

From Data-Driven to Design-Informed: A Socio-Technical Dialogue on AI, Context, and Design Futures

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Introduction

In contemporary architecture and urban practices, the interplay between standardized data protocols and the unique complexities of local contexts presents both a promise and a challenge. Standardized methodologies—emerging from the software industry's focus on uniform data structures—enhance efficiencies, interoperability, and AI analyses. However, built environments are shaped by cultural, social, historical, and environmental factors that defy uniformity. This chapter examines the tension between these imperatives, arguing that while standardized data practices can streamline large-scale projects and uncover spatial patterns, they may erode the characteristics that define distinctive urban and architectural settings. By integrating multi-modal data—from geospatial analytics and sensor readings to ethnographic insights and participatory contributions—this work comprehensively advocates a shift from data-driven design to design-driven data. In this approach, computational tools are employed not to dictate outcomes but to support creative exploration and critical reflection through collaboration among engineers, social scientists, and community stakeholders. Ultimately, this chapter contends that achieving a balance between technical optimization and contextual sensitivity is essential for fostering resilient, inclusive, and culturally responsive design.

Navigating Uniform Protocols Amid Local Complexities: Standardization or Context?

In contemporary architecture, urban design, and planning, a persistent tension arises between the drive for standardized data protocols and the imperative to account for the distinct complexities of local environments. The software industry has long prioritized uniform data structures and rigid frameworks, yielding efficiencies in collaboration and enabling advances in AI.¹ However, architecture and urbanism operate within a fundamentally different paradigm shaped by cultural, social, historical, and climatic specificities. The imposition of a singular standardized model risks homogenizing diverse urban and architectural settings, eroding the unique spatial, social, and material characteristics that define buildings, neighborhoods, and cities.

Despite these concerns, the rationale for standardization remains compelling. By systematizing data collection, classification, and processing, standardized methodologies enhance operational efficiency and facilitate interoperability across digital tools.² Large-scale urban projects, particularly those involving extensive datasets, increasingly depend on such efficiencies to optimize decision-making and coordination among stakeholders.³ The growing reliance on big data further amplifies this trend, as the potential to uncover latent spatial patterns and generate predictive models exerts considerable influence on urban strategies. Yet the rigidity of standardized metrics poses a critical challenge: reducing architectural and urban complexity to quantifiable parameters risks constraining creative agency and diminishing sensitivity to local contingencies. When stakeholder perspectives, historical contexts, and site-specific constraints are abstracted into uniform indicators, the value of place-based interventions may be compromised.

This challenge is further complicated by the expanding array of data sources that inform design and planning decisions. From microclimate

¹ Daochen Zha et al., "Data-Centric Artificial Intelligence: A Survey," *ACM Computing Surveys* 57, no. 5 (2025): 1–42.

² Matthias Buchinger, Peter Kuhn, and Dian Balta, "Towards Interoperability of Data Platforms for Smart Cities," in *Handbook of Smart Cities*, ed. Juan Carlos Augusto (Springer International Publishing, 2021), 1–22.

³ Simon Elias Bibri, "Data-Driven Smart Sustainable Cities of the Future: Urban Computing and Intelligence for Strategic, Short-Term, and Joined-up Planning," *Computational Urban Science* 1 (2021): 8.

sensors and transportation analytics to participatory workshops and ethnographic fieldwork, the proliferation of data streams presents both opportunities and obstacles.⁴ On the one hand, these diverse inputs offer a more granular understanding of spatial dynamics, revealing overlooked interdependencies and challenging entrenched assumptions. On the other hand, the vast volume and heterogeneity of data risk overwhelming stakeholders, fostering selective engagement that may reinforce preexisting biases rather than fostering genuine insight. As a result, the question extends beyond the mechanics of standardization to a more fundamental inquiry: which data are most relevant, and how should they be contextualized to support context-sensitive decision-making?

Ultimately, architects and urban practitioners must navigate this intersection of globalized technical infrastructures and locally-situated identities with caution. Striking a balance between efficiency and legitimacy requires a comprehensive approach that leverages the benefits of standardized protocols without compromising the specificity of context. The challenge lies not in rejecting standardization outright but in developing adaptable frameworks that accommodate both the demand of data-driven methodologies and the irreducible complexity of built environments.

Data as a Socio-Technical Lifeline: Keeping Designers in the Loop

The built environment is shaped by a complex interplay of social, economic, and technological factors, which collectively influence its design, function, and evolution over time.⁵ While quantitative metrics—such as land-use efficiency, resource consumption, and cost-benefit analyses—play a crucial role in informing design and planning decisions, an overreliance on technocratic methodologies risks neglecting the social and cultural dimensions that shape how built environments are experienced and interpreted.⁶ Cultural

4 Constantine E. Kontokosta, "The Quantified Community and Neighborhood Labs: A Framework for Computational Urban Science and Civic Technology Innovation," *Journal of Urban Technology* 23, no. 4 (2016): 67–84.

5 Matthew Carmona, *Public Places Urban Spaces: The Dimensions of Urban Design*, 3rd ed. (Routledge, 2021).

6 Cem Ataman, Bige Tunçer, and Simon T Perrault, "Asynchronous Digital Participation in Urban Design Processes: Qualitative Data Exploration and Analysis With Natural Language Processing," in *POST-CARBON—Proceedings of the 27th CAADRIA Conference*,

norms, local power structures, and everyday practices often elude purely data-driven analyses, necessitating a more integrative approach. In this context, human-centered inquiry remains indispensable. By engaging with the lived experiences and cultural values of communities, such inquiry transcends the limitations of quantitative methodologies, capturing the subtle ways in which individuals perceive, navigate, and interact with their built environments.

Architects and urban practitioners, therefore, do not simply interpret pre-existing datasets but actively mediate between algorithmic insights and contextual realities. Their role extends beyond passive engagement with standardized metrics; instead, they formulate hypotheses about behavioral patterns—such as how pedestrians interact with a new shopping center or how perceptions of trust shift in response to digital tool interventions—and validate these assumptions through both quantitative datasets and qualitative observations. This interdisciplinary collaboration among engineers, software developers, and data scientists, as well as community stakeholders, social scientists, and environmental scientists, further ensures that design and planning decisions remain technically robust, culturally sensitive, and ethically responsible.

In this socio-technical paradigm, data is not a neutral or static entity but an active agent in collaborative exploration. Rather than dictating deterministic outcomes, data serves as a medium through which competing perspectives and complex urban systems can be reconciled. Architects and urban practitioners, in turn, assume the role of facilitators across disciplines for inclusive decision-making processes. By resisting the reductive impulse to optimize environments solely according to measurable metrics, data-driven approaches can instead cultivate built environments that skillfully balance operational performance with a profound sense of place, ensuring alignment with the lived experiences and cultural needs of communities. This shift is particularly critical in ensuring that communities marginalized by digital exclusion—those unable or unwilling to generate extensive data footprints—are not rendered invisible within design and planning frameworks. Ultimately, integrating both computational and human-centered perspectives enables the built environment to remain functional, responsive, and contextually meaningful.

Data Fusion and Intelligent Workflows: Toward Complex Design Scenarios

Contemporary design and planning processes necessitate a robust methodological framework, allowing stakeholders to synthesize diverse datasets—ranging from geospatial analytics to ethnographic observations—into holistic, context-sensitive strategies. By integrating varied, multi-modal datasets that are multi-source, multi-scale, and multi-temporal, architects and urban practitioners can construct a systemic understanding of built environments from otherwise isolated parameters, revealing the complex interdependencies among infrastructural demands, environmental conditions, and human behaviors. While this integrated perspective enhances descriptive analyses, it also informs predictive modeling and scenario-based simulations, where AI-driven decision-support tools enable the exploration of “what-if” scenarios for urban interventions—such as public space design, amenity distribution, or climate-adaptive strategies. Supported by well-curated and integrated datasets, these systems illuminate trade-offs that might otherwise remain obscured, ensuring that design and planning decisions balance technical feasibility with socio-environmental responsiveness.

Nevertheless, the increasing reliance on algorithmic processes introduces challenges related to transparency, interpretability, and trust. AI-driven models, particularly those employing deep learning techniques, often function as “black boxes,” generating outputs with limited traceability.⁷ This opacity tends to weaken stakeholder trust and process reliability, especially in public sector contexts where accountability and democratic decision-making are paramount.⁸ Consequently, ensuring the accountability and interpretability of such algorithmic processes is critical. Clear documentation of data sources, modeling assumptions, and computational outputs, along with consistent stakeholder communication, is essential for shifting from passive acceptance of opaque system outputs to critical engagement with data systems and design workflows. The development of a shared interpretative framework—one

7 Mohammad Amir Khusrul Akhtar, Mohit Kumar, and Anand Nayyar, “Socially Responsible Applications of Explainable AI,” in *Towards Ethical and Socially Responsible Explainable AI, Studies in Systems, Decision and Control* (Springer Nature Switzerland, 2024), 261–350.

8 Cem Ataman, Simon Perrault, and Bige Tunçer, “Fostering Inclusive Urban Design and Planning: Enhanced Trust and Reliability through Descriptive Instructions for Digital Citizen Participation,” *Journal of Urban Technology* 31 (2024): 25–48.

that allows stakeholders with different domain knowledge to scrutinize data-driven models—thus becomes integral to effective, evidence-based decision-making.

Furthermore, when data-driven workflows and AI-supported processes intersect with established design heuristics, a persistent tension arises between automation and augmentation. While AI excels at searching large parameter spaces and detecting statistical patterns, it remains limited in its capacity for contextual reasoning and interpretive flexibility when familiar heuristics fail. Because machine learning algorithms generalize from historical data, architectural and urban practices—frequently confronted with unprecedented conditions and resistance to standardization—require more adaptive approaches. This recognition has spurred a paradigm shift in design education, where traditional pedagogies once focused on spatial composition and material experimentation now extend to include data literacy, coding proficiency, and algorithmic thinking. The aim is not to displace architectural intuition with computational logic but to cultivate stakeholders who can seamlessly integrate quantitative analysis with qualitative discernment.

Ultimately, the future of design and planning lies in a symbiotic relationship between intelligent workflows and human expertise. By leveraging the computational power of AI while retaining the critical, creative, and interpretive capacities of human designers, the field can move toward a more integrative approach—one in which data-driven insights inform, rather than dictate, design solutions. In this vision, innovation emerges not from the mechanistic application of algorithmic processes but from their contextual calibration within the socio-cultural and ecological dimensions of the built environment.

Case Spotlights: Data in Action

Data-driven design is most effective when it addresses concrete, context-specific problems rather than forcing every scenario into a universal template. The cases in this section illustrate how culture, climate, and interdisciplinary collaboration intersect with data analytics to inform decisions, ultimately leading to evidence-based, data-informed design and planning actions.

As discussed above, data-driven design and planning have evolved to incorporate both qualitative and quantitative data, spanning multiple scales and timeframes. Designers and planners operate in complex environments where they must switch between various scales and frame multiple, often overlap-

ping problems simultaneously. The integration of multi-source, multi-scale, and multi-time information into urban decision-making ensures a richer, evidence-based foundation for planning and design interventions. This approach moves beyond traditional intuition-driven methodologies by providing structured, data-backed insights that support adaptive urban strategies.

The selection and use of data sets in the following cases are context-sensitive, considering the specific needs of each urban scenario. By combining qualitative and quantitative data—ranging from small-scale community surveys to large-scale environmental monitoring—design and planning support tools and platforms have been created where planners can make informed choices that balance technological advancements with human-centric design. A key challenge in this data-driven design process lies in deriving behavioral hypotheses from diverse urban data sets and linking them to spatial and organizational patterns. The integration of big data, user preferences, and designer knowledge into urban planning enables a more nuanced approach that aligns infrastructure development with actual user needs.

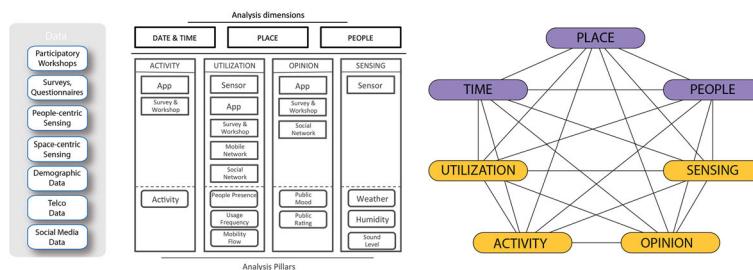
Advanced AI and data processing techniques—such as multivariate analysis, natural language processing (NLP), text mining, computer vision, and machine learning—have been integrated into design workflows. These technologies enable planners to make sense of complex, multidimensional urban datasets. AI-driven insights can assist in everything from traffic optimization to community engagement strategies, ensuring that urban environments are both efficient and responsive. When properly structured, AI-supported decision-making fosters a cooperative model where designers pose critical questions and AI generates data-informed scenarios, facilitating more dynamic and adaptable urban planning strategies.

Ultimately, platforms and applications that support data-driven design span multiple scales, from city-wide master planning to detailed neighborhood and street-level interventions, such as those described below. The use of data in such platforms extends beyond passive analytics; buildings and infrastructure can actively participate in urban processes through real-time data exchange. This paradigm shift reframes architects, urban designers, and planners as mediators between technology, environment, and community, where design is seen not just as a product but as an iterative, collective learning process.

A The Informed Design Platform: Multi-Modal Data for Urban Public Spaces

The Informed Design Platform (IDP) is a digital framework designed to assist urban designers by integrating multi-source, multi-scale, and multi-time data.⁹ IDP incorporates quantitative and qualitative datasets, including sensor networks, participatory data, and spatial analytics, to evaluate public space usage. The platform enables designers to assess factors such as pedestrian flow, thermal comfort, and user perceptions, providing a holistic approach to adaptive public space design. By merging real-time environmental readings with citizen feedback, IDP empowers designers to create responsive and user-centered urban interventions.

Fig. 21: Multi-source data collection, analysis dimensions and pillars, and information model diagram.

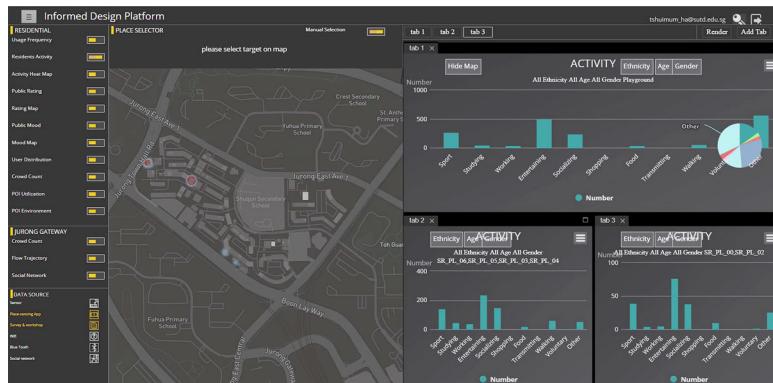


One of the significant strengths of IDP is its ability to bridge the gap between technical data analytics and intuitive, experience-driven urban planning. By allowing designers to visualize how various factors interact—such as how temperature variations influence pedestrian density or how seating

⁹ Billy Lau, Benny Ng, Chau Yuen, Bige Tunçer, and Keng Hua Chong, “The Study of Urban Residential’s Public Space Activeness using Space-centric Approach,” *IEEE Internet of Things Journal* 8, no. 14 (2021): 11503–13; Lin Lin You, Bige Tunçer, Rong Zhu, Hexu Xing, and Yuen Chau, “A synergistic orchestration of objects, data, and services to enable smart cities,” *IEEE Internet of Things Journal* 6, no. 6 (2019): 10496–507; Bige Tunçer and Lin Lin You, “Informed Design Platform: Multi-modal Data to Support Urban Design Decision Making,” in *eCAADe 2017*, vol. 2, *SHOCK! Sharing of Computer Knowledge*, ed. Antonio Fioravanti et al. (2017), 545–52.

arrangements impact social interactions—IDP provides a richer foundation for decision-making. Furthermore, the participatory aspect ensures that the end-users of urban spaces have a voice in shaping them, making public spaces more inclusive and attuned to community needs.

Fig. 22: IDP interface, displaying a comparative analysis of sensed and reposted activities conducted in various playground spaces.



In practice, IDP has been used to analyze multiple urban spaces, uncovering insights into how different population segments utilize shared environments. For example, in a high-density mixed-use area, IDP revealed that a combination of three functions—covered walkways, playgrounds, and coffee shops—acted as bottom-up community activity generators, influencing future urban design strategies. Additionally, the platform identified a disconnect in the utilization of public spaces between sub-areas of neighborhoods with demographic differences, leading to recommendations for better integration of suitable amenities and rest spaces.

Beyond its analytical capabilities, IDP can serve as a tool for predictive modeling. Through AI-driven simulations, urban planners can anticipate how changes in the built environment—such as the introduction of new green spaces, pedestrianized streets, or transit modifications—will impact user behavior. This predictive functionality allows for proactive rather than reactive design strategies, ensuring that urban spaces evolve in tandem with community needs. The potential for real-time urban analytics means that planners can make adjustments based on changing usage patterns, optimizing spaces dy-

namically rather than relying on static planning models. Future developments of IDP aim to incorporate machine learning algorithms that refine insights over time, making the platform even more adaptive to the complexities of modern urban living.

B Measuring Human Experience in the Built Environment

A case study exploring “Data-Driven Thinking” demonstrated how real-time physiological and environmental data could enhance design decision-making.¹⁰ Through a seven-day workshop, participants used wearable sensors to measure bodily responses to different urban conditions, integrating these insights with environmental data. This methodology highlights the potential of integrating human-centric metrics into urban planning, ensuring that design choices reflect not only functional efficiency but also psychological and physiological well-being. The approach bridges computational analytics with experiential design, fostering a more comprehensive understanding of the built environment.

Fig. 23: Sensors for data collection (left), data collection with mobile sensor station (middle), selected walking route (right).



By incorporating biofeedback data, such as changes in heart rate and skin temperature, this approach provides a granular perspective on how urban environments affect human stress levels, comfort, and engagement. For example, a shaded public square may intuitively seem more inviting, but physiological data might reveal that minor changes in humidity levels or noise pollution significantly alter its perceived comfort. The workshop findings underscore the

¹⁰ Bige Tunçer and Francisco Benita, “Data-driven thinking for measuring the human experience in the built environment,” *International Journal of Architectural Computing* 20, no. 2 (2021): 316–33; Francisco Benita, G. Bansal, D. Virupaksha, F. Scandola, and B. Tunçer, “Body responses towards a morning walk in a tropical city,” *Landscape Research* 45, no. 8 (2020): 966–83.

importance of interdisciplinary collaboration, with designers working alongside cognitive scientists, urban ecologists, and data analysts to refine methods for capturing human experiences.

Fig. 24: A visualization of a participant's stress levels on an urban walk, collected via a wearable physiological sensor. The size of the spheres represents stress levels, while the color intensity represents thermal comfort.



Beyond immediate physiological responses, this approach also sheds light on long-term well-being. Prolonged exposure to certain urban conditions—such as persistent noise, high traffic density, or inadequate green spaces—can contribute to chronic stress, impacting mental and physical health. By continuously monitoring biometric responses across different environments, urban planners can design interventions that promote both momentary comfort and sustained well-being. Moreover, the ability to combine these insights with subjective user feedback adds another layer of nuance,

allowing planners to understand not just how people react physically to their surroundings but also how they emotionally interpret those experiences.

Further expanding on this approach, researchers have begun integrating AI-powered emotion recognition into physiological monitoring, providing even deeper insights into how the built environment shapes human experience. For instance, facial recognition algorithms paired with physiological data can detect subtle changes in emotional states, helping to identify spaces that evoke stress or relaxation. Additionally, large-scale data aggregation from multiple test sites allows for comparisons between different urban environments, highlighting best practices in human-centered design. Future applications of this methodology could include large-scale, real-time monitoring of urban well-being, potentially influencing policy decisions related to health, urban planning, and sustainable development.

C Optimizing Pedestrian Comfort in Transit-Oriented Walkways

Pedestrian pathways play a crucial role in urban mobility, yet their design often prioritizes efficiency over human experience. In Singapore, a comprehensive study explored how transit-oriented walkways could be optimized to enhance pedestrian comfort while maintaining accessibility and efficiency.¹¹ The study combined large-scale digital preference surveys, virtual reality (VR) simulations, and environmental analytics to gain a deeper understanding of how design elements influence user perception and behavior.

A key aspect of the study was the integration of VR experiments, allowing participants to virtually experience different walkway configurations and provide real-time feedback. This approach revealed that factors such as walkway width, shading, material reflectivity, and noise levels significantly impacted perceived comfort. The study found that wider walkways with integrated greenery and noise-dampening materials led to a more pleasant experience, particularly for elderly pedestrians and individuals with mobility impairments. Furthermore, dynamic lighting solutions that adjusted based on time of day and foot traffic density were identified as an effective strategy to enhance safety and usability.

¹¹ Bige Tunçer et al., "Informed Design of Pedestrian Pathways," in *Accelerated Design: Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia*, ed. Nicole Gardner et al. (2024), 405–14, <https://doi.org/10.52842/conf.caadria.2024.2.405>.

Fig. 25: The eight design variants presented to participants in the VR experiment.

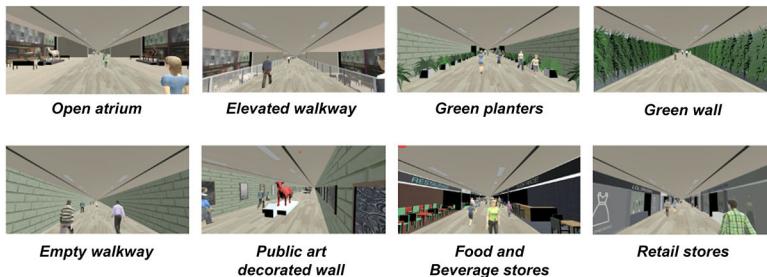
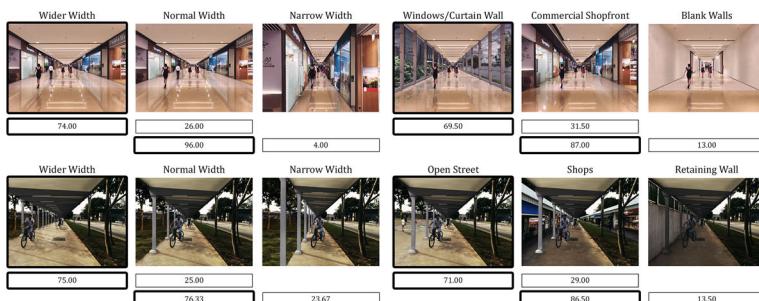


Fig. 26: Walkway widths in indoor and outdoor conditions (left 3 columns); edge conditions of indoor and outdoor walkways (right 3 columns).



Beyond environmental factors, the study examined behavioral patterns using GPS tracking and AI-powered pedestrian flow simulations. By mapping movement trajectories, researchers identified congestion points and areas where pedestrian flow was disrupted due to poorly placed obstacles or inefficient crossings. These insights informed recommendations for improved wayfinding systems, strategically placed rest areas, and enhanced connectivity between transit nodes and key urban destinations.

Another innovative component of the study was the use of biometric feedback to assess pedestrian stress levels in different walkway scenarios. Participants equipped with wearable sensors provided real-time physiological data, highlighting specific design conditions that triggered stress or discomfort. For instance, narrow passages with poor airflow and high foot traffic led to ele-

vated heart rates and increased reports of anxiety, whereas open, well-ventilated walkways promoted relaxation and ease of movement.

The findings of this study have been instrumental in shaping new pedestrian infrastructure policies in Singapore. By leveraging data-driven insights, urban planners have been able to implement targeted design modifications that prioritize pedestrian well-being without compromising transit efficiency. Future initiatives aim to integrate adaptive walkway technologies, such as smart pavement materials that adjust surface temperature and intelligent traffic management systems that dynamically reroute foot traffic based on real-time congestion patterns.

This research underscores the importance of human-centric urban design, demonstrating that pedestrian comfort is not merely an aesthetic consideration but a critical component of sustainable and livable cities. By combining advanced analytics, participatory feedback, and physiological monitoring, transit-oriented developments can evolve to meet the needs of diverse urban populations, ensuring that walkability remains a cornerstone of future urban mobility strategies.

Conclusion

As architecture and urban practices evolve in an era of unprecedented computational capabilities, the challenge goes beyond refining data-driven methodologies to ensuring they serve broader objectives of human and environmental well-being. While AI and algorithmic workflows offer powerful tools for analyzing spatial patterns, optimizing performance, and predicting urban dynamics, they must remain instruments of inquiry rather than arbiters of design. The true potential of data lies not in dictating outcomes but in revealing latent complexities, provoking critical reflection, and enhancing the depth of design discourse.

Moving forward, the discipline must transcend a technocratic fixation on optimization and efficiency to embrace a more integrative approach—one that recognizes the situated and contextual nature of design. Architectural and urban challenges are not abstract mathematical problems; they are deeply embedded in social, cultural, historical, and environmental realities that defy standardization. Processes that uncritically apply generalized datasets or rigid computational models risk oversimplifying the complexities of local contexts. Thus, the challenge is not to surrender expertise to machine intelligence but to

forge a symbiotic relationship in which data operates as a catalyst for creative exploration rather than a constraint on it.

Furthermore, this shift requires a fundamental rethinking of professional practice, research collaboration, and education. Instead of viewing data as an external imposition on design and planning, architects and urban practitioners must cultivate a capacity for critical engagement with computational tools, ensuring that design intelligence drives technological development rather than the reverse. This perspective calls for a transition from data-driven design to design-driven data—a paradigm in which data is not simply assembled for validation but is actively shaped to generate new insights, challenge assumptions, and foster meaningful stakeholder engagement. Toolchains and toolkits developed through research—encompassing multi-source, multi-scale, and multi-time data—can facilitate this paradigm shift by translating advanced AI techniques into actionable workflows that professionals can integrate into practice. This translation process requires not only refining computational methods but also working closely with relevant stakeholders, from engineers to policymakers, to align technological innovation with cultural and environmental objectives. In this context, transparency, inclusivity, and ethical accountability must be woven into every stage, ensuring that digital methodologies remain answerable to the diverse stakeholders, domains, and contexts they serve.

Consequently, the future of design does not hinge on a strict dichotomy between standardization and local adaptability, automation and human judgment, or data and intuition. Rather, it centers on striking a dynamic balance—leveraging computational intelligence while continuing to value lived experience, collective expertise, and human creativity. Moreover, these technological advancements in data analytics and algorithmic methods must be aligned with the foundational values of equity, sustainability, and cultural responsiveness. Architects and urban practitioners, in turn, bear a significant responsibility to shape built environments that are not only data-informed but also profoundly human-centered. This is not merely an aspiration; it is an imperative for forging a resilient, inclusive, and contextually attuned future.

