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A Conceptual Framework Explaining How Big Data–Integrated Teaching Enhances Sustainable Landscape Design Competence

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Abstract: *The rapid advancement of the digital age has made the application of big data technology in higher education a timely humanitarian endeavor. Integrating big data technology into landscape design curricula to enhance students' design capabilities is both an intriguing exploration and a meaningful initiative. This study proposes a comprehensive educational framework integrating TPACK theory, constructivist learning theory, and data-driven design theory. Within this framework, analytical skills, decision-making abilities, and integrated design capabilities form an organic synthesis of landscape design competencies. Education incorporating big data represents the manifestation of sustainable landscape design capabilities in this field. The integration of big data technology into education has established itself as a "cognitive scaffold" supporting conceptual leaps. Our goal is to foster a design approach that supports students' transition from intuitive to data-driven thinking. This reconfigured curriculum cultivates designers with a sustainable development perspective while providing implementation means to achieve UN Sustainable Development Goal (SDG) 4 (Quality Education).*

Keywords: Big data education, Landscape design, TPACK, Data-driven, Constructivist, SDG 4

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1. Introduction

The wave of big data and spatial analysis technologies is rapidly changing the landscape of higher education. Contemporary landscape architects are increasingly using geographic information systems (GIS), environmental simulation tools, and spatial data sets from multiple sources to support a digital framework for sustainable decision-making. Faced with critical challenges such as environmental degradation and the increasing complexity of urban systems, landscape architects are facing a wave of paradigm shift (Xinjie & Ying, 2025). Design processes must move beyond traditional "aesthetic-driven" approaches and enhance "data-driven" capabilities. The ability to integrate complex data streams has evolved from a supplementary skill to a core professional requirement. To respond to modern industrial transformation, the field of higher education design must also undergo corresponding adjustments. Particularly in landscape design education, data-driven teaching interventions play a crucial role in enhancing students' design capabilities.

Landscape design is no longer limited to traditional aesthetic design; it increasingly requires the use of digital technology to develop data skills and conduct scientific research. In designing educational curricula, students utilize complex data to address real-world project challenges. In such contexts, data processing tools transcend mere auxiliary functions, becoming essential professional competencies designers must master. Current landscape design pedagogy advocates implementing big data-integrated teaching interventions, effectively honing students' data literacy and systems thinking. Under data-driven pedagogical guidance, student learning processes achieve optimization, though engagement levels still hold significant untapped potential (Banihashem et al., 2022; Pan et al., 2024). Current education technology-focused teaching primarily centers on project-based learning and spatial reasoning courses, with limited research on big data integration within design-oriented disciplines (Williamson & Kizilcec, 2022).

Traditional landscape design education emphasizes experimental research, subjective analysis of place (Yu et al., 2022), and intuitive decision-making. While these approaches foster the development of students' creativity and aesthetic sensibility, they have proven insufficient when students are confronted with the vast environmental variables, complex ecological feedback loops, and large-scale challenges inherent in landscape design.

Although students place great trust in digital tools in the age of digitalization, attention should be paid to the discrepancy between their actual capabilities and their self-perception. This discrepancy reflects an imbalance in current educational approaches. Education often prioritizes the development of students' creativity, while the development of systematic design skills is often neglected.

Currently, big data-integrated teaching represents a promising educational force, yet research on the development of landscape design competencies remains limited. Addressing this gap, we focus on reimagining landscape design capabilities within data-interwoven environments. This study constructs a novel conceptual framework defining landscape design competencies in data-driven contexts as a dynamic developmental mechanism encompassing analytical skills, decision-making abilities, and integrated design capabilities. This framework elucidates how structured data can guide students through the digital wilderness, enabling them to propose more rational and scientifically grounded designs.

2. Literature Review

2.1 Big Data in Design Education

The ecological values of environmental protection and sustainable development have become deeply ingrained in public consciousness. Big data is no longer merely computer characters; it now provides new inspiration for landscape design through data-driven approaches (Cao, 2021). Big data technology is profoundly transforming educational practices. Big data primarily refers to structured and unstructured data naturally generated from various transactions, operations, planning, and social activities, all of which are interconnected with human life trajectories (Radu, 2020). Data intelligence has become the core component of big data, with its fundamental capabilities manifested in key technologies such as descriptive, prescriptive, diagnostic, predictive, and decision-making functions (Xu & Geng, 2019). Within design disciplines, the collection, analysis, and visualization of large-scale datasets enable big data to open a window of wisdom for personalized learning, real-time feedback, and data-driven instructional decision-making (Fischer et al., 2020).

Within design education, these capabilities offer opportunities to deepen students' understanding of complex environments and strengthen analytical inquiry within the design process. University education provides essential preparation for future landscape designers and professional practice.

In the field of landscape design, Geographic Information System (GIS) and spatial analysis tools can integrate multi-disciplinary data, especially playing an irreplaceable role in aspects such as topography, ecological indicators, and human activity patterns. Big data tools have facilitated systematic site analysis and evidence-based decision-making (Wu et al., 2022), and can also enhance the quality of spatial analysis, thereby improving the service efficiency of smart cities (Radu, 2020).

Especially in the specific field of landscape architecture, Geographic Information System (GIS) and spatial analysis tools are not only powerful tools for observing terrain, ecological indicators and human activity patterns, but also, catalyzed by data technologies such as artificial intelligence, Support the establishment of a framework for integrating multi-source data (Kamrowska-Zaluska & Obracht-prondzyska, 2018). Big data tools based on artificial intelligence have been widely applied in research fields that require high spatiotemporal resolution and accurate prediction, such as urban traffic monitoring systems and real-time crowd flow analysis (Yan et al., 2020).

By using digital parametric programming software such as Rhino and Grasshopper, parametric models are constructed to achieve the collection, analysis, simulation, creation and reproduction of landscape information. (Cao, 2021). Big data integrated teaching is not merely software skills training. Instead, it involves implanting evidence-based design thinking into the professional DNA to enhance students' abilities in analysis, design, and decision-making, thereby improving their overall design proficiency.

Under the global wave of education development, the potential of big data and artificial intelligence for people is huge. Digital transformation is a core strategy of the United Nations Sustainable Development Goal 4 (SDG4: Quality Education). However, the development of landscape design is somewhat lagging behind. The use of big data tools has not yet been applied on a regular basis. Many courses still focus on the assessment in aspects such as landscape visualization expression and creative aesthetics, without conducting in-depth mining of the logic behind the data.

2.2 Landscape Design Competence

Integrating digital tools like GIS into design enhances spatial comprehension, analytical capabilities, and technical proficiency. Existing research primarily examines student perceptions of digital learning environments, including satisfaction and technology acceptance. While positive attitudes toward digital tools are important, they do not necessarily translate to improved design competencies.

In the current era of information development, we are confronted with deeper considerations on how to define landscape design capabilities. Traditional models often emphasize creativity, spatial visualization and empirical intuition. However, in an increasingly data-intensive design environment, future designers need to possess rigorous analytical structuring capabilities, evidence-based reasoning skills, and multi-dimensional comprehensive integration abilities. This path is not strictly linear or deterministic, but rather explains the comprehensive integration of landscape design tasks from site interpretation to strategic decision-making, and ultimately to multiple dimensions. This conceptual framework makes the connection between instructional design and specific ability dimensions clearer.

2.3 Theoreticall Foundations

This study, supported by the TPACK theory, constructivist learning theory and data-driven design theory, attempts to depict how "big data integrated teaching" drives the evolution of students' design capabilities. The core logic is: to innovate teaching paradigms, activate data-driven education through data, and bring about a qualitative change in core design capabilities.

The TPACK theory is an integration of technical knowledge, teaching knowledge and content knowledge. Big data integrated teaching involves applying geographic Information system (GIS), visualization software, and data statistics software used in landscape design to landscape design teaching, fully leveraging the functions of data. The technical integration here is not merely about teaching the simple use of tools, but rather about integrating technical knowledge, pedagogical knowledge, and subject content together. In this study, T mainly refers to GIS spatial analysis, data visualization, multi-source environmental data, etc. Corresponds to the core contents of landscape design, such as site analysis, spatial organization, sustainable strategies and design justification. Emphasizes phased tasks, scaffolding support, criticism and feedback, iterative correction, etc. Students form an interactive and demonstrable design process of evidence in the teaching process

Constructivist learning theory emphasizes that learners actively construct knowledge through inquiry, collaboration and reflection in real task situations (Jin et al., 2025). Big data integrated teaching can be understood as a kind of "cognitive scaffolding" (Zhai et al., 2021). With the support of data tools, students can deepen their understanding of the site conditions through exploration activities, and thus make decisions that best conform to the design logic. The learning cycle of students follows the path of raising questions, evidence analysis, solution design, and feedback iteration.

The data-driven design theory can explain how data reconstructs the logic of design. After the computer processes large-scale data, use the data for design inference and decision-making (Quinons-Gomez et al., 2025). The landscape design major is undergoing a paradigm shift from emotional decision-making to data-driven planning (Xinjie & Ying, 2025). The relationships among the various elements of the landscape system receive relatively precise feedback through data collection, and students complete design decisions with reasonable data support..

This study proposes a development path for students' abilities supported by big data integration in teaching, namely analytical ability (interpretation and integration of site evidence), decision-making ability (selection and argumentation of solutions based on evidence), and integrated design ability (synthesis of evidence, decision-making and design expression into an implementable overall solution). The three theories together constitute the theoretical basis of this study.

Figure 1 presents the instructional mechanism model constructed in this study. This model emphasizes three levels—theoretical foundation, instructional intervention, and competency development—systematically elucidating the intrinsic logic of how big data-integrated teaching promotes the formation of landscape design competencies.

At the theoretical level, TPACK theory, constructivist learning theory, and data-driven design theory are integrated as the core theoretical framework. TPACK theory addresses the integration of technology, pedagogy, and subject content. Constructivist theory emphasizes knowledge construction in authentic contexts through inquiry and reflection. Data-driven design theory highlights the central role of evidence in design reasoning and decision-making.

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Together, these three theories provide the theoretical foundation for big data-integrated teaching.

At the pedagogical level, big data-integrated teaching is defined as a structured cognitive scaffolding intervention, rather than merely the introduction of technological tools. Its core lies in organizing learners' interactions with data to form evidence-based design reasoning pathways.

At the competency level, landscape design capability is decomposed into three dimensions: analytical ability, decision-making ability, and integrated design ability. The logical pathway of competency development is indicated by arrows, though this path is not mechanically progressive but exhibits dynamic interaction within actual design practice. The overall model reveals how theoretical integration, through instructional scaffolding mechanisms, facilitates the effective construction of structured competencies.

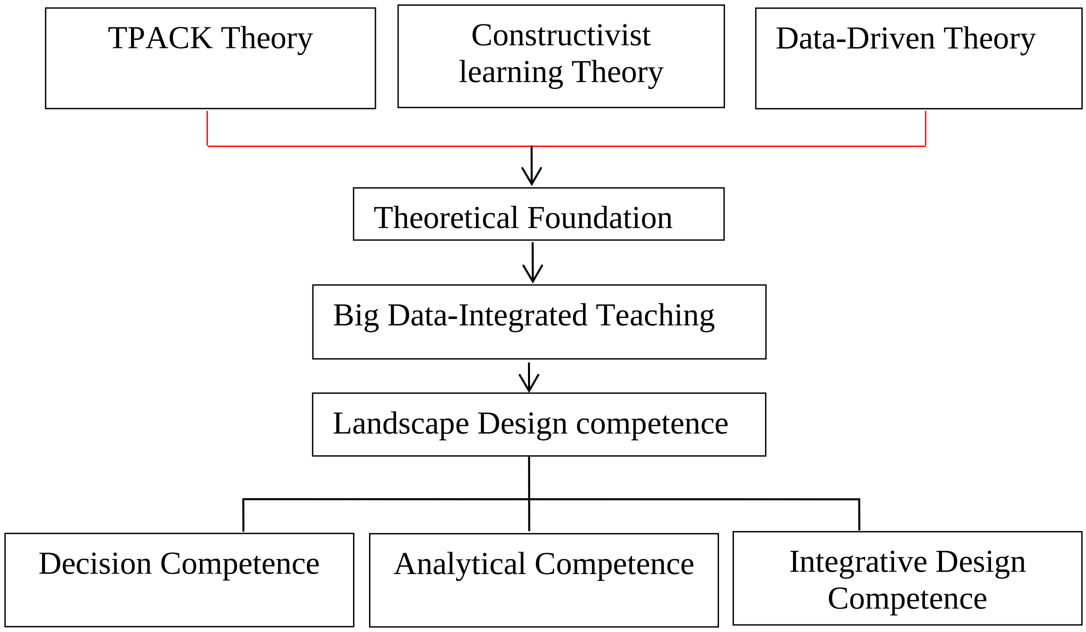

Figure 1: Instructional Mechanism Model

3. Instructional Mechanism Model

3.1 Analytical Competency: Data Perception and Mapping

Analytical competency refers to the ability to interpret, evaluate, and integrate complex spatial and environmental datasets during site analysis. In big data-integrated teaching scenarios, students must process structured data sources such as GIS layers, ecological indicators, and demographic information. Through data integration, thinking transcends descriptive observation. Students scientifically identify problems through data analysis.

3.2 Decision-Making Competency: Based on "Landscape Performance"

Decision-making ability is the ability to make choices after rigorous logical reasoning. In an environment of data inheritance, students can make a final choice after the site data hypothesis argumentation and scheme comparison. Data-driven approaches provide decision-making conditions for transportation routes, ecological restoration, and functional zoning. Decision-making ability is the transformation of analytical insights into structured design logic.

3.3 Integrated Design Competency: Multidimensional System Creation Integration

Integrated design capability reflects the ability to translate analytical insights and evidence-based decisions into coherent, feasible, and contextually responsive design solutions. At this stage, the creative integration of analytical and decision-making capabilities demonstrates foresight. For instance, it accounts for factors like plant growth cycles and ecological benefits, aligning with the learning objectives and competency development requirements of Sustainable Development Goal 4.7 (SDG4.7).

4. Propositions

Based on the proposed instructional mechanism model, the following theoretical propositions are put forward:

P1: Data-driven instructional scaffolding enhances learners' ability to interpret evidence and integrate information during site analysis (Analytical Dimension).

P2: Data-driven instructional scaffolding enhances learners' ability to evaluate and justify design options based on evidence (decision-making dimension).

P3: Data-driven instructional scaffolding enhances learners' ability to holistically integrate evidence, rationale, and design expression (synthesis dimension).

5. Discussion

5.1 Conceptual Contributions and Connections to Existing Research

This framework's big data integration teaching can promote the development of analytical and reasoning abilities in design tasks. The precise and effective use of big data tools in the design process leads to rather than merely relying on learners' perception of the application of technology. The integration of big data in teaching has helped to enhance the interactivity, innovativeness and creative efficiency of design schemes (Cao, 2021). This study not only discusses the effectiveness of the technical integration of teaching methods, but also explores the mechanism of designing ability formation explained from the perspective of cognitive structure reconstruction.

5.2 Theoretical Interpretation and Implications for Design Learning

From a constructivist perspective, digital analysis tools are a kind of cognitive framework. These tools are assisting students in completing systematic structured inquiry. Research shows that learning analytics techniques and data-driven feedback mechanisms can effectively promote iterative reasoning and enhance students' in-depth participation in complex information (Williamson & Kizilcec, 2022).

In the context of landscape design learning, the analytical tools of GIS are used to guide learners to base their design decisions on environmental evidence rather than relying on intuition and experience to make judgments. This shift in reasoning from experience-driven to analysis-supported not only embodies the core principles of data-driven design but also demonstrates the increasingly important role of big data integrated teaching in landscape design practice.

5.3 Sustainability Implications

By exploring pedagogical strategies that enhance learning quality and foster competencies relevant to higher education, this study aligns with Sustainable Development Goal 4 (Quality Education). Within this theoretical framework, integrating big data into landscape design education aims to strengthen learners' analytical logic and decision-making abilities, thereby preparing future practitioners for technology-driven and sustainability-oriented design practices.

6. Conclusion

This study proposes a theoretical framework to explain how big data integrated teaching can enhance landscape design capabilities through teaching scaffolds. This framework, by clarifying the development of analytical ability, decision-making ability and integration ability, not only enriches the theory of design education and teaching, but also lays the foundation for future empirical research. This framework is in line with the research conclusions of educational technology and systematically integrates data-driven teaching strategies, which can promote structured cognitive participation in higher education scenarios.

At the practical level, digital analysis tools perform best when strategically embedded in the early design stage, especially in site analysis and the early design validation phase. At this point, learners need to interpret environmental evidence based on data, analyze the specific circumstances of the project and form design logic. Big data integration has strengthened the analytical dimension of design learning and promoted the logical connection among evidence, decision-making and design synthesis. This research is conducive to enhancing the design ability and professional quality of design students in higher education. It is a teaching innovation that aligns with the realization path of Sustainable Development Goal 4 (Quality Education).

7. Implications and Future Research

The framework proposed in indicates that integrating big data into teaching as a phased instructional process (rather than an add-on technical component) maximizes effectiveness. Course activities may follow this sequence: structured site interpretation (analytical skills) → evidence-based spatial strategy development (decision-making skills) → integration into coherent design outcomes (synthetic design skills). Assessment frameworks should evaluate learners' analytical interpretation of site evidence, transparency and rationale of design logic, and the intrinsic connections between evidence, decisions, and design synthesis.

Future research may employ quantitative methodologies to empirically validate the propositions presented herein within academic settings. Multi-institutional or longitudinal studies could examine whether competency development follows the suggested pathway and explore correlations between specific big data tools (e.g., GIS analysis, simulation, visualization) and particular competency dimensions in sustainable landscape design education. Such validation would optimize the proposed pedagogical mechanisms, providing stronger guidance for implementing big data-integrated teach.

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Conflict of Interest

The authors declare no conflict of interest.

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