

Materiality, a crucial term in various interdisciplinary fields, explores how the physical properties of materials influence their function and significance. In the context of AI, the materiality encompasses not just hardware and physical components but also the material circumstances governing the operation of AI systems, including the data processed, the algorithms employed, and the necessary infrastructure and architecture. This underscores the necessity of addressing the epistemological and ethical aspects of AI's materiality.[6,7] The notion of materiality in AI encompasses not only hardware or physical components but also the material circumstances governing AI systems, such as the data they process, the algorithms they employ, and the infrastructures they need. This viewpoint emphasizes the dual aspect of AI, functioning

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as both a computational abstraction and a literally embedded entity. ML and data centers that support AI models are powerful, tangible structures characterized by substantial energy use, environmental impact, and geographical arrangement.[8,9] Software and hardware manifest algorithms, however abstract, in solid forms, influencing their performance and socio-technical consequences.[10,11]

AI and materiality converge in cultural, artistic, political, and social realms. AI technology is progressively integrated into creative processes, facilitating novel forms of generative art and reinterpreting concepts of creativity and authorship.[12,13] In social and organizational settings, AI systems affect decision-making, governance, and human interaction, frequently reflecting material and epistemic limitation.[14-16] For AI systems to be sustainable, both when they are being developed and when they are being used, their material effects must be thought about. These effects include using resources, energy, and making waste.[17,18]

This article seeks to bridge the gap between AI and materiality by exploring their intersections across multiple interdisciplinary dimensions based on existing literature. This study also seeks to offer thorough knowledge and perspectives on the interaction between AI and materiality by combining concepts from several disciplines, including philosophy (epistemic and agential materiality), engineering & materials science, creative and cultural AI, sociotechnical, and sustainability, as depicted in Fig. 1. We also advocate the philosophical underpinnings of materiality, the function of AI in creative and cultural endeavors, its utilization in sustainable development, and the obstacles and opportunities associated with the integration of AI into material systems.[19] This study highlights the need to analyze AI as a holistic system with significant ramifications, not just as a computational tool.

Within the past decades, there has been a growing trend in technical knowledge regarding the role of AI, ML, and NLP. The focus on materiality for sociotechnological, aesthetics, creativity, and cultural aspects seems notably apparent and impactful to our society in recent years, but a lack of holistic evaluation of interdisciplinary aspects is presented. A systematic review of technical publications summarizing overall aspects of research publications is neither fully presented nor discussed for difficulties and challenges in various aspects, including their roles. Therefore, the purpose of this paper is to compile, summarize, and condense the relevant 60 articles on materiality that address emerging AI, ML, and NLP technologies as well as provide comprehensive perspectives. Table 1 presents the adapted PICO (population, intervention, comparison, and outcome) process. Planned investigations used this PICO analysis to evaluate the instrument's role in establishing a search strategy.[20]

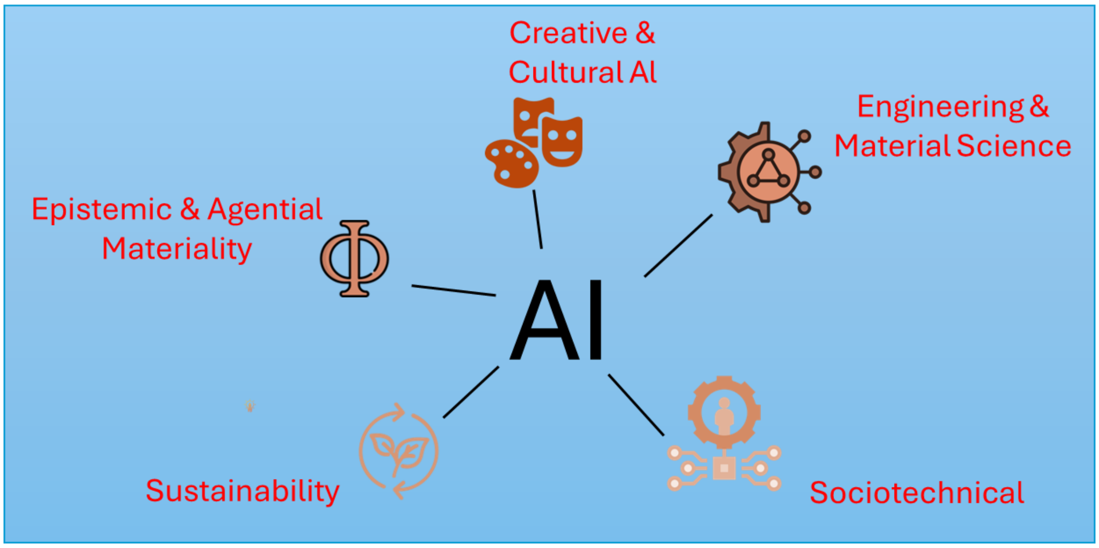


Fig. 1: Interaction concept between AI and materiality.

Table 1: PICO analysis of the systematic review.

PICO	Explanation
Problem -P	A lack of report determining the interdisciplinary role of AI in influencing the materiality aspects.
Intervention - I	Examine the effects of AI technology on materiality aspects in recent decade
Comparison - C	Compare and provide perspectives on the effects regarding epistemic & agential materiality, creative & cultural AI, sociotechnical, engineering & materials science and sustainability.
Outcome- O	Interactions, benefits, and challenges on ethics and sociotechnical barriers of AI in materiality still exist. Further research is needed.

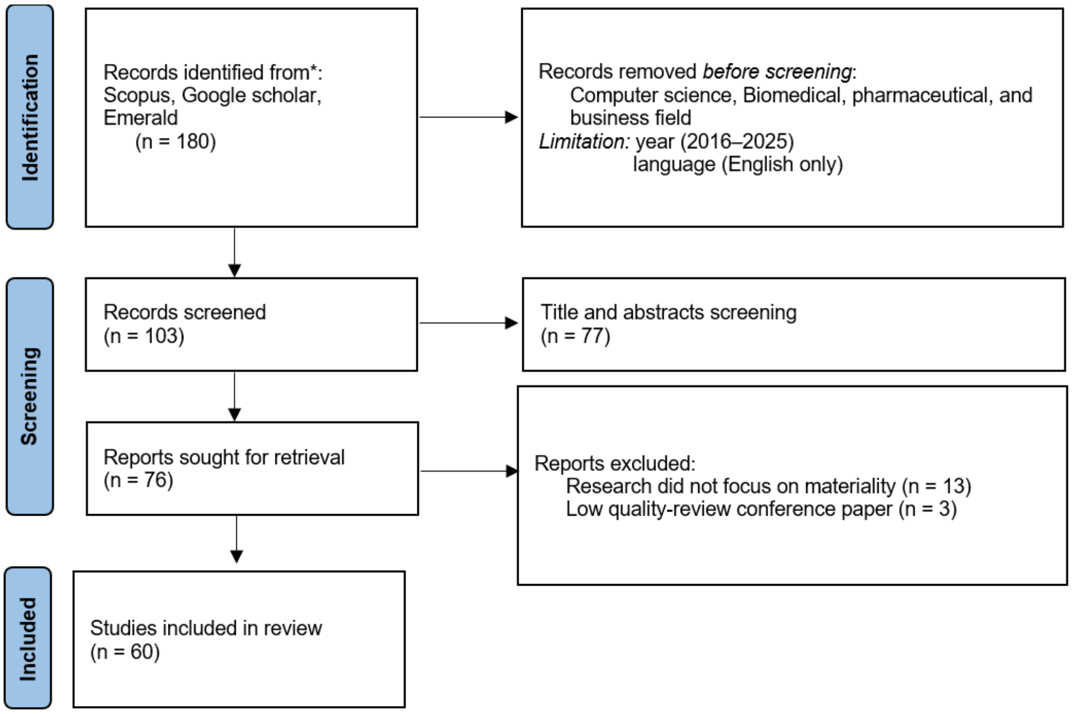


Fig. 2: PRISMA flowchart for the studies were identified, displayed, and included in the study.

The presence of various AIs in materiality aspects has been significantly influenced in our modern society these days. Our study underscores the impact of AI on epistemic and agential materiality, transforms creative sectors, and reconfigures sustainable development approaches. It elucidates ethical dilemmas, sociotechnical challenges, as well as prospects for sustainable development, aligning with United Nations Sustainable Development Goals (UN-SDGs).[21] The results advance an evolving framework for transdisciplinary research, designed to promote intelligent, sustainable, and morally accountable applications of AI. This work significantly contributes to the discussion on how AI could support ecological goals while taking into account its material and societal costs. It necessitates interdisciplinary collaboration to develop AI systems that are technologically sophisticated and adhere to the values of sustainability and inclusion.

2. Literature screening and analysis method

After determining the existing literature regarding the interdisciplinary topics of "AI" and "materiality" within this decade (2016–2025) in the Scopus, PubMed, and Google Scholar databases. The search was in December 2024, and the search terms were TITLE-ABS-KEY (materiality) and TITLE-ABS-KEY (artific* and intelligen*). The total publications based on Scopus, PubMed and Google Scholar databases were 141 articles. The present systematic review has utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting checklist, which is illustrated in Fig. 2. Initial searches of the specified databases resulted in 180 publications. The exclusion criteria of the searched articles entail:

- Exclude non-English language
- General argument, not specific findings addressed
- The paper is based on another study
- Conference review paper with insignificant results
- The investigation lacks adequate information regarding technology and social science.

Upon eliminating duplicate entries, categorizing by journal type, and restricting to English-language articles, the count of pertinent publications was decreased to 103. After examining the title and abstract, several papers were identified that explicitly focus on business background as well as AI algorithms and architecture. The excluded studies had minimal relevance to the topic. Despite this, the full version of these publications could not be downloaded. Also, satisfying papers that were not particularly noteworthy or that failed to demonstrate any novel concepts were not included in the study. A total of 76 pieces had been considered valid. There were 60 important papers that were then thoroughly reviewed after the whole text and the quality of the paper were carefully examined. A thorough review of the literature was carried out to find review components that were important to this analysis. As part of the publishing analysis, a Microsoft Excel spreadsheet was made with the titles, abstracts, keywords, authors' names and affiliations, journal name, and published year of the papers. After that, the author read the full texts of the remaining papers to determine if they were eligible.

Following the refinement, analysis, and compilation of the prior study, Microsoft Excel was performed to extract all keywords. Consequently, they have the ability to establish connections, visually represent relationships, and pinpoint regions necessitating additional investigation. One may implement a method of collecting, categorizing, analyzing, and presenting qualitative data with enhanced efficiency and precision. All ubiquitous keywords found include Practice-based research, Creativity, Basal cognition, Relational agency, Embodied cognition, Organizing, Algorithms, Sociomateriality, Interaction Design, Human-AI Interaction, and Governance.

3. Contexts and perspectives

Following the completion of the thematic analysis, this section outlines five key topics for discussion. Fig. 3 illustrated the topics derived from the thematic analysis of keywords. Five selected topics, including philosophical, sociotechnical, creative and cultural, engineering and material science, as well as sustainability, were classified, and details are given in Table 2.

3.1 Philosophical perspective: Epistemic materiality and agential materiality

The notion of materiality in AI research extends beyond only concentrating on physical elements, such as hardware or infrastructure. It expands the framework to encompass the epistemic frameworks and agency capabilities of AI systems. Many retrieved and literatures in this aspect were covered.[22-30]

Previous work examined epistemic materiality,[31] highlighting how the material affordances of AI systems—encompassing algorithms, data, and computational processes—influenced knowledge generation. These systems lack neutrality, shaping the parameters of what is considered "knowable" and dictating the processes of knowledge generation and validation. The structural framework of AI, encompassing data acquisition techniques and server processing capabilities, delineates the nature of the AI insights it can provide. This underscores the social creation and material incorporation of knowledge within the AI system itself. Furthermore, such human-like AI systems necessitate a foundation of socio-cultural materiality for their epistemologies. Robots cannot emulate the prior daily learning that accompanies human involvement.[32] Despite potential dissent among the AI field over 'context'-free interactions, it remains uncertain whether robots will ever acquire the capacity to learn like non-individualistic posthumans. Given the unpredictability of cultural materials, we can only accomplish the task if they allow it.[24] In addition, Rella conducted an examination of AI games,[29] blockchain technology, and machine learning, all of which were linked to the materiality of political economy. Her statement suggested that there are materially, epistemologically, and symbolically connections between games and AI. Games, like cryptocurrency games, generated computational demands that stimulated the arms race in computer parallelism, leading to the rapid development of powerful GPUs. These significantly influenced cybernetic interpretations of the economy and its administration since numerical games can earn digital coins, and the coins can be converted into fiat currency. GPUs have contributed to the parallelization of macroeconomic analysis and have introduced ML models to economics and econometrics that is progressively gaining prominence in the field.

Agential materiality broadens this concept to encompass the ways in which AI systems, via their computational and interaction mechanisms, affect both human and non-human agency. AI does not only digest information passively; it actively influences decisions and actions. New materialism and science studies collectively offer a post-humanist narrative that regards materials as co-participants in human culture and artificial intelligence understanding.[28] This is

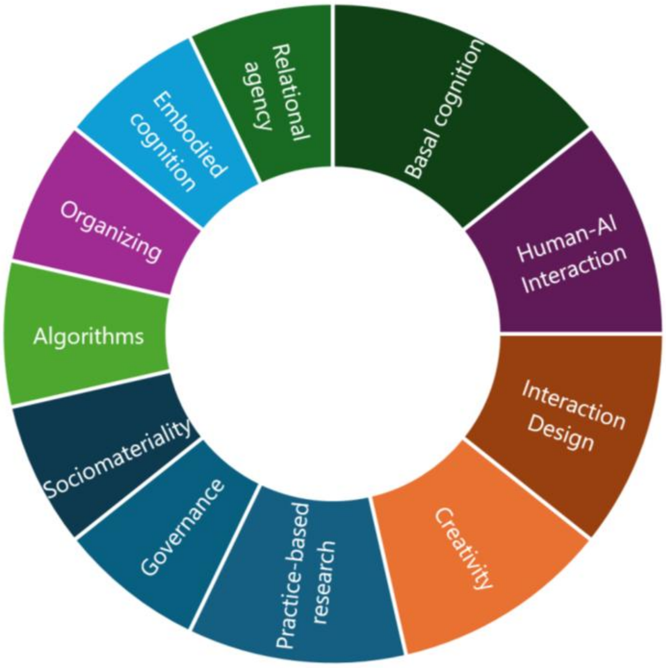


Fig. 3: Keywords analysis from the retrieved literatures.

Table 2: Details of 60 existing literatures.

Author	Perspectives					Year
	Philosophical	Sociotechnical	Creative/Cultural	Engineering/Science	Sustainability	
Heidt M.	✓		✓			2014
Whitelaw M.			✓			2015
Portmess L.			✓			
O'Hara F.			✓			2016
McCoy C.		✓				2017
Dourish				✓		
Murdock G.	✓					2018
Penny S.			✓			
Klischewski R.		✓				2019
Hasse C.	✓					
Caprotti, F.					✓	
Cugurullo F.					✓	
Justie B.		✓				2020
Yorks L.				✓		
Buchczyk M.				✓		
Strathearn C.				✓		2021
Bartle V.				✓		
Harrison D.				✓		
Johri A.		✓				
Laapotti T.		✓				
McGrath M.R.			✓			2022
Chedrawi C.		✓				
Geck K.	✓					
Nost E.					✓	
Gomes E.				✓		
Heyder T.		✓				
Valdez M.		✓				
Lakshmi A.J.		✓				
Munir S.			✓			
Lundman R.			✓			2023
Benjamin J.J.				✓		
McCormack J.			✓			
Albia, B.B.			✓			
Aljaaidi K.S.				✓		
Kudless A.	✓					
Guljajeva			✓			
Leonard N.			✓			
Oliveira B.					✓	
Burkhardt S.		✓				
Markauskas E.				✓		
Scott R.			✓			2024
Navarrete-Cardero L.			✓			
Tetiranont, S.				✓		
Matzner T.	✓					
Herzfeld N.			✓			
Prasittisopin L.					✓	
Tang K.-S.	✓					
Yamada-Rice D.			✓			
Celis Bueno C.			✓			

Author	Philosophical	Sociotechnical	Creative/Cultural	Engineering/Science	Sustainability
Armitage J.			✓		
Johannessen L.E.F.		✓			
Heffernan T.			✓		
Prasittisopin L.				✓	
Sánchez-Rojo A.			✓		
Rella L.	✓				
Mei Q.				✓	
Stein C.				✓	
Almrott C.			✓		
Svanberg J.					✓
Sum	8	12	20	14	6

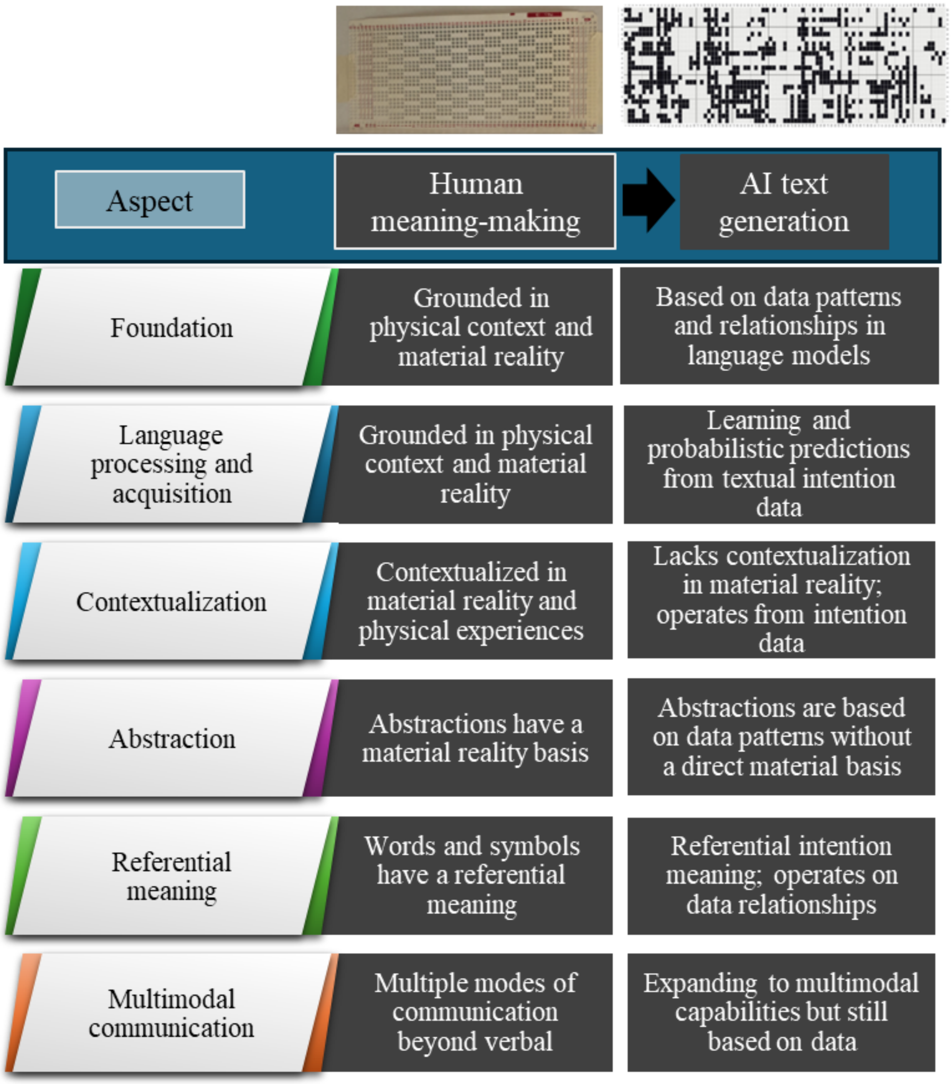
particularly evident in scenarios like business or governance decision-making, where AI technologies can guide and predict accurate outcomes, enhance workflows, and shape the course of operations. This position as a "co-actor" contests the traditional perception of AI as a simple technological instrument, proposing that AI systems play an integral part in social and organizational behaviors. Similar work[28] mentioned that GenAI models, in contrast to humans, are unable to engage with the extensional environment because of their absence of sensory inputs and embodied experiences inherent to human beings. Although GenAI can anticipate which words combine to create a coherent phrase or which pixels associate to produce an aesthetically pleasing image, they lack the referential significance of what those words and pixels represent in the external world, where their differences are summarized in Fig. 4. Also, Geck mentioned that interaction between GenAI and people, illustrated through the metaphor of knitting, offers tangible means to identify the consequences, relationships, and circumstances that arise. The metaphor implies that data is malleable and open to manipulation.[25] It reacts to the artisan's touch, creating novel patterns, intricacies, and surface textures. It becomes operational once it is integrated into the assembly of both humans and machines.

3.2 Sociotechnical perspective: AI and sociomateriality

The term “sociomateriality” is composed of two words, including social and materiality. Meaningly, this term presents that all materials are social, where they are created, developed, and employed through social contexts and that all social action is possible due to materiality.[33] Concerning AI technology, sociomateriality as examined in Orlikowski[34] offers a framework to comprehend the interconnection between AI technology and social behaviors. They contended that technology, human activity, and organizational frameworks were not distinct components but were instead profoundly interconnected. The social situations in which AI systems function both influence and shape them. In this regard, we covered several literatures.[35-46] Fig. 5 demonstrates that sociomateriality emphasizes the interrelationship of human acts, technical instruments, and material systems.

In organizational contexts, AI tools not only automate tasks but also collaboratively shape decision-making processes, affecting outcomes through both material constraints (*e.g.*, processing power or data limitations) and sociotechnical opportunities (*e.g.*, fostering new avenues for collaboration, efficiency, and creativity). This perspective supports the notion that AI is a fundamental component of the socio-technical system, functioning as a co-actor rather than a mere instrument. This co-actor concept emphasizes the influence of non-human actors—such as robots and AI technologies—in creating social connections and behaviors. This entailed comprehending the interaction between AI tools and human agents inside extensive networks, including companies, cultures, or societies. The significance of AI in these situations extended beyond its physical infrastructure; it encompassed the relationships, networks, and societal ramifications of AI's utilization and integration.[47,48] Moreover, Johri[38] used augmented reality (AR) to teach the idea of sociomateriality and said that the addition of AI significantly changed sociomateriality by allowing materiality to exhibit traits usually associated with human agents, thereby changing the composition of the sociomateriality assemblage.

Regarding fraud and cybersecurity, Kolkman determined the Risk Classification Model (RCM) case of fraud for child students.[45] Initially, statistics suggested that the algorithmic model possessed mechanisms that were assignable. The proximity to childcare services correlated with an increased risk of fraud and sexual harassment media. Nevertheless, the RCM developers employed ML models and did not attempt to ascribe such effects to processes within the target system. Consequently, the relationship between characteristics such as childcare facilities and the probability of fraud remained unclear. Additionally, a common cybersecurity tool called CAPTCHA can identify the difference between human and nonhuman action.[27,37] It is one of the most notable examples of how contested concepts of "content" and "identity" become real in modern internet infrastructure. There is a long and complicated history of AI that clearly shows how this shift from realist to relational models of intelligence happened.



Aspect	Human meaning-making	AI text generation
Foundation	Grounded in physical context and material reality	Based on data patterns and relationships in language models
Language processing and acquisition	Grounded in physical context and material reality	Learning and probabilistic predictions from textual intention data
Contextualization	Contextualized in material reality and physical experiences	Lacks contextualization in material reality; operates from intention data
Abstraction	Abstractions have a material reality basis	Abstractions are based on data patterns without a direct material basis
Referential meaning	Words and symbols have a referential meaning	Referential intention meaning; operates on data relationships
Multimodal communication	Multiple modes of communication beyond verbal	Expanding to multimodal capabilities but still based on data

Fig. 4: Differentiated aspects between human meaning-making and AI text generation.

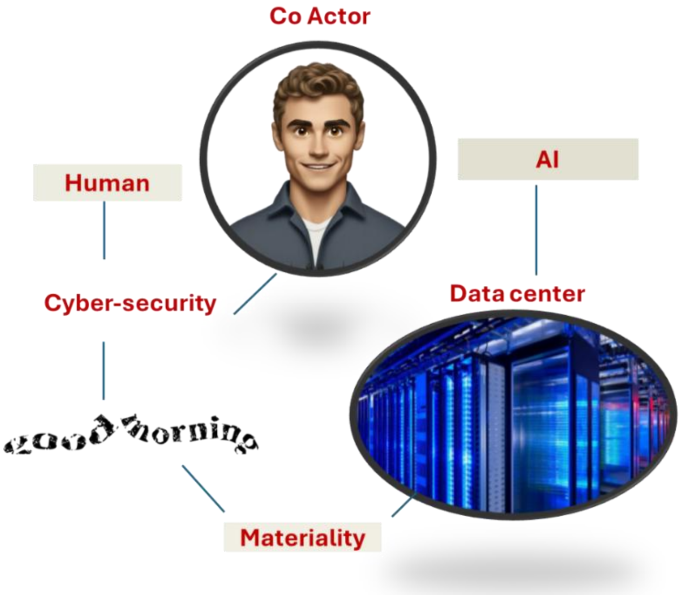


Fig. 5: Conceptual image of sociomateriality suggesting how social relationships, technology systems, and materiality all work together. The glowing lines show how they are linked and dependent on each other.

Ordinal cognitivism, which states that thinking is made up of calculating symbols that have both material reality and a semantic representation value, was identified as the symbolic approach that served as the initial framework for AI.[49] Similar past research can be found in elsewhere.[50-58]

Overall, sociomateriality underscores the importance of understanding the material aspects of AI technology infrastructures, such as ChatGPT and data centers, which might establish new power dynamics.[59-61] Similarly, Matzneranalyzed the environmental, social, and ethical implications of algorithms and data centers,[27] which serve as the concrete embodiment of AI. These infrastructures have the potential to create new expert jobs and are crucial for the functioning of AI systems. However, they also have significant environmental impacts, such as energy consumption and the depletion of natural resources.

3.3 Creative and cultural perspective: AI and generative art

AI-driven generative art and diffusion models signify major advancements in creative and cultural methodologies by utilizing the computational properties of AI and generative art systems. These technologies expand the limits of creative creativity, altering both the methodology and the results of art production. Many past studies have been carried out for these creative and cultural AI aspects.[22,62-81] Fig. 6 exhibits examples of creative and cultural AI in materiality

Central to AI-generated art is the capacity of algorithms to produce original artistic outputs—be they visual like Gen-AI,[78] musical like NIME,[81] or literary like NLP and Plagiarism check AI—frequently questioning the conventional concepts of authorship and originality linked to human artists.[67,76] Besides, AI-generated art integrated with ML, like the Entoptic Field Camera, can be used to improve research-through-design projects with mobile phones.[82]

The significance of AI in generative art resides in its ability to harness extensive computational resources, data sets, and algorithmic frameworks to produce outputs that embody learned patterns or novel amalgamations of styles, shapes, and concepts. These benefits are proved for 95% of the sample collection, where interview research was conducted by Mariani.[83] Extensive datasets train models like diffusion models, enabling them to produce content that surpasses mere duplication. They participate in innovative processes that can astonish even their originators, challenging the boundaries of art and presenting novel methods of expression. In this context, AI operates dynamically and interactively, generating outputs that evolve through computational processes rather than following predetermined instructions.

In the contexts of generative art, AI systems like Creative Adversarial Networks (CANs) have transformed the production of art.[84,85] Elgammal examined how CANs assimilate established creative styles and subsequently diverge from those conventions to produce novel and frequently unforeseen artistic expressions.[86] By challenging traditional limits, these ML produce artworks that are new and unique, embodying a synthesis of computer logic and human-inspired creativity. This process encompasses not just visual arts but also music, writing, and other creative fields. In each instance, ML systems acquire knowledge and develop via engagement with data, therefore challenging conventional standards of style, form, and genre.[87]

This transformation in creative methodologies is most apparent in the concept of co-creativity, when AI works with human artists during the artistic process. AI evolves from a passive instrument that only executes orders to an active collaborator, engaging with humans to generate novel creative expressions. The interaction is particularly evident in cultural informatics, where AI systems assess current cultural objects and generate new ones, consequently transforming cultural landscapes. The integration of AI in these processes facilitates the investigation of novel creative modalities, wherein the distinctions between the artist and the machine become indistinct. The concept of co-creativity posits that the artistic process is not only a human activity but rather a partnership between humans and robots, resulting in unparalleled opportunities for invention and expression.[88]

Not only does AI spur technological advancement in creativity, but also reconfigures authorship.[89,90] Conventional artistic production exclusively attributes authorship to human

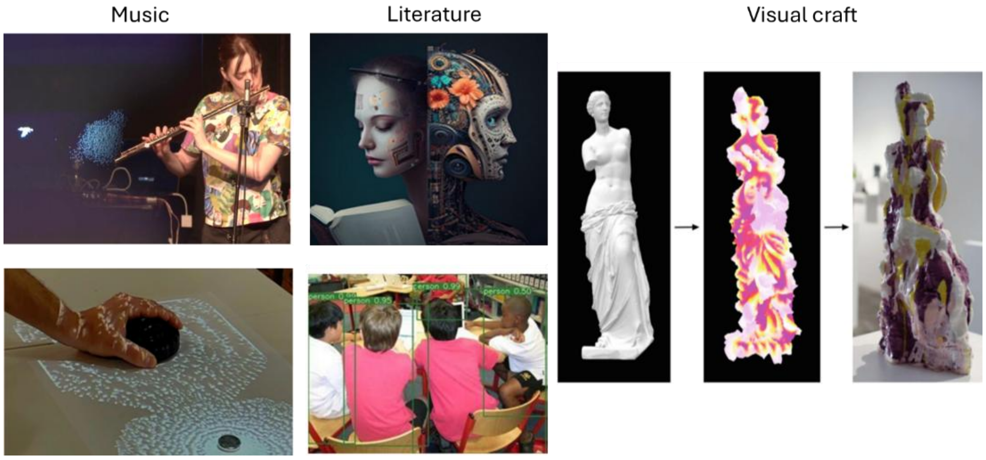


Fig. 6: Examples of AI-generated art for music, literature, and visual craft applications.

creators. Nonetheless, the growing integration of AI in the creative process raises new inquiries regarding the ownership of rights to AI-generated works and the attribution of creative copyright credit in journal article submissions.[91] Although the human artist is crucial to the creative process, AI's function as a collaborator challenges the concept of ownership. The creative and academic spheres are currently debating these philosophical and legal questions.[92] The increasing prevalence of AI in creative sectors highlights a transformation within cultural industries. AI-driven technologies are transforming the creation, distribution, enjoyment, and comprehension of art. AI is disrupting conventional culture production by facilitating the emergence of previously inconceivable creative forms. The democratization of creativity using AI technologies results in the decentralization of creative authority, enabling those without formal artistic training to produce art that competes with that of recognized artists. Moreover, the application of AI in cultural informatics facilitates novel avenues for historical cultural exchange and interpretation globally. For instance, one can easily search for the Tang Dynasty costume and Dharmaśāstra in Ancient India,[93,94] where artistic expression transcends distinct cultures or locations in historical and modern times. Similar recent research was found in past research.[95-100] In sum, AI facilitates the amalgamation of global influences, producing artworks that embody a more interconnected and diversified cultural milieu.

The practical use of AI in artistic production and its challenges to conventional modes of creation can be a current paradox issue. Main focused issues of such transformative changes (excluding ethical issue) entail economic effects for artists, public perception and cultural acceptance, and intellectual property and legal concerns.[101] Regarding Gen-AI is becoming prevalent across several industries, prompting apprehensions around job displacement and the possible oversaturation of the artistic and creative market. This creates anxiety Fear of Missing Out (FOMO), that is, an individual's apprehension that they are not able to experience enough of what is available.[102] Artists are progressively utilizing Gen-AI to ensure job security. Their works can be enhanced from productivity and the overall quality, and the value of expertise and fosters a uniformity of creative results is diminished.[103,104] Besides, Gen-AI faces challenges in public perception and cultural acceptance, particularly in recognizing and embracing AI-generated art.[105-107] Their artworks are currently determined as skepticism about their authenticity and emotional depth.[108,109] This skepticism may affect how AI art is integrated into the broader cultural narrative, potentially altering long-standing art forms and challenging cultural notions of artistry. The perceived impact on the artistic community also plays a role in shaping public perception. Furthermore, Gen-AI presents a challenge in intellectual property and legal concerns, particularly in attribution of authorship. Traditional copyright laws are unclear, making AI-generated art complex.[110-112] The US Copyright Office and EU copyright law has somewhat refrained from granting copyright protection to AI-generated works.[113,114] A rethinking of copyright laws is needed to protect human artists' rights while considering AI-generated materiality.

3.4 Engineering and material science perspective: AI in sustainable materials and smart infrastructure

The utilization of AI in material systems has demonstrated a revolutionary impact, especially in sustainable building and the advancement of smart materials. These developments are transforming building methods and urban systems, with AI significantly improving the performance, sustainability, and adaptability of materials utilized in diverse situations. As AI advances, it facilitates the integration of materials science, engineering, and technology, fostering the creation of more intelligent and sustainable infrastructure. Numerical research has been examined in this field.[32,82,115-126]

Concerning AI and urban smart cities, AI's impact transcends individual structures, contributing to the development of intelligent urban systems. Smart cities use AI to improve various urban operations such as traffic control, energy consumption, trash management, and water distribution. AI systems evaluate data gathered from sensors, cameras, and IoT devices integrated across the city to deliver real-time insights that enhance efficiency and sustainability. AI can enhance energy efficiency in buildings by forecasting usage patterns and modifying systems (such as heating, cooling, and lighting) to diminish energy waste by up to 70% in summer and 20% in winter.[127,128] In transportation, AI algorithms like Deep Flowcan optimize traffic flow,[129] decreasing queue lengths by approximately 5–8 meters and reducing emissions (up to 50% for Tesla, 25% for BYD, and 45% for H2 Mobility) through the dynamic adjustment of traffic signals and real-time route recommendations for autonomous city initiatives.[130,131]

The incorporation of adaptable materials in smart cities further illustrates the influence of AI. Smart materials are designed to react to environmental variations, such as temperature changes, humidity levels, or mechanical stress, modifying their characteristics to enhance performance. AI-driven self-healing materials can autonomously mend fractures or other flaws in infrastructure, minimizing the necessity for manual repairs and enhancing the durability of metropolitan systems.[132] Likewise, intelligent coatings may alter their characteristics to enhance energy efficiency in structures, such as modifying reflectivity to regulate solar heat absorption. These materials enhance energy efficiency by reducing the heat gain of 40% and indoor temperature drop of 2–4 °C and foster sustainability by mitigating the environmental effect of building and infrastructure upkeep.[133]

Similar studies regarding materiality for energy efficiency were also seen in other past works.[133-136] Furthermore, a significant trend in sustainable building and urban development is the growing interest in AI-enhanced smart materials. These materials are engineered to engage with their surroundings, adaptively responding to varying environments. AI enhances the creation and refinement of these materials by delivering data-driven insights that enable more accurate engineering and customized material solutions. For instance, AI can forecast the material performance program under diverse environmental situations, enabling engineers to create materials that optimize performance of 99.1% while reducing resource use of 98% and increasing community engagement of 98.5%, compared to the traditional program.[137]

For more specificity, AI facilitates the enhancement of resource management in firms, organizations, and urban planning. Aljaaidi evaluated 38 audit firms and found that AI primarily reduces costs, time, and effort, ranking first with an average score of 4.5/5.0.[119] This is followed by enhancing materiality determination, which ranks second with an average score of 4.3/5.0. This facilitates better-informed decision-making and promotes sustainable development practices. Integrating AI into these workflows enables the creation of intelligent management.

3.5 Sustainability perspective: AI for environmental impact

In terms of sustainability perspective, climate AI and AI have a significant impact on our environment. When integrating the materiality perspective into sustainability practices, businesses have to disclose their sustainability objectives and operations to demonstrate that their values extend beyond economic viability to encompass social responsibility and contribute to their long-term global development.[138] It encompasses factors related to environmental sustainability, ethical data utilization, and the societal implications of AI applications in achieving the UN-SDGs.[21] Zero Carbon AI seeks to eradicate or compensate for the carbon emissions linked to the development, training, and deployment of AI models and systems.[139] Many commercial AIs, such as AI for Earth, NOLA, Deep Mind, Carbon Tracker, and Mila, are available for purchase.[140] Several retrieved and similar studies relating AI to sustainable materiality were covered in this section.[126,140-150]

AI serves as a formidable instrument for sustainable growth. It can optimize energy use, minimize waste, recycle waste, and aid in monitoring and alleviating climate change.[151,152] The capability of AI to evaluate extensive environmental data allows it to enhance the development of more intelligent and resource-efficient systems that support sustainability objectives. Ukoba emphasized the potential of AI-driven solutions to optimize waste management, augment renewable energy infrastructures, and facilitate sustainable agriculture methods.[153] Within the realm of sustainable building, AI is advancing notably, especially in its capacity to monitor and optimize resource utilization. AI-driven technologies are progressively utilized to monitor and evaluate structural integrity in real time. AI-driven monitoring systems can identify early indicators of degradation or stress in materials, facilitating proactive maintenance and minimizing the necessity for expensive repairs. AI-enabled preventative maintenance reportedly yielded significant cost reductions between \$10,000 and \$30,000 per MW yearly.[154] AI sensors embedded in concrete or steel can perpetually assess structural integrity, delivering essential data that guides maintenance schedules and prolongs the lifespan of edifices. The application of AI in advancing sustainable materials is another significant advance. AI solutions enhance the integration of these materials into building processes, guaranteeing the appropriate quantities and compositions are utilized to improve performance and reduce environmental effect. AI can optimize the utilization of these alternative materials, improving their strength,[143,155,156] durability,[157,158] and cost-efficiency, as well as minimizing predictive uncertainty.[159-161] AI algorithms can find novel potential materials, thereby broadening the range of sustainable solutions accessible to the building sector.

AI is crucial in enhancing sustainable material flow and management by increasing energy efficiency, reducing carbon footprints, and promoting environmentally responsible behaviors through energy optimization and life cycle assessment (LCA).[162-167] AI-driven materiality solutions improve energy optimization in buildings, transportation, and industrial processes by predicting use patterns, automating control systems, and incorporating renewable energy sources, thereby substantially decreasing energy waste and operating emissions. For example, frequency modulation and LED lighting, a total energy saving rate of 25%.[97] Additionally, autonomous video-based AI can reduce traffic queue lengths by 5–10 meters, leading to emissions reductions of up to 34% for electric vehicles.[168-170] Furthermore, AI automation and machine like 3D printing promotes low-carbon innovation across several industries by enhancing supply chains, improving material selection, and optimizing manufacturing techniques.[155,171-178] This AI systematic methodology facilitates data-driven decisions that minimize resource usage, encourage circularity, and propel the shift towards low-carbon, seismic-resilient and climate-resilient systems, in terms of data management for materiality.[179-184] The environmental impacts of AI that can be quantified by LCA, especially due to energy-intensive training procedures and infrastructure, necessitate the creation of energy-efficient algorithms and sustainable hardware solutions to guarantee AI's net-positive effect on environmental objectives.[185]

The material implications of AI also raise significant ethical dilemmas. AI hardware, especially in large data centers that process cryptocurrency and run ML algorithms, significantly impacts the environment through energy consumption, resource extraction, and electronic trash generation. This, in turn, results in the creation of a carbon footprint.[186,187] Current estimates suggest that worldwide electricity demand for IT might rise to 20%, compared to around 1%.[188] The ecological impact of AI, especially with its infrastructure and technology (such as GPUs for deep learning), presents a significant sustainability problem.

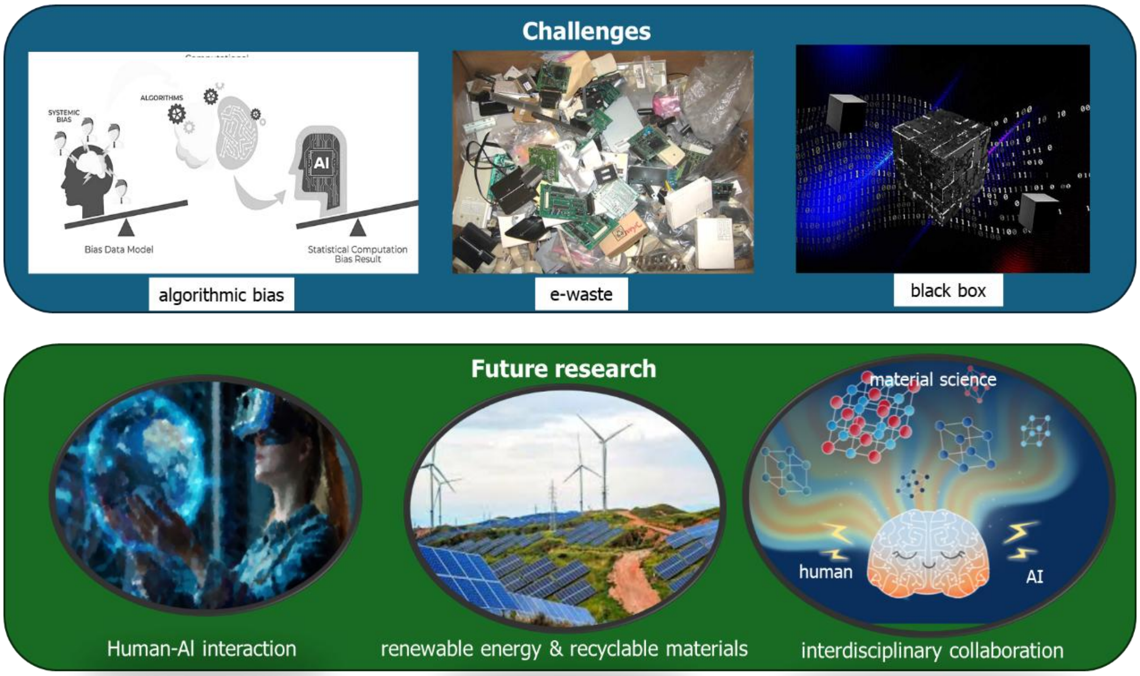


Fig. 7: Summary of the challenges and future research.

Alzoubi advocated for a more environmentally responsible approach to AI, incorporating sustainability considerations into its development and implementation.[18] As AI increasingly drives several industries, it is imperative to address the environmental costs associated with AI systems, including the development of energy-efficient algorithms and the design of responsible hardware.

4. Challenges and future directions

This section presents the existing challenges and suggested future research directions for the study. Fig. 7 summarizes the challenges and future research of this study.

4.1 Implications and challenges

4.1.1 Ethical and epistemic aspects

The ethical and epistemic implications of AI's integration with materiality are significant, as demonstrated in the article. Epistemically, AI systems operate not just as passive instruments but also as active participants in the co-creation of knowledge. Although problems need to raise by human, the AI can accelerate and facilitate the process. Subsequently to reduce unethical issue, human requires to validate the materiality which AI creates. If the human found bias and error, this process needs to reconstruct by the creation of AI again. The process is shown in Fig. 8. Their inherent material affordances—such as algorithmic logic, data structures, and computational architectures—determine what is seen as knowable, believable, and actionable. Gen-AI image generators can be “Future Shock” distorting group identities and incorporate prejudices, frequently resulting in the appropriation and reinforcement of stereotypes.[189,190] This has substantial implications for fields dependent on objective reasoning, as AI intermediates digital materials and information through value-influenced processes.[191] The text emphasizes that epistemic principles, such as instrumental efficacy and model consistency, frequently have implicit ethical implications, including the quest for social relevance or fairness.[192-194] Prioritizing the "debiasing" of algorithms is both an epistemic rectification and an ethical obligation to fairness. Moreover, the epistemic authority of AI is contingent upon context and culturally situated, prompting inquiries over which information is prioritized and disregarded.[195-197] This necessitates a thorough reevaluation of epistemic fairness in AI design, particularly in transdisciplinary contexts related to environmental sustainability, governance, and creative sectors.[198]

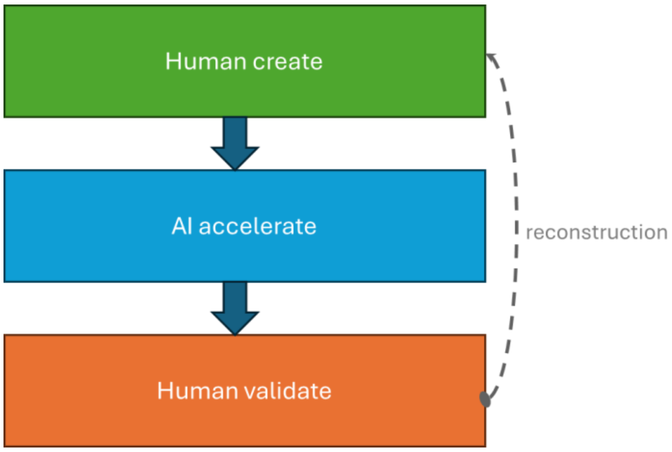


Fig. 8: The debiasing process of AI interacting with human.

The ethical implications of AI's integration into infrastructures, ecosystems, and social systems present pressing challenges including bias, accountability, and transparency.[199-202] The physical manifestation of AI, encompassing data centers and smart gadgets, generates quantifiable environmental consequences, hence complicating its contribution to sustainable development.[203,204] Furthermore, the opaque characteristics of some AI models complicate conventional paradigms of accountability and transparency, especially when these systems impact real-world decisions in sectors like healthcare, education, and urban planning. The disparate access to AI technology and resources worldwide highlights distributive inequities, potentially intensifying digital colonialism. The article compellingly contends that AI ethics must be reconceptualized as fundamentally linked to epistemic norms, acknowledging that knowledge generation under opaque systems raises moral issues. Therefore, multidisciplinary collaboration implication is crucial for establishing socially inclusive, and epistemically transparent AI systems.

The amalgamation of AI with materialism presents substantial ethical and epistemological dilemmas that necessitate resolution to harmonize technological advancement with social principles. A significant ethical concern is algorithmic bias, when AI systems unintentionally reinforce or intensify societal disparities owing to biased data or design deficiencies. These biases can yield significant repercussions when AI technologies are integrated into key infrastructure, material systems, or decision-making processes. Moreover, the manufacturing and disposal of AI technology exacerbate environmental deterioration, necessitating a moral need to tackle these concerns at both design and regulatory levels.

Assuming that the most useful ethical and epistemic principles are selected, an innovative new project would be to examine the linkages between them generated by instances of AI in materiality principle, given that the epistemic principles hinge on value-laden choices and have ethical implications. For instance, one could argue that the selection of instrumental efficacy as a principle beyond that of relevance stems ultimately from a moral objection to practically inefficacious knowledge and a desire for material adoption. Equally, the language of ‘consistency’, when cashed out in terms of ‘debiasing’ AI models, naturally lends itself to the ethical demand for justice, although one is formally an epistemic and the other an epistemic principle.

Epistemic issues like openness and accountability are vital for comprehending the interaction of AI systems with material settings. Transparency entails rendering the decision-making processes of AI systems comprehensible and accessible to users and stakeholders, a task that is especially daunting due to the intricacy of contemporary AI models. Implementing measures to hold creators, developers, and deployers of AI systems responsible for their results is necessary for accountability. In material systems, these issues grow more obvious as AI progressively impacts supply chains, manufacturing, and environmental monitoring, where errors or oversights might result in significant repercussions. Confronting these epistemic issues necessitates multidisciplinary cooperation to develop systems that are both explicable and equitable. Moreover, uneven resource distribution, cultural biases in AI systems, and the differential environmental consequences of AI deployment in developing regions is the new challenge existing in the global scale.[205,206]

4.1.2 Environmental aspect

E-waste tackles the wider societal ramifications of its tangible effects. The incorporation of AI technology into material systems has yielded significant progress while also increasing the production of electronic trash (e-waste). E-waste from AI-enabled gadgets, like mobile phone, battery, and notebook, includes toxic compounds such as lead, mercury, and cadmium, which can infiltrate soil and water, so damaging ecosystems and presenting health hazards.[207-209] Furthermore, these gadgets frequently utilize rare earth elements (REEs) and precious metals, the extraction of which depletes limited resources and leads to habitat damage and greenhouse gas emissions.[210-213] The swift obsolescence of AI gadgets, propelled by technical advancements, intensifies this issue by reducing product lifespans and producing considerable waste.

The recycling and recovery of materials from AI-based systems is a significant problem owing to their intricate composition, which encompasses metals, cellulose, polymers, and ceramics.[214-218] Contemporary technologies frequently exhibit inefficiency in recovering high-value components such as rare earth elements, resulting in material losses, heightened waste, and air pollution such as microplastic and PM2.5.[219-221] Unregulated e-waste handling in emerging nations exacerbates the problem, endangering workers with dangerous compounds and resulting in uncontrolled pollution. Moreover, the carbon footprint associated with e-waste processing, particularly via incineration, detracts from initiatives aimed at mitigating climate change.

4.1.3 Sociotechnical aspects

Sociotechnical barriers represent “black box” that encompasses resistance to technological adoption and the misalignment of AI systems with material practices. It poses significant challenges to the seamless integration of AI and materiality in various industries. These barriers often arise from a lack of alignment between technological advancements and the established workflows, cultures, and practices within specific sectors. For instance, in industries such as construction or urban planning, traditional methods and deeply ingrained habits can conflict with the requirements and capabilities of AI-driven systems. Additionally, the absence of comprehensive frameworks to bridge the gap between AI technologies and material practices exacerbates these challenges, leading to inefficiencies and resistance.[222-225] This misalignment not only delays the adoption of AI but also highlights the need for more tailored solutions that consider the unique sociotechnical dynamics of each industry.

Addressing these barriers requires a holistic and interdisciplinary approach, emphasizing the importance of stakeholder engagement, collaboration, and ethical considerations. The integration of AI must go beyond technical innovation to incorporate principles of fairness, transparency, and accountability, ensuring that systems are not only efficient but also socially responsible. Ethical concerns have emerged as central in these discussions, as industries grapple with the implications of AI on decision-making processes, equity, and trust. Furthermore, interdisciplinary research that combines expertise from fields like engineering, social sciences, and ethics is essential for developing adaptive strategies that align AI with existing material practices.[226-229] By fostering collaboration and dialogue among diverse stakeholders, the adoption of AI in resistant sectors can be facilitated, paving the way for more equitable and effective technological integration.

4.2 Suggested future research

Future research should prioritize interdisciplinary collaborations, bridging AI, material science, and social sciences. This approach will enable a holistic understanding of AI-materiality interactions and foster innovative applications.

(1) Human-AI Interaction: Understanding the materiality of human-AI interactions will be crucial in designing systems that enhance usability, accessibility, and ethical considerations. This includes examining how material properties influence AI-mediated experiences.

(2) Sustainable Development: AI's potential to enhance sustainable development necessitates further exploration of its material applications. Emphasis should be placed on developing eco-friendly AI technologies and integrating them into material systems to address global challenges such as climate change. While many studies emphasize the role of AI in sustainability, some may criticize AI for its unsustainable aspects, such as the high energy consumption of large-scale AI models, the environmental impact of hardware production, or the social impacts of AI-driven job displacement in creative and industrial sectors.

(3) Interdisciplinary collaboration between AI, human, and materials science: Future research should investigate the possibilities for multidisciplinary collaboration across AI, human knowledge, and materials science to tackle difficult issues and foster innovation as AI transforms numerous sectors. This project will examine how AI algorithms may improve the comprehension, design, and utilization of sophisticated materials while maintaining the primacy of human decision-making and creativity in the process. A primary emphasis will be on establishing frameworks that amalgamate AI with materials science to enhance material characteristics and forecast performance across various situations.

5. Conclusion

This paper examines the convergence of AI and materiality, highlighting the increasing impact of AI on material systems across all disciplines. It emphasizes essential issues, such as epistemic and agential materiality, the sociotechnical integration of AI, and its revolutionary effects on creative industries and sustainability. The results illustrate how AI transforms knowledge creation, creative workflows, and resource efficiency, presenting avenues for innovation while posing ethical dilemmas like algorithmic bias, responsibility, and transparency. The perspectives from the review can be drawn: a. AI profoundly affects epistemic and agential materiality, transforming knowledge creation, creative methodologies, and sustainable development initiatives which can be performed as computational equipment, physical infrastructure, creative media, and even human society. b. Ethical concerns, including algorithmic bias and responsibility, and environmental repercussions such as e-waste and energy consumption, persist as significant challenges within the AI-materiality relationship. c. Resistance to technology adoption and the discord between AI systems and conventional material practices obstruct seamless integration, necessitating customized multidisciplinary solutions. d. The results support the advancement of environmentally sustainable AI technologies and their incorporation into material systems to tackle global issues, including climate change and resource management. It is advisable to focus on collaborative frameworks that facilitate the progression of AI-driven material breakthroughs, while emphasizing human decision-making, interdisciplinary collaboration, and sustainability principles.

Acknowledgements

This project was also funded by National Research Council of Thailand (NRCT) and Chulalongkorn University (N42A660629).

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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