Front. Struct. Civ. Eng. 2024, 18(5): 805–814
https://doi.org/10.1007/s11709-024-1102-2

REVIEW ARTICLE

# Proposing a development framework for sustainable architecture, engineering, and construction industry in China: Challenges, best practice, and future directions

**Peixian LI[a,b], Yujie LU[c,d*], Xuwen XIAO[c,e]**

[a] *College of Architecture and Urban Planning, Tongji University, Shanghai 200092, China*
[b] *Key Laboratory of Ecology and Energy Saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai 200092, China*
[c] *College of Civil Engineering, Tongji University, Shanghai 200092, China*
[d] *Key Laboratory of Performance Evolution and Control for Engineering Structures of Ministry of Education, Tongji University, Shanghai 200092, China*
[e] *China State Construction Engineering Corporation, Beijing 100029, China*
[*] *Corresponding author. E-mail: Lu6@tongji.edu.cn*



**ABSTRACT** China's architecture, engineering, and construction (AEC) industry needs a clear and sustainable development roadmap. Drawing inspiration from speeches delivered at a seminar hosted by the Chinese Academy of Engineering and extensive literature research on Chinese policies, this article presents a summary of the current trends in the AEC industry in four dimensions: industrialization as the foundation, intelligence as the enabler, lean management as the strategy, and green development as the goal. These four dimensions are intricately interconnected and rooted in multiple disciplines. The article provides a detailed review of the current practices, challenges, and future directions associated with each dimension. Additionally, ten grand challenges were proposed to stimulate discussions on the future of the AEC industry. This article offers an overarching understanding of the AEC industry and presents a four-dimension framework for sustainable development, which can be valuable for AEC practitioners.

**KEYWORDS** green building, lean construction, prefabrication, smart construction, sustainable development

## 1 Introduction

On October 21, 2020, the Chinese Academy of Engineering convened a prestigious International Conference on Structure and Civil Engineering in Shanghai, China. The conference aimed to explore the latest issues at the intersection of architecture, engineering, and construction (AEC) with green ecological technology, and to examine the current status, challenges, and frontier technologies in this field. Organized by Nanqi Ren and Xuwen Xiao, both Academicians of the Chinese Academy of Engineering, the conference was themed "Green−Ecology−Livability−Smart". Distinguished experts from academia and industry participated in this seminar, and their names can be found in the Appendix. Drawing on the insights shared during the seminar, we have proposed a four-dimension framework for a sustainable AEC industry to provide valuable references for policy formulation and future development of the AEC industry in China.

*Article history: Received Oct 7, 2021; Accepted Jan 15, 2024*

## 2 Four dimensions of the architecture, engineering, and construction industry

Through a comprehensive analysis of the presentations delivered at the seminar and a thorough examination of Chinese policies, we have identified four dimensions that underpin China's AEC industry in the new era, as illustrated in Fig. 1. These dimensions are industrialization, intelligence, lean management, and green

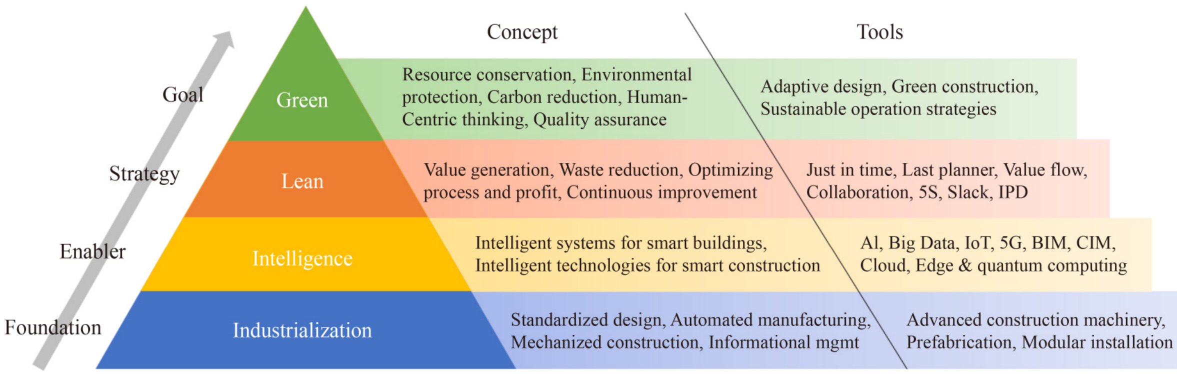


**Fig. 1** The proposed four dimensions of the sustainable AEC industry.

development. These dimensions are applicable across the entire life cycle of projects, including the design, production, construction, operation, demolition, and recycling, and are relevant to projects of varying scales, ranging from materials and structural components to facilities, buildings, and entire cities.

Industrialization is the foundation of the AEC industry. The industrialization of building materials and machinery holds the potential to enhance construction efficiency and quality by incorporating prefabricated components manufactured in factories and assembled on-site. This emerging trend is fueled by advancements in information technology, facilitating standardized building design, automated manufacturing, mechanized construction techniques, and efficient project management through data-driven approaches.

Intelligence is the enabler to achieve a green AEC industry. Intelligence in the AEC industry comprises multiple smart technologies, including artificial intelligence (AI) models, the Internet of Things (IoT), cloud and edge computing, building information modeling (BIM), and robots, applied across the design, construction, and operation phases. Additionally, intelligence manifests as smart "products", such as smart construction and smart buildings, transforming the AEC industry in terms of product development, business models, production methods, management strategies, and regulatory frameworks. Ultimately, the aim is to provide human-centric engineering products and services that align with the evolving needs of society.

Lean management is the strategy to achieve a qualitative leap in the building sector. Lean construction is the application of lean principles in the AEC industry, aiming to streamline processes, improve productivity, and optimize profits [1–4]. Lean construction focuses on value flow, waste elimination, and maximizing output while minimizing input. Its core principles include optimizing the entire process, continuous improvement, waste reduction, value generation, and emphasis on process efficiency and flow. By addressing various forms of waste, such as construction defects, repetitive processes, unnecessary material transportation, idle time, inefficient operations, and excess inventory, lean construction seeks to enhance efficiency and eliminate inefficiencies.

Green development is the ultimate goal of the AEC industry. Green construction is a tangible expression of ecological civilization and sustainable development in the AEC industry, incorporating environmentally responsible practices throughout project planning, design, and construction. The five core objectives of green construction include resource conservation, environmental protection, carbon reduction, human-centric design, and quality assurance. When applied to the operational phase, green construction also aims to create a healthy and livable environment, mitigate indoor and outdoor pollutants, enhance building climate adaptability, and foster sustainable development of the built environment.

With the support from a diverse range of disciplines as depicted in Fig. 2, the interdependence and synergy among the four dimensions are evident, as they mutually reinforce each other. The pursuit of green goals has the potential to redefine industrialization's values, shifting toward sustainable development rather than purely economic growth. Conversely, advancements in industrialization, such as prefabrication, can support green development. This process fosters engineering breakthroughs and human-machine collaborative workflows, leading to intelligent applications. Intelligent decision-making enhances industrial production efficiency. Green development provides practical cases for intelligent applications, focusing on environmental sustainability and human-centricity. Simultaneously, intelligent control of buildings and facilities contributes to achieving green goals, including energy conservation and carbon emission reduction. Lean management theory aligns with the principles of industrialization, forming a solid foundation for co-development [5]. Integrating lean construction with BIM and prefabrication [6] emerges as a strategy to achieve green goals, enhancing construction efficiency and reducing costs and carbon emissions [7]. Wu et al. [8] proposed a green construction management approach based on lean construction and further substantiated the synergistic relationship between lean construction and green development.


**Fig. 2** The interdisciplinary support for the four-dimension AEC.

## 3 State-of-the-practice of four dimensions

Drawing from the wealth of knowledge shared during the speeches, this section presents a comprehensive overview of the current best practices in the domains of industrialization, intelligence, lean management, and green development (Fig. 3). These insights aim to provide guidance for practitioners and stakeholders in the AEC industry seeking to achieve excellence in the four dimensions.

In promoting prefabricated and modular construction, China has made progress in factory industrialization, on-site industrialization, and installation industrialization, but the mechanization and automation level varies.

1) Under the "Made in China 2025" initiative, most factories that produce building components have been mechanized. Advanced examples include the highly automated steel structure manufacturing plants. These plants have implemented steel-structure intelligent production lines, which incorporate automatic edge finding, offline programming, and welding seam tracking [9].

2) On-site industrialization, also known as prefabricated construction, has experienced significant growth, yet it remains a developing field. The proportion of prefabricated floor areas in newly constructed floor areas has risen from 2.7% in 2015 to 20.5% in 2020 [10,11]. Advanced construction machinery includes aerial building machines, residential building machines, steel frame welding and forming production equipment, portable steel bar tying machines, etc. [12].

3) Installation industrialization, although promising, is still in its nascent phase and has only been implemented in a limited number of projects. This approach encompasses the modularization and prefabrication of electromechanical equipment, curtain walls, interior walls, and bathrooms.

The intelligence within the AEC industry is undergoing rapid development in China, encompassing various aspects such as smart design, smart production, smart construction, and smart operation. However, the intelligence level is relatively higher in the production and operation stages compared to the design and construction phases.

1) BIM has provided a strong basis for digital design, while the emergence of AI-generated design has occurred more recently. According to a survey, the adoption rates of BIM in small, medium, and large projects are 42.66%, 61.99%, and 70.97%, respectively, demonstrating its increasing prevalence within the industry [13]. Since 2023, advanced AI models like Transformer have facilitated the development of AI-generated content

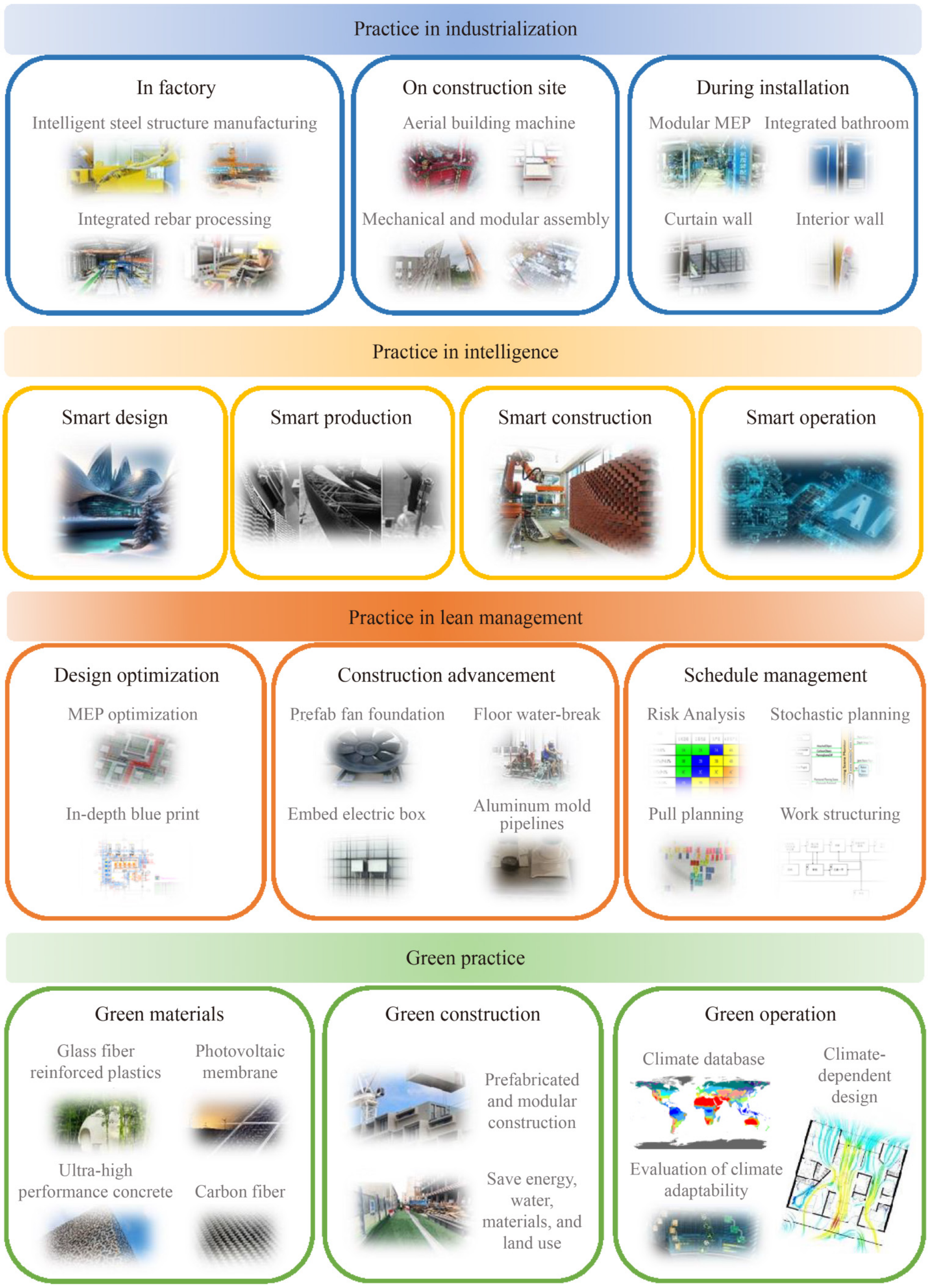


**Fig. 3** Current practices of the four dimensions.

(AIGC), resulting in the emergence of new design tools. While some tools are capable of generating preliminary architectural designs, there is currently a lack of tools for smart structural design and optimization.

2) Smart factories, enabled by the integration of intelligence and industrialization, have revolutionized building component production. A prominent effort made by Chinese researchers is the FUROBOT software, which enhances the automation level of component production by seamlessly connecting the design and production stages [14].

3) Smart construction has been extensively promoted in China [9], showcasing a range of construction robots as exemplars of "smart" technology. These include plastering robots, portable pipeline welding robots, concrete floor drilling robots, rubber-plastic insulation board cutting robots, flange automatic positioning welding robots, walking building three-dimensional (3D) printing robots, etc. Additionally, smart construction management utilizes IoT and big data, such as the Construction Engineering Big Data Service Platform. This platform integrates vital project indicators and elements, extracting

valuable insights and rules to support decision-making processes [12].

4) Smart operation in the AEC industry encompasses buildings, cities, and companies. Public buildings constructed recently are often equipped with building automation systems to facilitate intelligent facility management. In China, many cities have taken initiatives to develop city information models (CIM) to enhance urban planning and management. Guangzhou established smart city industry alliances to foster innovation and technological adoption within the AEC sector [15,16]. Additionally, digital transformation is emerging as businesses seek to leverage technological advancements to enhance their operations and overall competitiveness.

Lean construction principles have been implemented successfully in several cases in China, where they have resulted in reduced idle time, increased productivity, and improved quality [17]. Lean management methods such as the last planner system [18], the 5S method [19], the slack concept [20], and integrated project delivery (IPD) [21] can be implemented in design and technology management. Specific practices include design optimization, construction technology advancement, and schedule management.

1) Design optimization aims to cut down unnecessary construction processes, reduce quality defects, and reduce waste, requiring collaboration between architecture, structural engineering, and mechanical engineering. Meticulous blueprints of mechanical rooms, meticulous layout planning of mechanical and electrical pipelines, and provision of openings for mechanical engineering are instances of design optimization.

2) Construction technology advancement can lead to improved first-time success rates and overall productivity. For instance, the use of prefabricated foundations for fans, accurate embedding of electric boxes and aluminum mold pipelines, and proper treatment of temporary openings and floor water-breaks can greatly enhance construction efficiency and quality.

3) Schedule management can improve the efficiency of construction projects by identifying the critical processes and carefully planning construction procedures for different parts, including basement, above-ground interior, roof and facade, and exterior works. Lean tools such as risk analysis matrix, stochastic planning, pull planning, and work structuring can be employed to optimize scheduling and resource allocation.

The integration of green practices in the AEC industry encompasses various aspects, including the use of green materials, adoption of green construction techniques, and the implementation of sustainable operation practices.

1) Green materials encompass enhanced concrete and steel [22], as well as novel low-carbon materials like lightweight and high-strength carbon fiber materials, offering advantages such as rapid construction and recyclability [23]. An exemplification of sustainable construction is the zero-carbon resort in China, which utilizes carbon fiber and glass fiber-reinforced plastics as primary building materials, demonstrating their potential in sustainable construction applications [24].

2) Green construction has gained significant acceptance, with numerous cities in China enforcing a considerable proportion of green construction floor area relative to the total completed floor area, often surpassing 70% [25–27]. Prefabricated construction serves as a viable solution to reduce material waste and labor [28]. During the construction of the National Speed Skating Stadium, the implementation of prefabricated steel structures resulted in substantially lower labor requirements, with approximately 1000 workers involved, in contrast to the cast-in-place concrete stands which necessitated around 7000 workers [29].

3) In line with the "Carbon Peak and Carbon Neutrality" objectives, the AEC industry in China has dedicated substantial efforts toward green operations. A noteworthy contribution to enhancing the climate adaptability of public buildings was made by Cui and his team [30], who conducted an analysis of the interrelation between physical space and climate parameters and developed tools for evaluating climate adaptability. These initiatives underscore the increasing focus on sustainable operational practices to ensure the long-term environmental performance of built environments.

## 4 Challenges and future directions for four dimensions

Despite notable advancements in recent years, industrialization in the AEC industry encounters various challenges (Fig. 4), including the conflict between standardization and customization, the immaturity of prefabrication, and a fragmented supply chain. In the production phase, there is a discrepancy between industrialized mass production and the increasingly diverse demand for buildings [14]. In the construction phase, current prefabricated construction still faces issues such as inefficient structural nodes, difficult quality assurance, water seepage problems, and limited automation and intelligence in construction equipment [12]. Additionally, persistent information and technical barriers across life-cycle phases impede the development of standardized solutions necessary for industrialization [12]. To address these challenges, the future progression of industrialization in the AEC industry is likely to focus on the following directions.

1) Design for mechanical assembly (DFMA). By considering ease of handling, accessibility for maintenance, and compatibility with automated assembly processes, DFMA facilitates smoother coordination and

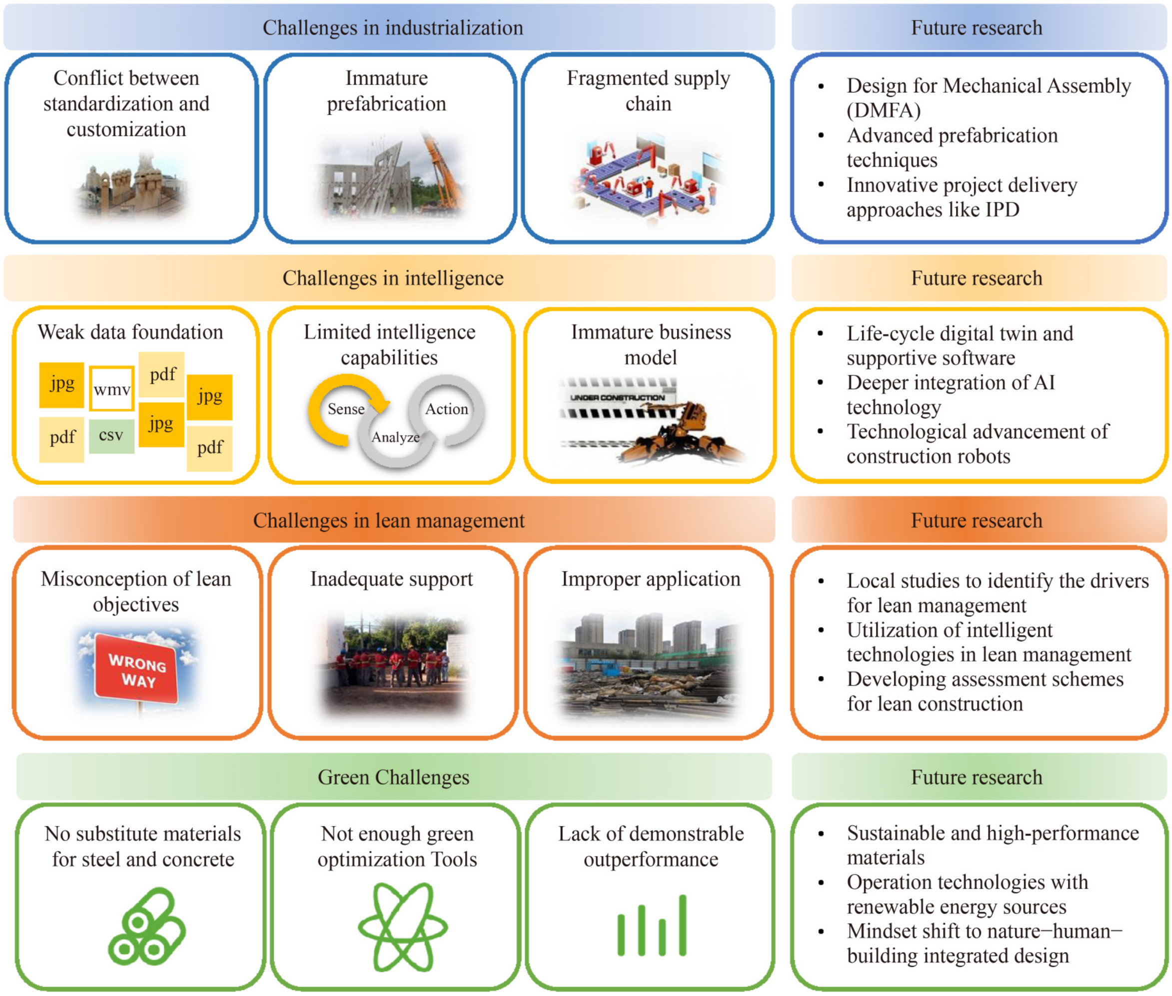


**Fig. 4** Challenges and future of the four dimensions.

integration among stakeholders in the supply chain, enhancing overall efficiency and effectiveness in the manufacturing process.

2) Advanced prefabrication techniques. 3D printing, robotic assembly, and modular construction systems should be further developed to enhance the efficiency, precision, and quality of prefabricated components.

3) Innovative project delivery approaches. For instance, IPD can facilitate integrated workflows, interdisciplinary coordination, seamless information exchange, and real-time collaboration. Early and ongoing communication among stakeholders is essential to strike a balance between evolving needs and the efficiency of industrialized construction.

The AEC industry has seen numerous intelligent practices, but it continues to face significant challenges (Fig. 4), including a weak data foundation, limited intelligence capabilities, and an immature business model. First, despite the availability of vast amounts of data, the heterogeneous unstructured data can hardly be used. Secondly, intelligent applications primarily focus on sensing, while intelligent analysis, decision-making, and execution are still in their early stages. Lastly, the lack of a profitable model for construction robots hinders their widespread adoption in the industry. To overcome these challenges, future development of intelligence in the AEC industry should prioritize the following aspects.

1) Life-cycle digital twin and supportive software. These are crucial to facilitate structured data collection, achieving a unified digital model from design to operation.

2) Deeper integration of AI technology, such as AI-generated design, AI-enabled structural analysis, and AI-assisted operations for urban planning, construction, and management [31,32].

3) Technological advancement of construction robots, to reduce their costs for increased adoption and profitability.

The promotion of lean construction in China faces several key challenges (Fig. 4), including misconceptions, inadequate support, and improper application. First, some practitioners mistakenly associate lean management with prioritizing fast construction over quality. They may view design optimization as an excuse for change orders and have concerns about the impact of early professional entry on cash flow. These misconceptions often result in insufficient support from stakeholders, such as delayed acceptance from the government, uncooperative suppliers, and delayed involvement of subcontractors. Consequently, improper application of lean principles leads to suboptimal outcomes due to a lack of coordination among different specialties. Future research in lean construction may concentrate on the following areas.

1) Local studies to identify the drivers for lean management, such as those related to human psychology, organizational evolution, social capital, and social networks. These would contribute to the development of educational promotion campaigns and customized lean construction regulations for different stakeholders.

2) The utilization of intelligent technologies in lean management. For instance, digital twin technology allows for enhanced visualization and identification of clashes and conflicts. AI-powered algorithms can optimize construction schedules by considering factors such as resource availability and weather conditions, resulting in improved project timelines.

3) Developing assessment schemes for lean construction, including project-level performance evaluation and organization-level capability assessment [33], to clarify practitioners' expectations and facilitate efficient lean management.

The AEC industry in China faces significant green challenges as the building sector contributes to half of the national energy consumption and carbon emissions [34], and construction waste accounts for 40% of total municipal solid waste. These challenges encompass both technological and social aspects (Fig. 4). Technologically, there is a lack of green materials that can replace traditional building materials such as steel and concrete, and the current software systems have limitations in incorporating green requirements into optimal spatial design for public buildings [35]. Socially, green buildings often lack demonstrable outperformance, resulting in delayed acceptance among the general public [31]. Future research on green development can focus on several key aspects.

1) Sustainable and high-performance materials, such as bio-based materials and recyclable, low-carbon alternatives, to enhance the environmental performance of buildings.

2) Green building operation modes that align with renewable energy sources. Key technologies to consider include distributed photovoltaic systems, distributed energy storage, low-voltage DC distribution networks, and flexible load control.

3) Shifting the mindset from accumulating end-use technologies to embracing nature-human-building integrated design. This approach can encompass adaptive design, post-occupancy evaluation [36], structural health monitoring, and other related efforts.

In addition to the specific challenges discussed in the four dimensions of AEC industry modernization, practitioners must also consider the broader challenges from a holistic perspective. We put forth ten thought-provoking questions for contemplation, noting that the numbering does not necessarily denote their respective significance.

1) Is it feasible to solely achieve green development through intelligent means? How can conflicts between green and intelligence be resolved?

2) How can the path and pace of development in the four dimensions be effectively controlled? Which dimension takes precedence when conflicts arise?

3) What are the fundamental drivers of green development? Can commercial values of green be identified and leveraged to promote green initiatives?

4) How can the advantages of industrialization be harnessed to achieve green development? Specifically, what improvements are needed to fully capitalize on prefabrication techniques?

5) How should we promote intelligence and industrialization in the AEC industry, considering the potential impact on profit models of construction companies? How can a smooth transition be achieved, and what factors determine the pace of this transition?

6) How can the AEC industry be revitalized to address the declining interest from young students and practitioners? Can the interdisciplinary nature of the four dimensions create new research opportunities and enhance the appeal of the AEC discipline?

7) How can human rights and interests, such as the well-being, privacy, safety, and employment opportunities of individuals, be protected in the face of rapid advancements in the industry?

8) What paradigm shifts are essential for the four-dimension development in the AEC industry? For example, mindset changes such as "repair instead of build" and "body conditioning instead of space conditioning" can contribute to green development.

9) How can a Chinese model of lean construction be developed, taking into consideration the unique cultural challenges that may arise?

10) How can lean management be effectively integrated with the other three dimensions in both research theory and practical implementation?

## 5 Conclusions

This article presents the concept of four dimensions for China's AEC industry: industrialization, intelligence, lean management, and green development. The integration of multiple disciplines forms the foundation for the synergy among these dimensions, with complex interrelationships among them. The article discusses the current best practices, challenges, and future directions associated with these four dimensions. Additionally, it proposes ten grand challenges from a general perspective, aimed at stimulating critical thinking among AEC practitioners on how to effectively and rapidly develop these dimensions. However, it should be noted that the practices discussed in the article are primarily based on the "Green−Ecology−Livability−Smart" seminar organized by the Chinese Academy of Engineering and may not be exhaustive. The ten grand challenges are raised as prompts for further discussion and do not have definitive answers at this stage. The intent is to inspire constructive discourse to guide the future development of China's AEC industry.

**Acknowledgements** The authors would like to thank all the speakers at the seminar for their insights. This study was supported by the National Key Research and Development Program of China (No. 2022YFC3801700), National Natural Science Foundation of China (Grant Nos. 52108090 and 52078374), Chinese Academy of Engineering (No. 2022-XZ-21), Science Foundation for the Science and Technology Commission of Shanghai Municipality, China-Carbon Peaking and Carbon Neutrality Program (No. 22dz1207100 and 22dz1207800), and Top Discipline Plan of Shanghai Universities-Class I.



**Competing interests** The authors declare that they have no competing interests.

## Appendix

**Table A** Attendees of the "Green−Ecology−Livability−Smart" seminar

| Role | Name | Affiliation |
|---|---|---|
| Convener | Nanqi Ren | Harbin Institute of Technology |
| Convener | Xuwen Xiao | Tongji University |
| Keynote Speaker | Hao Wang | China Institute of Water Resources and Hydropower Research |
| Keynote Speaker | Zhiqiang Wu | Tongji University |
| Keynote Speaker | Kai Cui | China Architecture Design and Research Group |
| Keynote Speaker | Ai-Jie Wang | Harbin Institute of Technology |
| Keynote Speaker | Kun Zhang | China Construction Third Engineering Bureau Group Co., Ltd. |
| Expert | Yi Cai | Tongji University |
| Expert | Hongxiang Chai | College of Environment and Ecology, Chongqing University |
| Expert | Hao Chen | Hunan Construction Engineering Group Co., Ltd. |
| Expert | Qiuwen Chen | Nanjing Hydraulic Research Institute |
| Expert | Shuo Chen | Shanghai Zero-Carbon Pavilion |
| Expert | Yinguang Chen | Tongji University |
| Expert | Wen Cheng | Xi'an University of Technology |
| Expert | Jie Ge | China Construction Eighth Engineering Division Co., Ltd. |
| Expert | Jianxiang Guo | Arcplus Group PLC |
| Expert | Rui He | Tongji University |
| Expert | Chen-Guang Huang | China Construction Fourth Engineering Division Co., Ltd. |
| Expert | Pengkang Jin | Xi'an University of Architecture and Technology |
| Expert | Rui Jin | Zhejiang Construction Engineering Group Co., Ltd. |
| Expert | Guojian Li | Zhongyifeng Construction Group Co., Ltd. |
| Expert | Jiulin Li | Beijing Urban Construction Group Co., Ltd. |
| Expert | Junqi Li | Beijing University of Civil Engineering and Architecture |

(*Continued*)

| Role | Name | Affiliation |
|---|---|---|
| Expert | Heng Liang | Harbin Institute of Technology |
| Expert | Chao Liu | Tongji University |
| Expert | Jiahong Liu | China Institute of Water Resources and Hydropower Research |
| Expert | Xiaochang Liu | Tongji University |
| Expert | Yujie Lu | Tongji University |
| Expert | Chao Mei | China Institute of Water Resources and Hydropower Research |
| Expert | Ligang Qi | China Construction Eighth Engineering Division Co., Ltd |
| Expert | Yisheng Shao | China Academy of Urban Planning and Design |
| Expert | Xuejun Tan | Shanghai Municipal Engineering Design Institute (Group) Co., Ltd. |
| Expert | Yu Tao | Harbin Institute of Technology, Shenzhen |
| Expert | Chao Wang | China Institute of Water Resources and Hydropower Research |
| Expert | Hui Wang | China Construction Second Engineering Bureau Ltd. |
| Expert | Kaiqing Wang | China Construction Third Engineering Bureau Group Co., Ltd. |
| Expert | Yayi Wang | Tongji University |
| Expert | Yi Wang | Xi’an University of Architecture and Technology |
| Expert | Shengji Xia | Tongji University |
| Expert | Yang Xiao | Hohai University |
| Expert | Tiefu Xu | Heilongjiang University |
| Expert | Gang Xue | Donghua University |
| Expert | Haowen Ye | China State Construction Engineering Corporation |
| Expert | Shuili Yu | Tongji University |
| Expert | Feng Yuan | Tongji University |
| Expert | Nan Zhang | Shanghai Zhongsen Construction and Engineering Design Consulting Co., Ltd. |
| Expert | Ming Zhang | Tongji University |
| Expert | Chen Zhao | Nanjing University |
| Expert | Jianshi Zhao | Tsinghua University |
| Expert | Xuefei Zhou | Tongji University |

## References


1. Howell G A. What is lean construction-1999. In: Proceedings of International Group for Lean Construction. Berkeley, 1999, 1
2. Koskela L, Howell G, Ballard G, Tommelein I. Design and Construction: Building in Value. New York: Routledge, 2002
3. Tommelein I D. Journey toward lean construction: Pursuing a paradigm shift in the AEC industry. Journal of Construction Engineering and Management, 2015, 141(6): 04015005
4. Feng S, Liu Y. Research on the theoretical system of lean construction. Project Management Technology, 2008, 3: 18−23 (in Chinese)
5. Li Z, Li X. Research on the support and synergistic relationship between building industrialization and lean construction. Construction Economy, 2016, 37(11): 92−97 (in Chinese)
6. Chen J, Ban L. Lean management model for promoting prefabricated building lean construction based on building information model. Science and Technology Management Research, 2020, 10: 196−205 (in Chinese)
7. Fu F, Sun J, Pasquire C. Carbon emission assessment for steel structure based on lean construction process. Journal of Intelligent & Robotic Systems, 2015, 79(3): 401−416
8. Wu D, Shi L, Xu G. Study on green construction management mode based on lean construction. Building Technology Development, 2015(1): 69−73
9. Zhang K. Developmental trends and thinking of new construction method for construction engineering. In: Proceedings of International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
10. Liu L. In the first 10 months of this year, 127 million square meters of prefabricated buildings were built. 2017. Available at the website of Ministry of Housing and Urban-Rural Development of the People’s Republic of China
11. Circular of the department of standard quota of the ministry of housing and urban-rural development on development of prefabricated buildings in China in 2020. 2021. Available at the

website of Ministry of Housing and Urban-Rural Development of the People's Republic of China
12. Qi L. Speech at International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
13. Editorial Board of BIM Application Analysis Report of China Construction Industry (2020). BIM Application Analysis Report of China construction Industry (2020). Beijing: China Building Industry Press, 2020 (in Chinese)
14. Yuan F. Architectural robotics augmenting intelligent construction. Speech at International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
15. Li G. Traditional enterprises need to achieve "three innovations" to realize digital transformation–technological innovation, organizational innovation, and management innovation. In: International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
16. Huang C. Speech at International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
17. Xing W, Hao J L, Qian L, Tam V W, Sikora K S. Implementing lean construction techniques and management methods in Chinese projects: A case study in Suzhou, China. Journal of Cleaner Production, 2021, 286: 124944
18. Ballard G, Tommelein I. Current process benchmark for the last planner system. Lean Construction Journal, 2016, 89: 57−89
19. Obulam R, Rybkowski Z K. Development and testing of the 5S puzzle game. In: Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC). Pontificia: PUCP, 2021, 309–319
20. Formoso C, Tommelein I D, Saurin T A, Koskela L, Fireman M, Barth K, Bataglin F, Viana D, Coelho R, Singh V, Zani C, Ransolin N, Disconzi C. Slack in construction-Part 1: Core concepts. In: Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC). Pontificia: PUCP, 2021, 187–196
21. Laurent J, Leicht R M. Practices for designing cross-functional teams for integrated project delivery. Journal of Construction Engineering and Management, 2019, 145(3): 05019001
22. Zhong R, Wille K, Viegas R. Material efficiency in the design of UHPC paste from a life cycle point of view. Construction and Building Materials, 2018, 160: 505−513
23. Abbood I S, aldeen Odaa S, Hasan K F, Jasim M A. Properties evaluation of fiber reinforced polymers and their constituent materials used in structures—A review. Materials Today: Proceedings, 2021, 43: 1003−1008
24. Chen S. Zero-carbon house. Speech at International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
25. Hu M. The city issued a plan to propose that by 2022, green building area in new urban buildings should account for 80%. 2020. Available at the website of Ministry of Housing and Urban-Rural Development of the People's Republic of China
26. Liao X. Chongqing has issued an action plan to create green buildings, and green building area will account for 70% of new urban buildings by 2022. 2020. Available at the website of Ministry of Housing and Urban-Rural Development of the People' s Republic of China
27. Wang B. The proportion of green building area in Hebei will reach 92% in 2022. 2020. Available at the website of Ministry of Housing and Urban-Rural Development of the People's Republic of China
28. Li Z, Shen G Q, Alshawi M. Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. Resources, Conservation and Recycling, 2014, 91: 27−39
29. Li J. The thinking about green construction and sustainable development of stadiums. In: International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
30. Cui K. Research and development of intelligent technology system of green building. In: International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
31. Wu Z. The future of urban technology and new infrastructure logic. In: International Conference on Frontiers of Structural and Civil Engineering. Shanghai, 2020
32. Li P, Lu Y, Yan D, Xiao J, Wu H. Scientometric mapping of smart building research: Towards a framework of human-cyber-physical system (HCPS). Automation in Construction, 2021, 129: 103776
33. Li S, Fang Y, Wu X. A systematic review of lean construction in Mainland China. Journal of Cleaner Production, 2020, 257: 120581
34. China Association of Building Energy Efficiency. 2022 Research Report of China Building Energy Consumption and Carbon Emissions. 2022 (in Chinese)
35. Shi X, Tian Z, Chen W, Si B, Jin X. A review on building energy efficient design optimization rom the perspective of architects. Renewable & Sustainable Energy Reviews, 2016, 65: 872−884
36. Li P, Froese T M, Brager G. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. Building and Environment, 2018, 133: 187−202