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Transformative Impact of Technology in Landscape Architecture on Landscape Research: Trends, Concepts and Roles

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Abstract: The role of technology in landscape architecture (TLA) has significantly evolved since the 19th century, increasingly integrating with digital tools and technologies in the 21st century. Despite its growing importance, there is a notable deficiency in the scholarly literature regarding the progression of TLA trends and their interplay with the core domains and research themes within landscape research. The influence of TLA on landscape research remains ambiguous, especially concerning its ability to generate new knowledge and impact design and sustainability practices. Furthermore, there is a critical need to delineate how TLA differs from allied general digital technology tools and to identify specific specializations that are emerging within the TLA field. To explore the above gaps, this study utilized a mixed methods approach involving secondary data from peer-reviewed publications, primary data from the archival research of winning projects, and expert interviews based on the two major research types of "Research through Design (RTD)" and "Research for Design (RFD)" to explore the TLA's contribution. This research is significant as it: (1) identified the trend of TLA; (2) conceptualized the TLA, and (3) identified its role in relation to the core domains and research themes of landscape research.

Keywords: technology in landscape architecture; theory-building; digital tools and technology; core domains; trends and theme

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1. Introduction

Landscape architecture, recognized as an interdisciplinary field, continuously expands its boundaries to incorporate related disciplines like ecology, geology, and architecture [1–3]. Despite this broad scope, the discipline has yet to clearly define its core technologies. Since the late 20th century, numerous scholars in landscape architecture have highlighted digital tools and technologies as pivotal for conducting landscape research [4,5]. However, this perspective is not universally accepted among scholars from allied disciplines. This research aims to bridge these differing views by exploring the relationship between applied digital tools and technologies and the core domains of landscape architecture. It will investigate research themes, analyze trends, and classify outcomes to establish a foundational understanding of the conceptualization of technology in landscape architecture. This study is intended to be a benchmark in landscape research, contributing to the development of a grounded theory and refining the definition of the discipline for the 21st century.

1.1. Trends of Technology in Landscape Research since the Late 20th Century

In the late 20th and 21st centuries, the emergence of technology in landscape research was dominated by the application of digital tools and technology (DTT) [6–11]. Digital tools and technology within landscape architecture research have been observed within topics or specializations such as visualization, geodesign, big data/data analytics, green-blue infrastructure, techniques, and research instruments, among others [12]. This suggests that digital tools and technology have been assisting in expanding the scope of research within the landscape discipline. In this context, digital tools and technology appear to act as a medium and a path to explore the emergence of technology in landscape architecture (TLA). According to several studies on research trends and the theoretical development of the landscape architecture discipline, computers and other types of technological hardware (3D printers, robotics) and software (rendering and 2D representational programs (such as Adobe Suites) ArcGIS Pro, and satellite mapping, among others) have evolved in landscape research as digital tools and technologies, and as a major topic and category for TLA in the 21st century [6–11,13–18].

To be specific, Powers and Walker [6] highlighted the integration of construction technologies, with a particular focus on performance and materials. Also, the sophisticated use of materials, operational methodologies, and system construction have been identified by Margolis and Robinson [13]. Techniques and the utilization of Geographic Information Systems (GIS) for computer graphics and visualization have been discussed by Gobster et al. [7]. Steinitz [19], in particular, concentrated on the technique aspect, and on enhancing GIS's capabilities in relation to landscape research. Also, a notable trend in the literature is the pivot towards digital software and technologies, with a particular focus on advanced techniques, as indicated by authors such as Amoroso [20,21], Amoroso and Hargreaves [22], and Cushing and Renata [8]. Meijering et al. [9] continued this trend, reinforcing the importance of digital software and technologies in shaping the field. There is a growing emphasis on computational design, artificial intelligence, and machine learning among numerous scholars [14–16,23,24], who have collectively underlined the convergence of representation, modeling, animation, responsive environments, data sensing, and the use of artificial intelligence in landscape research. Vicenzotti et al. [10], on the other hand, shed light on the relevance of construction technologies alongside the selection of planting and materials, whereas Langley et al. [17] concentrated on digital software. Newman et al. [11] broadened the scope by integrating tools for virtual reality and geodesign, applying them to applications such as visualization and social media, which opened up new avenues for data analytics and evaluation research within landscape architecture.

The above literature indicates a close relationship between digital tools, technology and TLA. Thus, it represents a breakthrough in exploring the trends, conceptualization, and roles of TLA in landscape research in the 21st century.

1.2. Role of Technology and Core Domains for Landscape Research since the Late 20th Century

To continue, understanding the role of digital tools and technology necessitates an analysis of the core body of knowledge of landscape architecture so as to help reach the goal of this research. This knowledge core has been defined in terms of "domains", "core domains", or in terms of categories and emerging topics of knowledge within the landscape architecture discipline. Key scholarly works have explored the landscape core domains and are summarized chronologically. The Landscape Architecture Body of Knowledge Study Report [25] was a foundational report based on survey research designed to answer questions about the landscape profession's core competencies and the fundamental body of knowledge expected of all graduates of accredited landscape architecture programs. Other studies examine current landscape core domains, and involve analyses of the content of the primary peer-reviewed landscape journals and expert interviews [6–11,17]. Analyzing the above literature, nine landscape core domains were formulated and ranked. They are Landscape Planning and Ecology (C1), Human and Environment Relationships (C2), History, Culture and Theory (C3), Design Education and Pedagogy (C4), Sustainability (C5), Urban Design (C6), Landscape Performance (C7), Landscape Design and Implementation (C8), and Digital Tools and Technology (C9). The formulation of these nine domains, noted below, was achieved through an analysis of the number of times or frequency at which a particular core domain was indicated, as below (Figure 1).

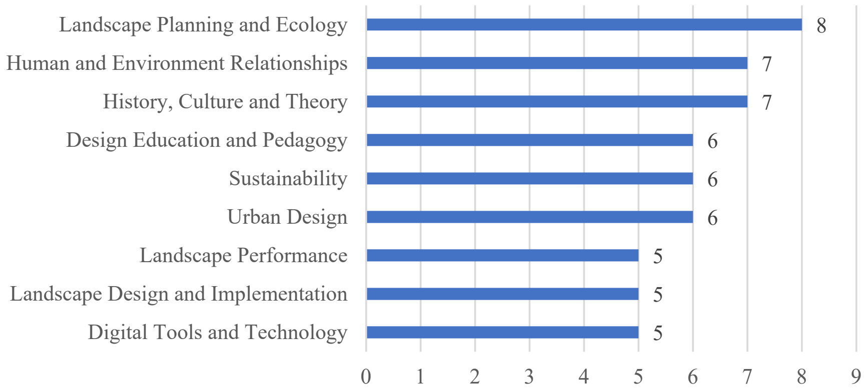

Figure 1. Nine primarily considered core domains in landscape research.

Figure 1 identifies digital tools and technology as a core domain, supporting the initial claim that landscape architecture scholars consider digital tools and technology essential for research in the field. However, Figure 1 does not adequately discuss the core technologies specific to landscape research, leading to potential confusion between digital tools and TLA. It is worth questioning whether these concepts are conflated by scholars or if TLA has been insufficiently defined. Previous studies [6,11] have noted similar concerns.

1.3. TLA from Digital Tools and Technology and Priorities Research Approaches

Carl Steinitz emphasizes the importance of digital tools and technology in exploring various subjects such as climate, geology, hydrology, ecology, and perception. He highlights its role in generating new research outcomes, which he categorizes as aspects of TLA [26]. Frayling [27] notes two priority research approaches within landscape architecture that contribute to generating it: (1) Research through Design (RTD) and (2) Research for Design (RFD). RTD refers to researchers who generate new technology by understanding the current state and then suggesting an improved future state in the form of a design [28]. RFD is another research approach that landscape scholars utilize to generate new technology within the landscape discipline. It refers to scholarly research that informs design as a way to improve the quality of the designed artifact and to increase its reliability. The designer then translates such knowledge to substantiate the design, with examples illustrated by Deming and Swaffield [29] (pp. 90–100). In Frayling's words [27], this "gathering of reference materials" culminates as a product. The major sources for RTD are professional projects, and the major sources for RFD are based on scientific research from disciplines related to the field of landscape architecture. However, works from both RTD and RFD are rarely discussed in terms of their contributions to new knowledge in 21st century TLA, trends and themes of landscape architecture research, or ways these emergent technology-based strategies could be framed now, or applied in the future [30,31].

The literature discussed above indicates that TLA has not been investigated meaningfully. This suggests a gap that has been exasperated by rapid changes and innovations in technology, particularly as regards the common deployment of personal computers and the use of computer workstations among landscape practitioners and researchers. This research also suggests that digital tools and technology, landscape core domains, and trends and themes in landscape architecture research appear to be interconnected. Yet, few studies have examined the phenomenon of TLA, its related specializations, and the ways that digital tools cross and intersect the various landscape core domains.

1.4. Research Goals and Questions

Between Sections 1.1 and 1.3, the text identifies three significant gaps that obscure the role of TLA in landscape research:

- The ambiguous relationship between digital tools and technology and TLA;
- The unclear identification of TLA within the core domain of landscape architecture;

- The lack of conceptualization and categorization for TLA.

To fill the above gaps, understanding the shift in the relationship among TLA, landscape core domains, digital tools and technology and research themes helps us to better explore the role of TLA. Hence, the research will focus on the following research questions:

- RQ1—How can the relationship between TLA, the core domains of landscape architecture, digital tools and technology, and research themes be interpreted?
- RQ2—How should TLA be conceptualized based on these explored relationships?

This work is instrumental in laying the foundation for defining core domains and related emerging topics. It also establishes a theoretical framework for investigating TLA, along with potential correlations or interrelationships among the emerging topics within these core domains of the landscape discipline. The intent of this research is to bridge this knowledge gap by systematically exploring the role of TLA in the 21st century. Based on the findings from the literature review, the research questions have been refined into a series of primary and secondary questions that reflect these identified gaps.

2. Methodology

Figure 2 provides an overview of the mixed methods (both for data collection and data analysis) utilized for this exploratory study. Secondary data were drawn from the major landscape architecture peer-reviewed publications from certain periods that have yet to be analyzed. Primary data were drawn from archival research on projects that received awards from ASLA from 2005 to 2021, as well as expert interviews. This research also incorporated grounded theory, whereby content analysis of the primary data generated from responses to the semi-structured interviews of "experts" (practitioners and scholars) helped determine patterns, categories, and codes.

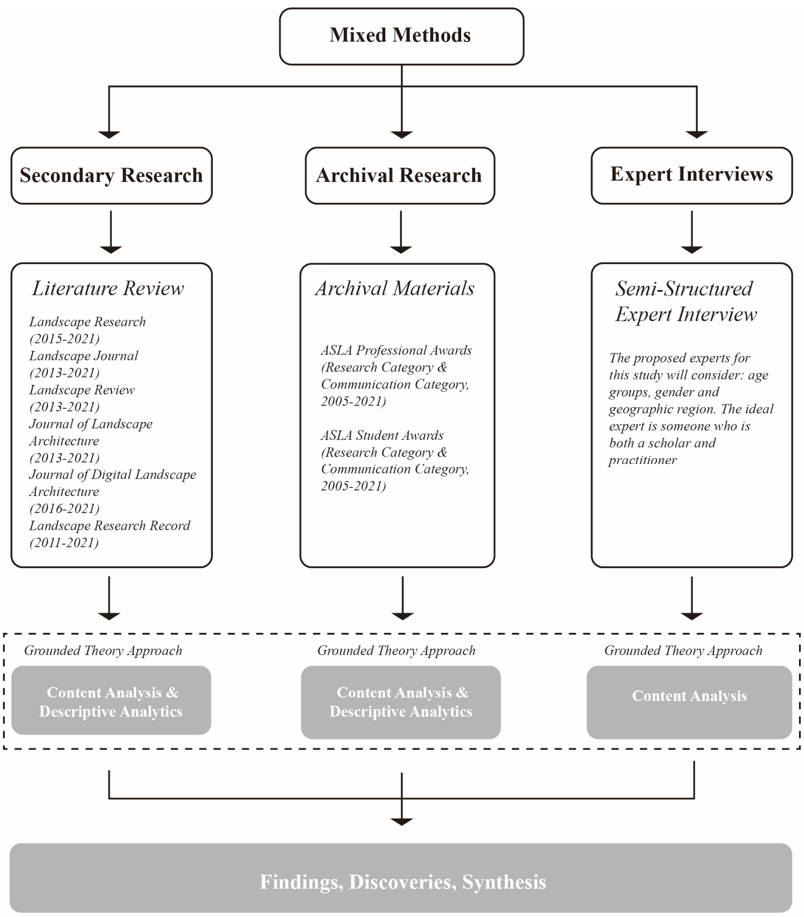

Figure 2. Analytical framework.

2.1. Data Collection

2.1.1. Stage One: Secondary Research

The initial phase of data collection focused on secondary research, specifically tailored towards RFD within the realm of landscape architecture. This comprehensive review targeted peer-reviewed literature from a select set of journals between 2011 and 2021, including the Journal of Digital Landscape Architecture, Landscape Research, Landscape Journal, Landscape Review, Journal of Landscape Architecture, and Landscape Research Record. The primary goal was to unearth and analyze studies specifically addressing the integration and application of digital tools and technology within RFD. This methodical scrutiny was designed to collate data on the research objectives, methodologies, tools utilized, and the significant outcomes from each study, providing a solid foundation for understanding how digital tools and technology contribute to and enhance the design process in landscape architecture.

2.1.2. Stage Two: Archival Research

The second data collection stage involved primary data drawn from archival research and the ASLA archive of award-winning annual projects. As stated earlier, Zimmerman and Forlizzi [28] noted that the major source of RTD is derived from design research projects. Primary data were collected through a systematic review of the ASLA archive of award-winning projects by professionals and students in the “Research” and “Communication” categories from 2005 to 2021. These two categories represent RTD’s standard of excellence. Key data were drawn from the project statement, narrative, and captions from award-winning presentation boards and images.

2.1.3. Stage Three: Expert Interviews

The third stage of data collection consisted of expert interviews. Primary data were gathered from the responses to semi-structured (open-ended) survey questions. This interview process consisted of a one-on-one dialogue between the researcher and participant, guided by a flexible interview protocol that was supplemented with follow-up questions, probes, and interactive discussions. This complied with social science interview standards and allowed the researcher to collect open-ended data from the interviewees’ responses in order to explore their thoughts, feelings, and beliefs about a particular topic [32]. These responses provided primary data. To achieve reliability and validity in the data, the experts represented a range of ages, genders, and geographic regions. All invited experts had been scholars and design practitioners for at least ten years. Audio recordings of the expert interviews allowed for effective and fluid communication; the recordings were later transcribed. According to Creswell [33], 15–20 experts represents an appropriate sample population for expert interviews. Thus, 18 experts served as the target number for this study. For the semi-structured interviews with open-ended questions, the protocol and procedure began by describing the context of the research and then asking the fundamental questions as follows:

1. What are your thoughts on conceptualizing TLA in the 21st century?
2. What are your thoughts on the relationships between TLA and landscape core domains?
3. What are your thoughts on the relationships of research themes and associated topics with TLA?
4. What are the differences between digital tools and technology and TLA?
5. What methods of inquiry do you apply in your research, and what is the meaning of TLA to your research?

2.2. Data Analysis

2.2.1. Data from Secondary Research

Content analysis and descriptive analytics were applied to the data gathered in the first stage of Secondary Research. The major components considered for analysis included landscape core domains, research topics, methods of inquiry, research strategies, digital tools and technology, and TLA specializations. Table 1 illustrates how the data from secondary research were sorted and organized for the analysis. The reference number, notably, represents the nine landscape core domains summarized in Figure 1, Section 1.2. Appendix A shows the full list of datasets [34].

Table 1. Data collection sample.

Reference Number	*C1*
Article Title	*Digital Age for Observations: The Use of GIS for Analyzing Observations and Behavior Mapping*
Core Domain	*Landscape design and implementation*
Research Topic	*Landscape assessment*
Method of Inquiry	*Secondary research—RFD*
Digital Tools and Technology Incorporated	*GIS*
TLA Specializations	*A tool for observing the water experiences of children (TOWEC)*

To further illustrate the Table 1, the data from secondary research were sorted, and the majority claimed Research for Design (RFD) as their dominant "Method of Inquiry". In addition, based on the data analysis strategies in grounded theory, content analysis comprised two steps to classify the data taken from the "Abstract", "Research Method", and "Conclusions" of each sample to "Digital Tools and Technology Incorporated", "Research Topic" and "TLA Specializations". The categories in the "Core Domain" were drawn from Figure 1. After the data were converted from samples to Table 1, descriptive analytics was applied to identify and determine specializations, trends, and themes related to digital tools and technology and landscape core domains.

2.2.2. Data from Archival Research

Data gathered in this second stage of archival research and reviews of ASLA Award-winning projects utilized content analysis and descriptive analytics. In this archival review, the content analysis involved extracting keywords from the "Project Statement", "Method", and "Conclusions" for each ASLA Award-winning project, which were then categorized by applying the same data classification method as used in Stage Two in Section 2.1.1 to landscape core domains, research themes, and associated topics and digital tools and technology (Table 1). Descriptive analytics helped with pattern recognition and with determining themes and trends in relation to digital tools and technology, landscape core domains, and landscape research topics.

2.2.3. Data from Expert Interviews

The content analysis of the responses to the expert interviews (primary data) was performed via descriptive analytics. Similar to the two datasets from the secondary research (select literature) and archival research of ASLA Award-winning projects, the objective was to discover the relationship between digital tools and technology, specializations, trends and themes, and landscape core domains for TLA in the 21st century. The data from expert interviews were sorted into two groups based on their major research approaches (RTD or RFD). This assisted with the subsequent analytical and synthetic stages, which will be discussed later.

3. Results

A total of 298 peer-reviewed articles were reviewed for the secondary research phase and represent RFD. A total of 42 ASLA Award-winning projects from the "Research" and "Communication" categories were reviewed during the archival research phase and represent RTD. Eighteen experts were interviewed for the Expert Interview phase. The data from the Expert Interviews were classified as either RTD or RFD according to each interviewee's expertise.

3.1. Findings from Secondary Research (RFD)

3.1.1. RFD Trends of the Landscape Core Domains Intersecting with TLA

This section discusses the analysis of landscape core domains intersecting with TLA in Secondary Research. It examines trends based on patterns of annual changes and the frequency of TLA-related research intersecting with each core domain (Figure 3). This research explored the TLA in the 21st century based on research incorporating digital tools and technology, meaning that digital tools and technology was not considered with the other landscape core domains. Thus, they were excluded from this analysis. The findings indicate a trend for research based on RFD emerging for TLA, intersecting with "Landscape Performance" and "Landscape Planning and Ecology" from 2013 to 2018. From 2018 to 2021, TLA's intersection with "Landscape Planning and Ecology", "Human and Environment Relationships", and "Sustainability" appeared to increase more rapidly than in the other landscape core domains.

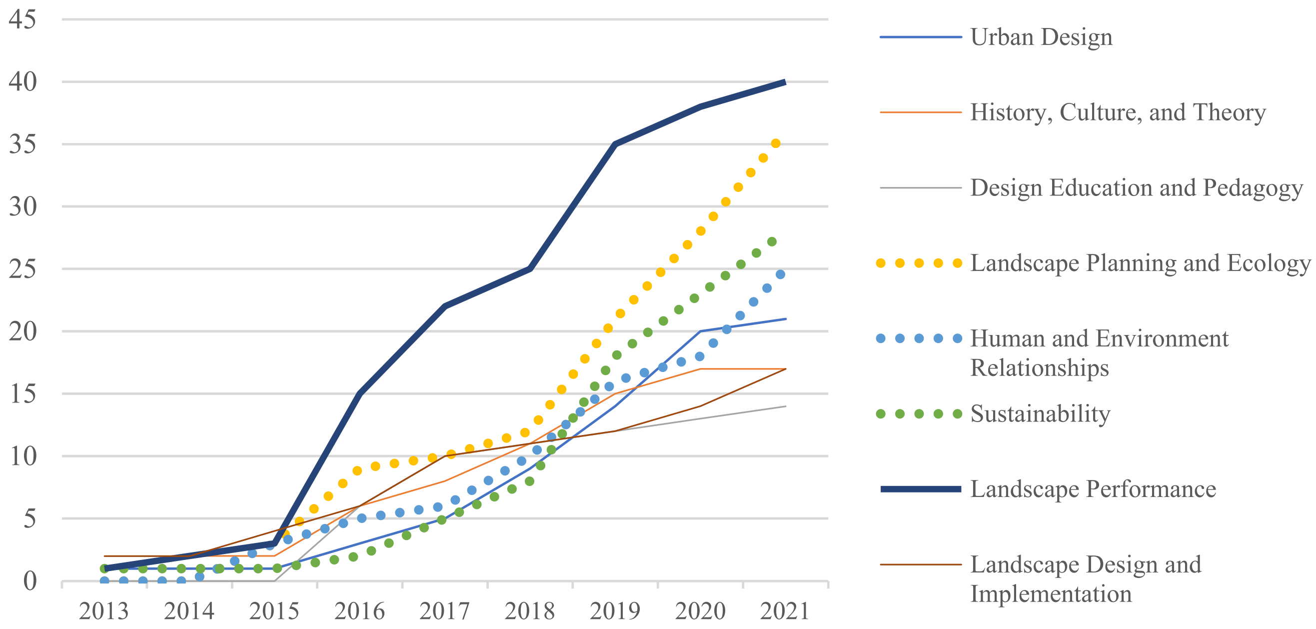

Figure 3. Secondary research—finding: yearly annual change of intersected landscape core domains with TLA (2013–2021).

3.1.2. RFD Trends of the Research Themes Intersecting with TLA

Based on the analysis of data collected through secondary research, 14 themes were identified, referring to the 2022 CELA research tracks [12], and organized according to the landscape core domains. The frequency of research themes emerging in the database is shown in Table 2. As noted in Figure 1, nine core domains were utilized for this study: Human and Environment Relationships (HER); History, Culture and Theory (HCT); Design Education and Pedagogy (DEP); Landscape Planning and Ecology (LPE); Urban Design (UD); Sustainability; Landscape Performance (LP); Landscape Design and Implementation (LDI), and Digital Tools and Technology (DTT).

Table 2. Secondary Research—Analysis and Frequency: Research Themes for TLA.

Research Themes	Freq.	LPE	HCT	HER	UD	SS	DEP	LDI	LP
1 Environmental Monitor and Assessment	112	x			x	x		x	x
2 Coastal Resilience, Hazard and Water Management	91	x				x		x	x
3 Urban Public Space Design and Management	85	x		x	x	x		x	x
4 Ecology Restoration Enhancement	72	x		x	x			x	x
5 Construction Materials and Infrastructure	51	x			x	x	x		x
6 Climate Change and Adaptive Design	51	x		x	x	x		x	x
7 Human Behavior and Environment.	44	x	x	x				x	
8 Community Engagement and Participatory	32	x		x	x	x		x	
9 LA Education Strategies	28	x	x		x	x	x	x	
10 LA Research and Experiments	28	x			x	x	x	x	
11 Visual Communication	17	x					x	x	
12 Social Equity and Landscape Identity	14		x	x			x		x
13 Historical Preservation and Management	11		x		x	x	x	x	
14 Wildlife Habitat and Biodiversity	10	x			x	x		x	

To explore the trends of these research themes, this research examined the yearly patterns of their frequency (Figure 4).

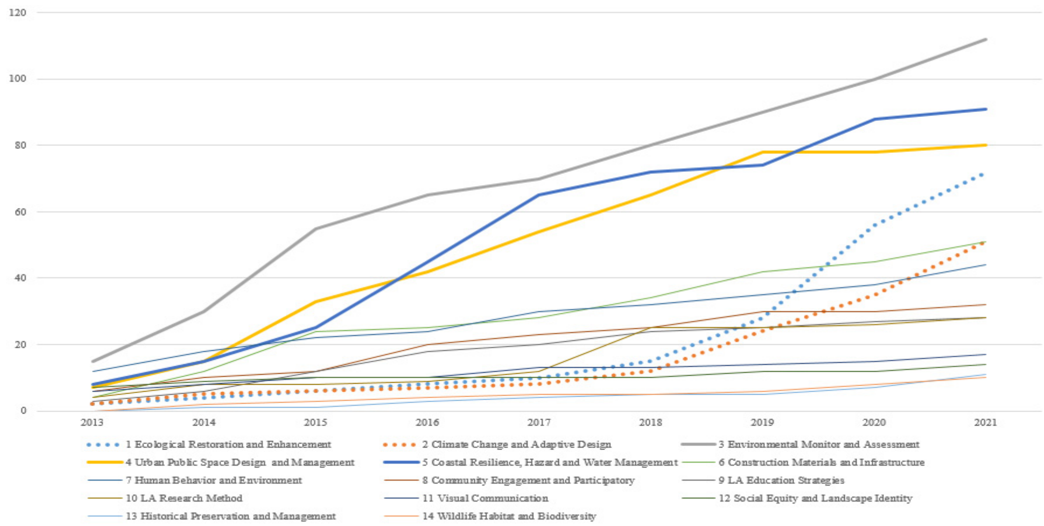

Figure 4. Secondary research—findings: yearly patterns of research themes (2013–2021).

The findings indicate that, in the five years from 2013 to 2018, "Environmental Monitor and Assessment", "Urban Public Space Design and Management" and "Coastal Resilience, Hazard, and Water Management" were the three dominant research themes. However, from 2018 to 2021, "Ecological Restoration and Enhancement" and "Climate Change and Adaptive Design" appear to have increased more rapidly than the other research themes. In the analysis of the dominant research themes of the topics, it appears that studies based on RFD shifted their themes from "Environmental Monitor and Assessment" and "Coastal Resilience, Hazard, and Water Management" to "Ecological Restoration and Enhancement" and "Climate Change and Adaptive Design".

3.1.3. RFD Categories and Trends of Digital Tools and Technology Intersecting with TLA

Based on the analysis of the data derived from Secondary Research, nine categories of digital tools and technology have been identified and ranked by their frequency of application in the literature (Table 3).

Table 3. Secondary research—findings: categories of digital tools and technology for TLA.

Research Themes	Freq.	LPE	HCT	HER	UD	SS	DEP	LDI	LP
1 Geographic Information System (GIS)	151	x	x	x	x	x	x	x	x
2 Parametric and Computational Algorithms	62	x	x	x	x	x	x	x	x
3 3D Modeling	60	x	x	x	x	x	x	x	x
4 Photography-Based Digital Visualization	47	x	x	x	x	x	x	x	x
5 Statistical Modelling	41	x		x	x				
6 Virtual Reality	30	x	x	x	x		x	x	
7 Remote Sensing	29	x	x	x	x	x	x	x	x
8 Mobile Technologies	23		x	x	x	x	x	x	
9 Computational Analysis and Evaluation	21	x		x		x			x
10 Social Media Data Mining Processes	19	x	x	x		x	x	x	x
11 Global Positioning System (GPS)	16	x	x	x	x	x	x	x	x
12 Unmanned Aerial Vehicles	16	x	x		x	x	x	x	x
13 Web-Based Interactive Map	15		x	x	x	x	x	x	x
14 Augmented Reality	14	x	x	x		x	x	x	x
15 Crowdsourcing	14		x	x				x	x
16 Physical Sensors	12	x	x			x	x	x	x
17 Gaming Engine	11	x	x	x	x		x	x	
18 3D Point Cloud	11		x	x	x	x	x	x	
19 Building Information Modeling (BIM)	11	x						x	
20 Topology Evaluation	11	x			x	x			x
21 Web-based App	10					x	x		x
22 Open Source and Programming	9		x		x		x	x	x
23 Video, Audio and Visual Technology	8				x	x	x	x	
24 Planning Support System	5	x	x	x		x			x
25 Artificial Intelligence	5	x	x	x				x	x
26 Tangible User Interface (UI)	4	x					x	x	
27 Computational Fluid Dynamics (CFD)	4	x				x		x	x
28 Robotic Processes	4					x		x	
29 Digital Twin	4	x						x	
30 Agent-Based Modeling	3			x	x			x	
31 Digital Surface Models (DSM)	3			x	x			x	
32 Fractal Dimension	3				x				x
33 Image Segmentation	3				x				x
34 Decision Support System (DSS)	2		x		x				
35 Emotion-Detection Software	2			x					

To determine trends, the annual changes in frequency for each category of digital tools and technology were analyzed (Figure 5).

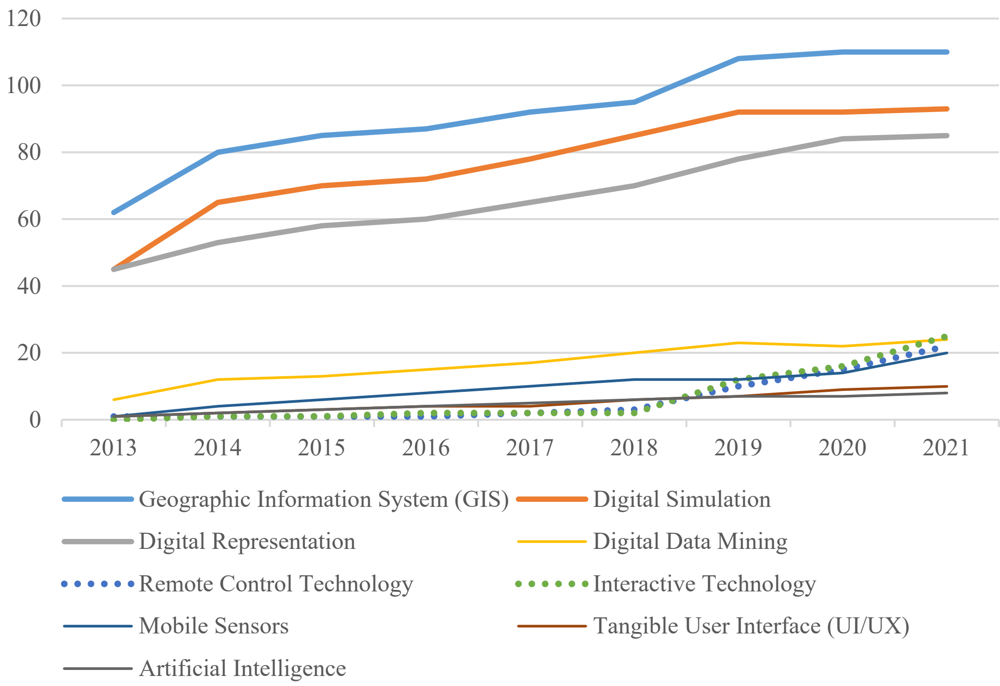

Figure 5. Secondary research—findings: annual change for categories of digital tools and technology (2013–2021).

From 2013 to 2018, the frequency of GIS and "Digital Simulation" increased and appeared to dominate the category of digital tools and technology. However, after 2018, the trend for research based on RFD appeared to incorporate more "Remote Control Technology" and "Interactive Technology". This suggests a change in digital tools and technology for TLA.

The specific modes of implementation of different types of digital technologies in the eight landscape core domains (except DTT) are illustrated in Figure 6.

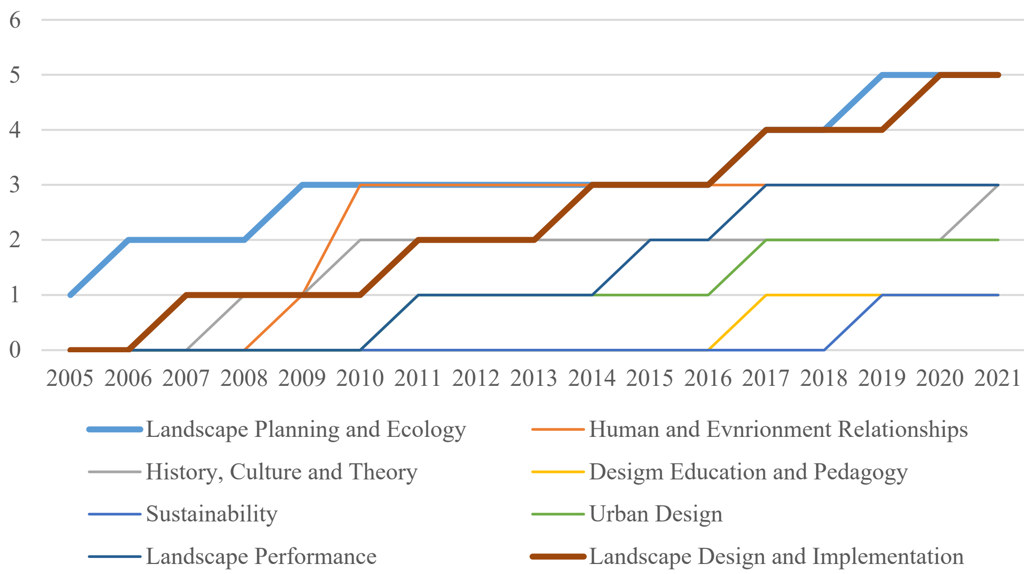

Figure 6. Archival research—finding: annual change of intersected landscape core domains with TLA for the professional projects (2005–2021).

According to the analysis of 298 peer-reviewed articles from Secondary Research, TLA was mentioned in 195 articles. Based on the analysis and findings, discoveries of dominant themes and emerging specializations were made. These are summarized in Table 4.

Table 4. Secondary research—summary of findings.

Trends	2013–2018	2018–2021
Dominant Landscape Core Domains	• Landscape Planning and Ecology • Landscape Performance	• Landscape Planning and Ecology • Sustainability • Human and Environment Relationships
Dominant Research Themes	• Environmental Monitor and Assessment • Coastal Resilience, Hazard and Water Management • Urban Public Space Design and Management	• Ecological Restoration and Enhancement • Climate Change and Adaptive Design
Categories of DTT	• Geographic Information System (GIS) • Digital Simulation	• Remote Control Technology • Interactive Technology

3.2. Fidnings from Archival Research (RTD)

Data analysis strategies in Secondary Research were applied in the second stage of data collection for archival research. As noted earlier, archival research was analyzed using the RTD approach. In total, 18 student awards and 26 professional awards were selected for analysis in this research.

3.2.1. RTD Trends of the Landscape Core Domains Intersecting with TLA

This section discusses the analysis of landscape core domains intersecting with TLA in archival research. It examines trends based on patterns of annual changes and frequency of TLA-related research intersecting with each core domain. The findings indicate a trend for research (both professional and student projects) based on the RTD approach that emerged for TLA, where it intersected with "Landscape Design and Implementation" and "Landscape Planning and Ecology" from 2005 to 2021 (Figures 6 and 7). These two core domains increased more rapidly than the others.

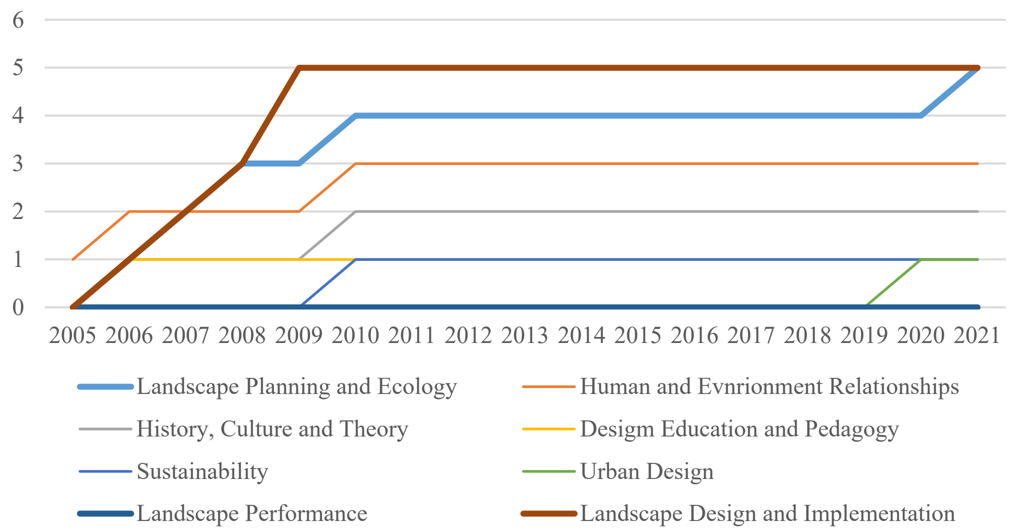

Figure 7. Archival research—finding: annual change of landscape core domains intersecting with TLA for the student projects (2005–2021).

3.2.2. RTD Trends of the Research Themes Intersecting with TLA

Based on the analysis of the data generated through archival research, 12 research themes were sorted into the landscape core domains according to the CELA tack [12]. This involved frequency analyses of the archival database (Table 5).

To determine trends in professional projects, the frequency analysis found that "Visual Communication" and "Urban Public Space Design and Management" were two of the dominant research themes from 2005 to 2018. "Coastal Resilience, Hazard and Water Management" and "Climate Change and Adaptive Design" emerged as two of the dominant research themes in terms of frequency from 2018 to 2021 (Figure 8).

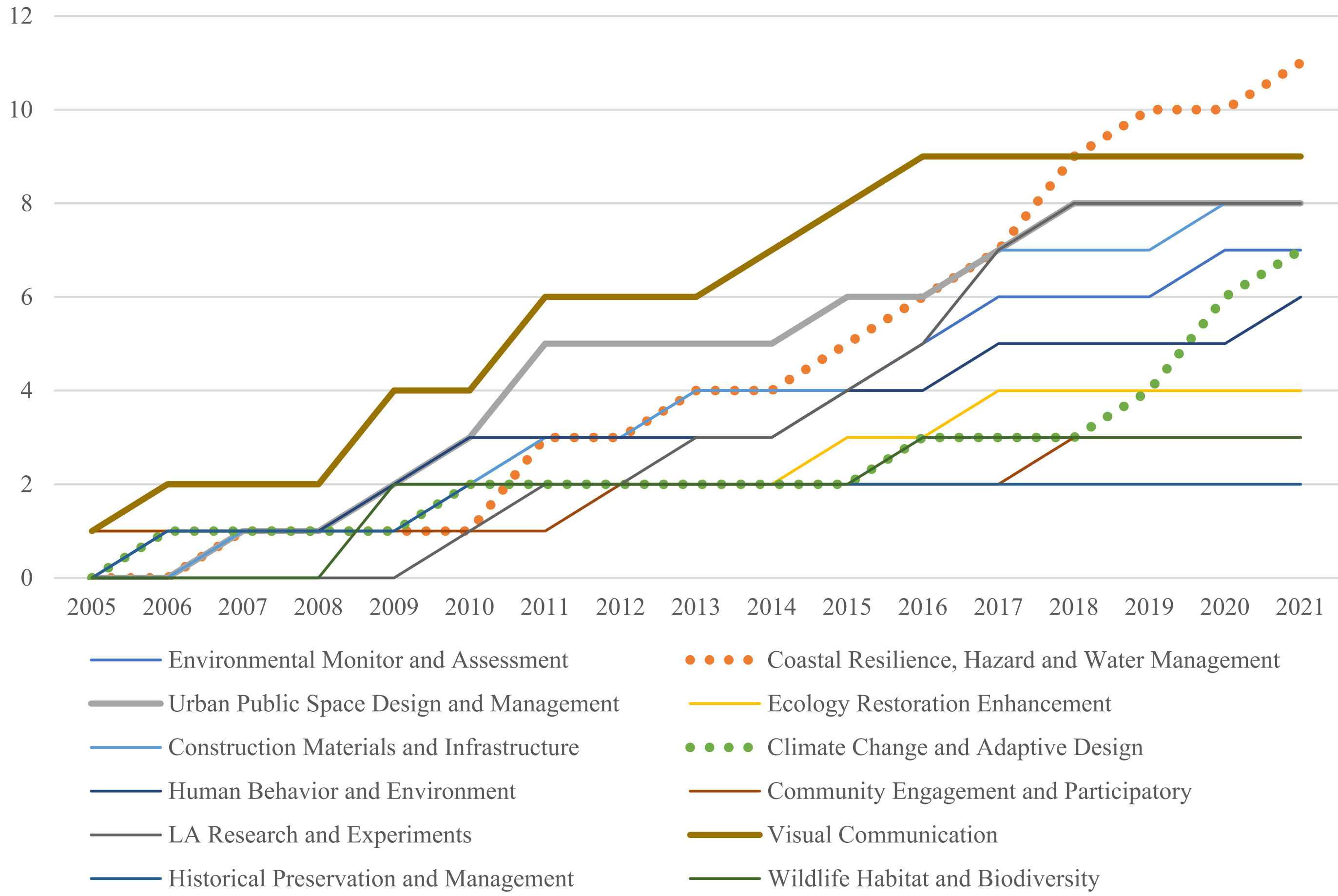

Figure 8. Archival research—findings: yearly patterns of research themes in the professional projects (2005–2021).

To determine trends in student projects, we found through frequency analysis that "Visual Communication" and "Urban Public Space Design and Management" were two of the dominant research themes from 2005 to 2018. "Coastal Resilience, Hazard and Water Management", "Ecological Restoration and Enhancement" and "Climate Change and Adaptive Design" emerged as three of the dominant research themes in terms of frequency from 2018 to 2021 (Figure 9).

Table 5. Archival research—analysis and frequency: research themes.

Research Themes	Freq.	LPE	HCT	HER	UD	SS	DEP	LDI	LP
1 Construction Materials and Infrastructure	30				x	x	x	x	x
2 Coastal Resilience, Hazard and Water Management	25	x				x		x	x
3 Visual Communication	18	x					x	x	
4 Urban Public Space Design and Management	18	x			x	x		x	
5 Environmental Monitor and Assessment	15	x			x	x		x	x
6 Human Behavior and Environment	14		x	x		x		x	
7 Community Engagement and Participatory	12			x	x	x		x	
8 Ecology Restoration Enhancement	10	x						x	x
9 Climate Change and Adaptive Design	10	x			x	x		x	x
10 LA Research and Experiments	8					x	x	x	
11 Wildlife Habitat and Biodiversity	8					x		x	
12 Historical Preservation and Management	5		x				x		

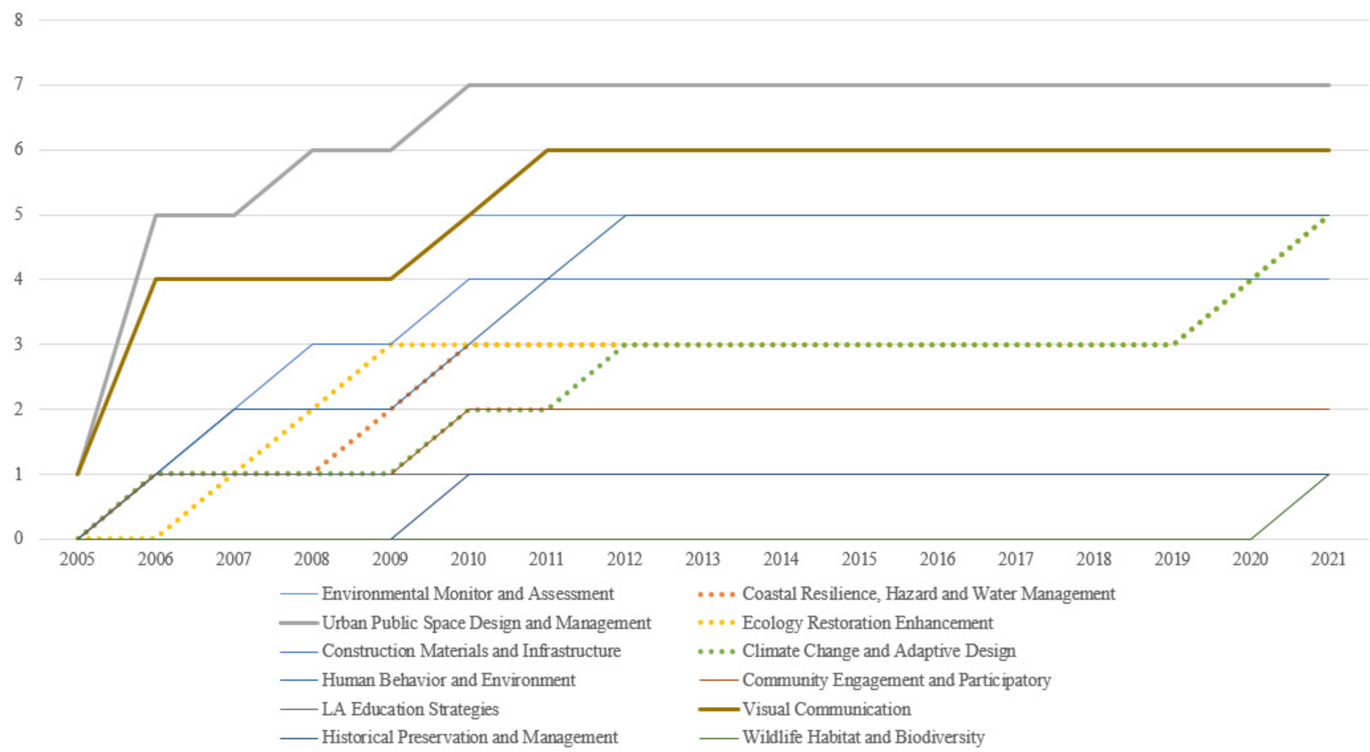

Figure 9. Archival research—findings: yearly patterns of research themes in the student projects (2005–2021).

3.2.3. RTD Categories and Trends of Digital Tools and Technology Intersecting with TLA

Based on the analysis of the primary data generated through Archival Research, seven categories were identified according to the CELA research track in 2022 [12] (Table 6).

Table 6. Archival research—findings: categories of digital tools and technology for TLA.

Research Themes	Freq.	LPE	HCT	HER	UD	SS	DEP	LDI	LP
1 Geographic Information System (GIS)	151	x	x	x	x			x	x
2 3D Modelling	60							x	x
3 Photography-Based Digital Visualization	47	x	x	x	x		x	x	
4 Statistical Modeling	41		x		x			x	x
5 Remote Sensing	29		x						
6 Virtual Reality	24						x		
7 Mobile Technologies	23						x		
8 Computational Analysis and Evaluation	21	x		x				x	x
9 Global Positioning System (GPS), Google Earth	16	x	x						
10 Web-based Interactive Map	15	x		x	x				
11 Crowdsourcing	14							x	
12 Video, Audio and Visual Technology	12	x		x			x		
13 Physical Sensors	12					x			x
14 Web-based App	10				x		x		x
15 Social Media Data Mining Processes	10				x			x	
16 Parametric and Computational Algorithms	5							x	

From 2005 to 2018, the frequencies of the "GIS" and "Digital Representation" categories of digital tools and technology appeared to dominate both student and professional projects. From 2018 to 2021, the frequencies of the "Interactive Technology" and "Digital Simulation" categories appeared to dominate both the student and professional projects (Figures 10 and 11).

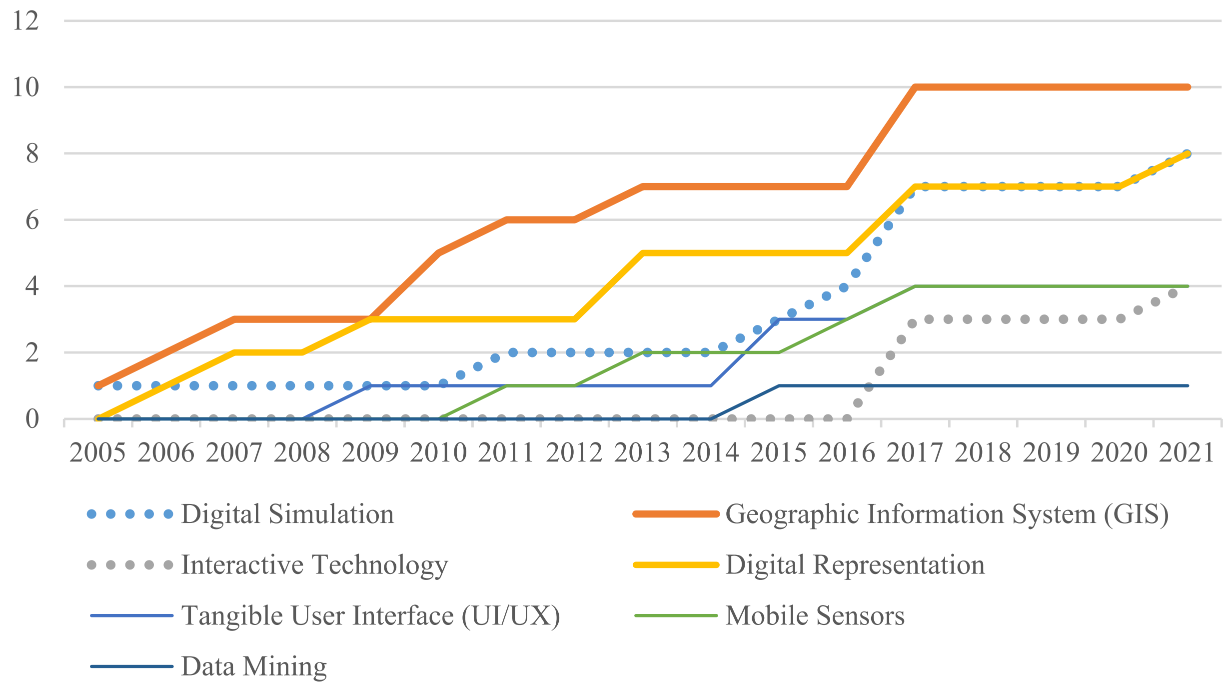

Figure 10. Archival research—findings: annual change for categories of digital tools and technology for the professional projects (2005–2021).

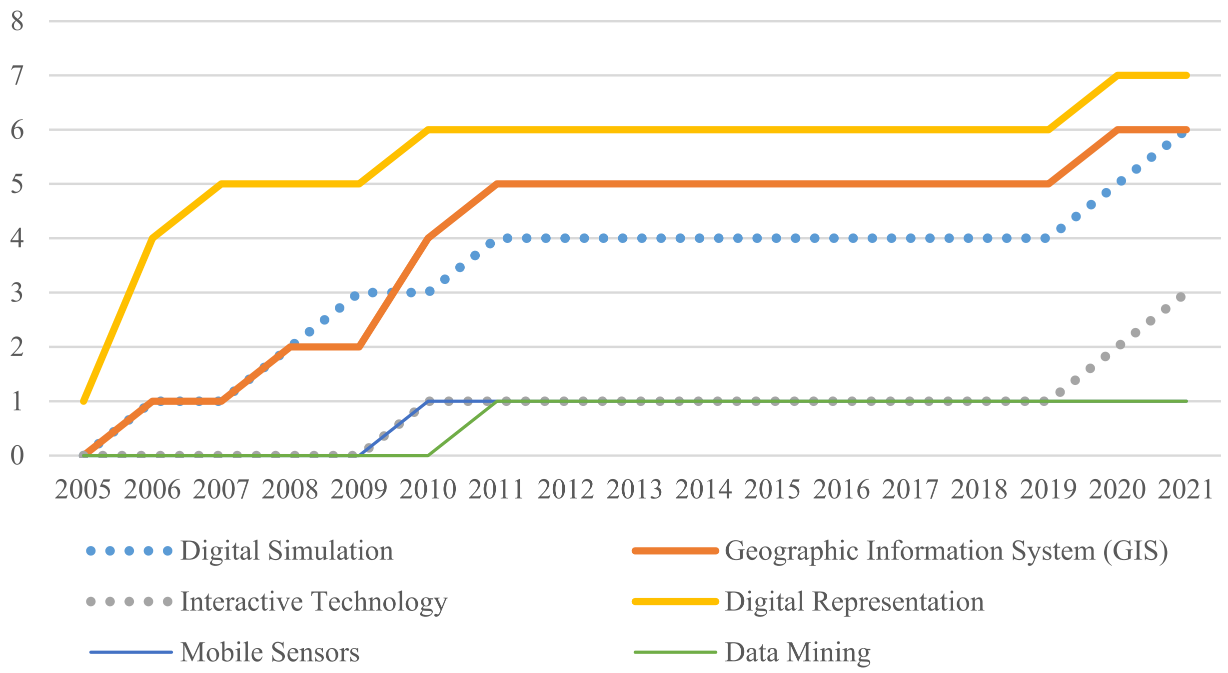

Figure 11. Archival research—findings: annual change for categories of digital tools and technology for the student projects (2005–2021).

According to the analysis, 43 projects (18 student awards and 25 professional awards) appear to represent TLA knowledge. Based on the above analysis, the findings are summarized below (Table 7).

Table 7. Archival research—summary of findings.

Trends	2005–2018	2018–2021
Dominant landscape core domains (student and professional projects)	• Landscape Design and Implementation and Landscape Planning and Ecology	
Dominant research themes (student and professional projects)	• Visual Communication • Urban Public Space Design and Management	• Coastal Resilience, Hazard and Water Management • Climate Change and Adaptive Design • Ecological Restoration and Enhancement (trend for student projects only)

3.3. Findings from Expert Interviews

Among the 18 experts, 11 stated their research was significantly based on the RFD, while the remaining 7 described their work as significantly based on RTD. This research was categorized into two groups (Group A—RFD and Group B—RTD) and utilized axial codes.

3.3.1. Expert Interviews Trends of the Landscape Core Domains Intersecting with TLA

Finding 1: Research themes intersected across different landscape core domains. In the code analysis, Group A and Group B experts pointed out different core domains incorporating similar research themes and topics. Their intersection provides ways to understand the trends for TLA.

Finding 2: TLA should be considered one of the landscape core domains. In the analysis of responses from both Group A and Group B, TLA should be considered one of the landscape core domains. In the responses, "Technology" was shown to be integral to the landscape architecture discipline. For example, experts noted that technology in architecture refers to fields like structure engineering, plumbing design, and mechanical engineering. These were the exclusive technologies for architecture. However, landscape architecture appears to offer no definition of its exclusive core technology. The concept of TLA has the potential to determine the technology used exclusively in the landscape architecture discipline. Hence, there is a need to designate TLA as one of the core domains and expand upon landscape architectural knowledge.

3.3.2. Expert Interviews—Trends of the Research Themes Intersecting with TLA

"Climate Change and Mitigation" was a trend in the research based on both RFD and RTD, and contributed to TLA. The experts from both Group A and Group B indicated a trend whereby current research based on the RFD and RTD approaches was focused on environmental issues such as climate actions, sustainability, and ecological planning. The responses noted that landscape discipline was helping to realize a carbon-neutral future in the built environment. For example, the practitioners planned and designed dense, walkable communities that reduced emissions from transportation and sprawl.

For site-scale research based on RTD, the experts' responses indicated landscape architecture's contribution to the built environment regarding energy and carbon efficiencies with strategies such as green roofs, water-efficient design, and the use of sustainable materials and construction practices. For regional-scale research based on RFD, the landscape experts discussed defense and expanded their knowledge on carbon-sequestering landscapes such as forests, wetlands, and grasslands, which help to draw down atmospheric carbon dioxide. These can be interpreted as community-oriented strategies whereby communities are enabled to better adapt to climate change and improve their resilience.

3.3.3. Expert Interviews—Categories and Trends of Digital Tools and Technology to TLA

Finding 1: Clarification between digital tools and technology and TLA. In the code analysis, both Group A and Group B responded that digital tools and technology and TLA were different. The experts' responses indicated that digital tools and technology evolved in three stages. In the first stage, digital tools and technology was a digital simulation toolkit focused on visual communication, such as Adobe products and AutoCAD by Autodesk. In the second stage, digital tools and technology represented a digital analytics tool that focused on simulation and modeling research, such as GIS, Landscape Information Model (LIM), Building Information Model (BIM), Stormwater Management Model (SWMM), and Grasshopper. These tools also inform data-driven landscape design. The third stage comprised a digital data communication toolkit used to request data or to send a result of the action back to the user, such as Augmented Reality (AR), Virtual Reality (VR), and An Unmanned Vehicle (UAV). In addition, the experts identified that all of this technology was from other disciplines, not landscape architecture. These digital tools and technologies were described as tools that helped research and could be interpreted as contributions to TLA, like the Land F/X software program. The technical product may be a digital-based application, a method or a process. It appears that landscape research lacks the use of 21st-century technology. This may imply a "blurring" of the core of landscape and its boundary with allied disciplines. The evolution of digital tools and technology appears to have expanded the TLA. Some digital-based TLA appears to be a part of digital tools and technology. However, digital tools and technology from other disciplines are not defined as TLA.

Finding 2: The trend of incorporating "Interactive Technology" based on RTD and RFD contributes to TLA. The codes in the analysis indicate the experts' responses to applied RTD and RFD, representing a growing preference for "Interactive Technology" such as AR, VR, and wearable devices in landscape research. The analysis of the experts' responses illustrates that digital analog software such as GIS, Grasshopper, and Rhino were the dominant forms of technology utilized in landscape research 8–10 years ago. Within the last 5–8 years, the experts' responses indicate that more scholars tend to use interactive equipment to explore the human perception of the built environment. For example, one expert cited a study that generated a framework to use spontaneous invasive plants in reconstructing the landscape of contaminated local sites through the use of interactive equipment and analyses of the plants' ecological performance. Table 8 summaries the findings and compare the differences between RFD approach and RTD approach.

Table 8. Expert interviews—summary of findings.

	RFD Approach	RTD Approach
Relationship between Research Themes and Associated Topics with TLA	Finding 1: Climate change and mitigation are trends in research based on both RFD and RTD, and contribute to TLA.	
Relationship Between Landscape Core Domains and TLA	Finding 1: Research themes intersected different landscape core domains.	
	Finding 2: TLA should be considered as one of landscape core domains.	
Relationship Between Digital Tools and Technology and TLA	Finding 1: Clarification between digital tools and technology and TLA.	
	Finding 2: There is a trend of using "Interactive Technology" based on RTD and RFD approaches to contribute to TLA.	

4. Discussion

This chapter involves interpreting the result of findings discussed in Sections 3.1–3.3, which concerned the (1) relationship between TLA, the core domains of landscape architecture, digital tools and technology, and research themes, and the (2) conceptualization of TLA in the 21st century.

4.1. Relationship between TLA, the Core Domains of Landscape Architecture, Digital Tools and Technology, and Research Themes

4.1.1. Interrelationship of Landscape Core Domains within the Context of TLA

One key finding of the analysis of the interviewees' responses indicates that TLA should be considered as its own landscape core domain. The experts stated that TLA supports the development of other core domains. Additionally, digital tools and technology have been designated as a landscape core domain. However, digital tools and technology from other disciplines (DTT-od) should not be considered part of the landscape core domain. The analysis of the interviewees' responses indicates that digital tools and technology can be considered one of the landscape core domains. This analysis indicates the experts' preference for TLA, essentially disregarding DTT-od and promoting TLA as its replacement. This signifies a growing recognition that existing, externally developed technologies may not fully address the unique challenges and opportunities faced by landscape professionals. By fostering a deeper understanding of technological capabilities, landscape professionals can seamlessly integrate technology into the design process, leading to groundbreaking solutions. Examples include designing smart green spaces that dynamically adapt to environmental conditions or utilizing virtual reality to create immersive experiences within planned environments. The landscape architecture field grapples with issues such as climate change, urbanization, and resource scarcity. A TLA focus could equip professionals with the tools to tackle these challenges head-on. For instance, developing bioremediation techniques or designing sustainable infrastructure solutions might necessitate expertise in specific technological areas.

In addition, to interpret the shift in the intersection of TLA with other landscape core domains, the research findings illustrate the impacts of Research for Development (RFD) and Research through Design (RTD) on TLA over different periods. From 2013 to 2018, RFD helped TLA gain prominence through its integration with "Landscape Ecology and Planning" and "Landscape Performance", highlighting a focus on ecological systems and the effectiveness of landscape interventions. The trend shifted from 2018 to 2021, with TLA increasingly intersecting with "Sustainability", reflecting a global shift towards sustainable development practices. Simultaneously, from 2005 to 2021, RTD influenced TLA predominantly in "Landscape Design and Implementation" and "Landscape Planning and Ecology", indicating a strong emphasis on practical, ecologically informed landscape solutions. The shift in research focus over time reflects broader trends in landscape architecture towards more sustainable and ecologically integrated practices. The prominence of ecology and sustainability in recent years highlights the profession's response to global environmental challenges, such as climate change and biodiversity loss, emphasizing the role of landscape architects in creating resilient and sustainable environments.

4.1.2. Interrelationship of Research Themes within the Context of TLA

To interpret the findings from the research across three different datasets—secondary research, archival research, and expert interviews—a structured approach can be helpful. Both Research through Design (RTD) and Research from Design (RFD) have significantly contributed to the growth of TLA across multiple themes. Prior to 2018, RTD was primarily influential in themes like "Visual Communication" and "Urban Public Space Design and Management", while RFD was dominant in "Environmental Monitoring and Assessment", "Coastal Resilience, Hazard and Water Management", and "Urban Public Space Design and Management". From 2018 to 2021, both RTD and RFD played dominant roles in "Ecological Restoration and Enhancement" and "Climate Change and Adaptive Design". The emergence of "climate actions" as a research trend since 2018 indicates a shared direction in both RTD and RFD approaches, emphasizing their importance in addressing contemporary issues like climate change.

A key difference observed is that RTD, unlike RFD, continued to strongly influence the theme of "Coastal Resilience, Hazard and Water Management" even after 2018. RTD-based research tends to focus more on practical applications that expand knowledge in TLA through solutions like green roofs and walls, which are direct interventions for climate mitigation and habitat creation. In contrast, RFD-based research has expanded the knowledge base by developing ecological strategies, urban forestry policies, wetlands management, and human-centered design approaches, suggesting a more policy- and strategy-oriented approach compared to the more direct design interventions of RTD.

The findings suggest that RTD is more closely aligned with direct design and physical interventions in landscape architecture, contributing both aesthetically and functionally to urban and environmental challenges. RFD, however, leans towards a broader strategic and policy-making role, influencing landscape architecture through research that informs guidelines, policies, and broader management strategies. The convergence of RTD and RFD in newer research themes like "Ecological Restoration and Enhancement" and "Climate Change and Adaptive Design" post-2018 reflects a collaborative and integrated approach towards solving modern challenges through both design and strategic research. The insights from expert interviews indicate a recognition and validation of these varied approaches, emphasizing the need for a diverse yet cohesive research strategy within TLA to effectively address emerging global concerns such as climate change. This exposes a knowledge gap—traditional experience may not suffice. These topics necessitate a more comprehensive TLA. Ecological strategies require environmental modeling expertise. Urban forestry/wetland policies demand knowledge of urban planning frameworks. Human-centered design necessitates a familiarity with UX research. A broader TLA interpretation is needed, encompassing skills like parametric design software, 3D modeling, and UX research, alongside traditional design. This shift brings opportunities and challenges. Landscape architecture can become key in environmental issues and human well-being design. However, overcoming resource limitations and refining the definition of TLA are crucial for the successful navigation of this paradigm shift.

4.1.3. Interrelationship of Digital Tools and Technology within the Context of TLA

The differentiation between digital tools and technology and TLA is pivotal for advancing the field. Digital tools and technology encompass a wide array, such as Geographic Information Systems (GIS), Digital Simulation, Interactive Technology, and Remote Control Technology. The application of these tools has evolved significantly, marking the transition from simple visualization to complex interactive design processes.

Evolution of digital tools and technology in landscape architecture:

1. Visualization and communication—Initially, digital tools and technology were used primarily for digital simulations that focused on visualizing and communicating landscape designs;
2. Modeling and simulation—Over time, digital tools and technology expanded to include sophisticated modeling and simulation tools, enhancing data-driven design processes;
3. Interactivity and data generation—The latest developments in digital tools and technology incorporate interactive technologies such as AR, VR, and UAVs. These tools are pivotal for generating new data and fostering original research, representing a shift towards dynamic, user-centric design experiences.

TLA, in contrast, refers to the application of these digital tools within landscape architecture, aiming to foster innovative design practices and research methodologies. TLA encompasses a methodological and conceptual shift towards technology-driven design and research, transforming traditional landscape architecture practices. The evolving role of digital tools and technology in landscape architecture signifies a significant shift. Once primarily a tool for visual communication, digital tools and technology is expanding its functionalities to encompass simulation, modeling research, data-driven design, and interactive data exploration via AR/VR/UAV technologies. This empowers landscape architects to not only analyze data, but also generate their own through these interactive toolkits, fostering a deeper understanding of design challenges and contributing to the growing body of knowledge in TLA. Furthermore, digital tools and technological transformation open doors for collaboration with other disciplines, and potentially lead to more user-centric design outcomes. However, this evolution also necessitates the development of new skillsets in data analysis, as well as modeling techniques, and interactive technologies for landscape architects. In general, the field needs to be aware that digital tools and technology, as well as TLA, may generate unsolved conceptual and value conflicts, which need to be resolved in a timely fashion in the process.

To further interpret the trends of intersection of digital tools and technology with TLA within landscape research, the findings indicate that research using the Research through Design (RTD) approach identified Geographic Information Systems (GIS) and Digital Representation as the primary digital tools used until 2018. After this, there was a noticeable shift towards employing Digital Simulation and Interactive Technology. Similarly, the research based on Research for Design (RFD) findings confirmed a strong emphasis on GIS and Digital Simulation from 2013 to 2018. Post-2018, there was a significant increase in the use of "Remote Control Technology" and "Interactive Technology", indicating a trend towards more advanced digital tools and highlighting the ongoing development of knowledge within TLA.

4.2. Conceptualizations of TLA in the 21st Century

The expert interviews reveal a need to clarify, define and potentially categorize TLA. This next section suggests ways to clarify TLA. Based on the analysis of the three datasets, TLA is framed in terms of categories and specializations. As an interpretive approach, several terminologies were used to understand TLA. Through analysis of three datasets, several specializations emerged: "Method", "Approach", "Guideline", "Strategy", "Framework", and "Software". However, most of these terms appeared to yield similar interpretations, and were difficult to distinguish. This necessitates future analysis and a deeper understanding, which can be achieved by reviewing the literature and the experts' responses.

According to the code analysis of interviewees' responses, "Method" is a particular design or research process. In other words, it is the way in which something is done. In this sense, it is similar to "Approach", which is the way something is proposed. "Approaches" have to be decided before selecting the "Method". "Approaches" and "Methods" are approaches that deal with general philosophies of implementation [35]. However, a "Method" practically implements an "Approach".

In the code analysis of interviewees' responses, instructional TLA is included, which includes "Guideline" and "Strategy". "Strategy" refers to a plan of action designed to achieve an aim [36]. Based on that, a "Guideline" establishes the LA design and research criteria. It could be a new standard, metric, or principle that could affect design considerations that designers apply with discretion.

The code analysis from interviewees' responses shows that TLA is expected to be a technical product/application. The responses note that it could be the "Framework" of the application and the "Software". Pragmatically, a "Framework" is a platform for developing specific software and applications. It supports logical, functional, computational, interaction, and application aspects [37]. "Software" is a set of instructions, data, or programs based on the implementation of a "Framework", and used to operate computers and execute specific tasks [38].

Based on the analysis of the above terms, this research has identified three specializations of TLA:

- Instruction (Strategy and Guideline);
- Process (Approach and Method);
- Application (Framework and Software).

To explain the three categories, "Process" describes "what" is done, and "Instruction" describes "how" it is done [39]. "Application" is a digital program that computers can use directly. Figure 12 illustrates their relationships.

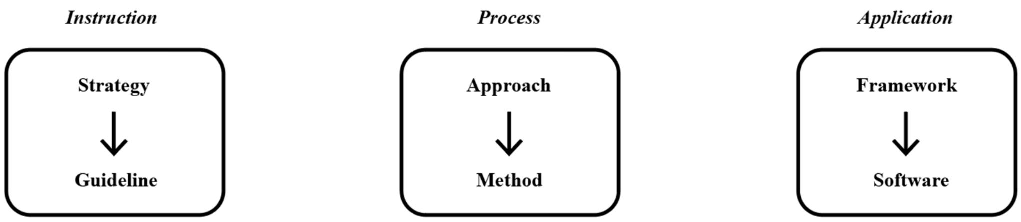

Figure 12. Relationships of categories and specializations of TLA in the 21st century.

In addition, according to the analysis of the data generated from Archival Research and Secondary Research, this research found that both RTD and RFD contribute to "Approach" and "Method" as two dominant specializations of TLA. In addition, these two specializations of TLA appeared to increase more rapidly than others based on the patterns of annual change and frequency prior to 2018. From 2018 to 2021, both the patterns of annual change and frequency and the analysis of codes based on interviewees' responses indicated a trend towards utilizing TLA as an "Application". Overall, the analysis of the experts' responses indicates that scholars became increasingly aware that TLA had the potential to become a technical product for future landscape research. Figure 13 indicates the structure of TLA in the 21st century.

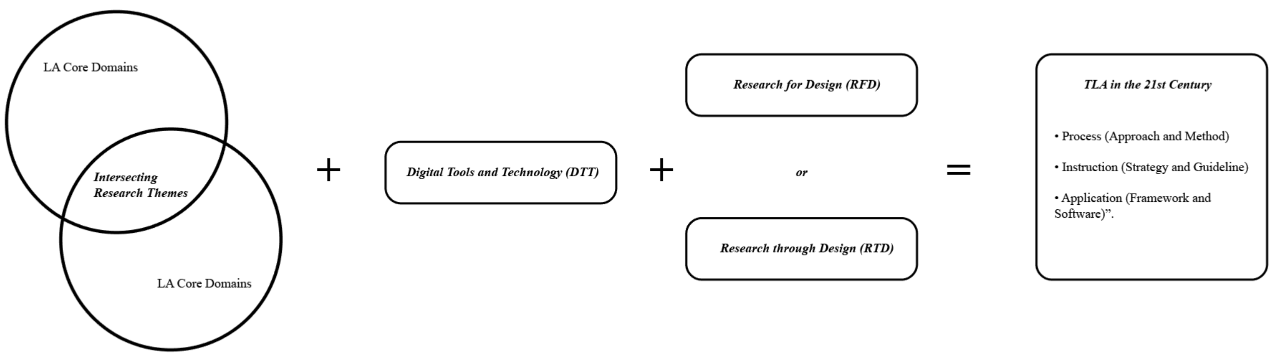

Figure 13. Structure of TLA in the 21st century.

4.3. Impact on Future Landscape Research

The proposed conceptualization could potentially impact on three future key areas of landscape architecture: "Digital Practice", "Design Computation", and "Design Representation".

(1) Digital Practice—It is crucial to integrate TLA as a data source and communication medium. However, the research suggests that TLA's impact on the design process might be less significant in areas like sustainability and human-environment relationships. Here, the focus should be on equipping students with a stronger understanding of TLA terminology and mechanisms through relevant coursework. The core objective should be expanding the scope of TLA knowledge. The scholarships should also encourage leveraging TLA to generate practical knowledge for landscape practice;
(2) Design Computation—Design computation aims to optimize design efficiency and accuracy through TLA. The research suggests that certain design tasks, especially in landscape planning and ecology, and potentially in design and implementation, could be automated with new software, platforms, and methods. The focus of TLA education in this aspect should equip students with the necessary software and platform proficiency;
(3) Design Representation—While the study found the limited integration of TLA in RTD and RFD, the value of TLA in communicating final design solutions to an audience with various backgrounds is undeniable. The integration process is likely smoother, as it requires fewer theoretical debates than other areas. Therefore, we should enhance the training on visual representation, integrating TLA across diverse landscape architecture courses.

5. Conclusions

The objective of this study is to examine the roles and conceptual frameworks within landscape research, interpreting trends and relationships across landscape core domains, research themes, digital tools and technologies and TLA. This exploration was conducted through Archival Research, Secondary Analysis, and expert interviews. The findings reveal that digital tools and technology categories have transitioned from simple digital simulations to complex interactive technologies that have played a crucial role in environmental design and planning over recent years. This shift is marked by the increased utilization of Geographic Information Systems (GIS), Digital Simulation, and newer technologies such as Remote Control and Interactive Technologies, which are now pivotal in fostering innovative, data-driven design solutions. Further, TLA has emerged as a pivotal domain within landscape research, markedly enhancing traditional practices and spearheading the development of sophisticated methodologies by integrating digital tools and technologies. Notably, there is a pronounced trend towards utilizing digital tools and technology in aspects ranging from communication and visualization to interactive technology. This integration substantially intersects with key research themes, such as landscape planning, ecology, and sustainable urban design—all vital for tackling issues like ecological resilience, climate change and enhanced human-environment interactions.

The relationship between digital tools and technology categories and TLA within landscape architecture reveals a dynamic and evolving connection. Digital tools and technology have been instrumental in expanding the research and practical capabilities of landscape architecture, pushing the field towards more data-driven and interactive approaches, and enabling landscape architects to undertake complex planning and design tasks with greater precision and effectiveness. On the other hand, TLA represents a broader conceptualization of technology within landscape architecture, embodying the integration of digital tools into the core practices of the field. It suggests a shift towards a more integrated approach, whereby technology is not just a tool but a fundamental aspect of landscape architectural practice. TLA includes the application of digital tools and technology in specific projects and the broader methodological shifts these tools enable, such as improved environmental modeling, user interaction through immersive technologies, and enhanced data analysis capabilities.

Furthermore, the study underscores the significance of categorization and specialization within TLA, delineating three main areas: "Instruction" (encompassing strategies and guidelines), "Process" (covering approaches and methods), and "Application" (involving frameworks and software). The research identifies two major research types—RTD and RFD—that leverage digital tools and technologies, intersecting with various research themes linked to different core domains to effectively cultivate TLA.

6. Limitation

In the data collection process, particularly during the archival research phase, while ASLA provides a comprehensive collection of award-winning projects with detailed descriptions that facilitate thorough analysis, it predominantly reflects trends and practices within the United States. Recognizing the need for a more diverse understanding of landscape architecture practices globally, other significant sources were considered, including awards from the International Federation of Landscape Architects (IFLA) and the European Foundation for Landscape Architecture (EFLA). However, these additional sources often lacked sufficient project descriptions, which are crucial for an in-depth analysis. The limited availability of detailed project information from these international sources constrained the ability to incorporate a wider perspective into our research. Consequently, while this study continues to rely on the ASLA Awards to yield a substantive dataset, we acknowledge this reliance as a limitation. This restriction highlights the challenge of accessing detailed, comparable data across different global landscape architecture awards, and underscores the necessity for future research to explore more varied sources, potentially encouraging international bodies to standardize the documentation of award-winning projects to support academic investigation.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Datasets of Secondary Research and Archival Research

Due to the length of Appendix A, we have uploaded it to the google sheet. The link is: https://docs.google.com/spreadsheets/d/14ddDEtjNZ7lHwzbx_G_sVEhgsmhJK6dekoyhtgDfuRs/edit?usp=sharing (accessed on 1 May 2023)

Secondary Research:

* A = Journal of Digital Landscape Architecture; B = Journal of Landscape Architecture; C = Landscape Research Record; D = Landscape Research; E = Landscape Review; F = Landscape Journal.

Archival Research:

G = ASLA Professional Award-Winning Projects; H = ASLA Student Award-Winning Projects.

* Red text refers to the articles or projects that do not generate specific TLA knowledge.

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