


Article

Examine an Intelligence Education Framework of Landscape Architecture (EFLA) Based on Network Model of Technology in Landscape Architecture (NMTLA)

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Abstract: The discipline of Landscape Architecture (LA) is currently expanding its disciplinary boundary. The supporting Technology in LA (TLA) is always evolving and optimized to solve environmental problems. Considering the uncertain classification of the current LA knowledge for education and the importance of technology in LA education, a refined education framework of LA is needed. This research first established a Network Model of Technology in LA (NMTLA) using Network Analysis (NA) and expert interviews. Then, this research proposed an Education Framework of LA (EFLA) based on the NMTLA. To build the NMTLA, this research identified 23 key categories of TLA through content analysis of secondary research. Then, the expert interview and network theory were used to analyze and visualize the relationships among the categories. By examining the degree centrality, closeness centrality, and betweenness centrality of different TLA, this study developed an EFLA which summarizes the twenty-three categories of TLA into four domains: core techniques, applied technologies, integrated technologies, and specific technologies. This study also proposes a series of suggestions for how to apply different categories of TLA in today's and future LA education. The proposed NMTLA and EFLA in this research can contribute to the development of future LA higher education. They also can potentially address the Sustainable Development Goals (SDGs) in LA education and industry. However, the scope of this study is currently limited to LA education in the USA, which could be expanded to include a worldwide perspective in future research. To enhance the validity of the conclusions, a larger sample size for interviews should be employed in further studies.

Keywords: technology in landscape architecture (TLA); landscape architecture (LA) education; interdisciplinary collaboration; network analysis (NA); SDGs



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1. Introduction

The discipline of LA is currently expanding its disciplinary boundary. Scholars and practitioners in LA discipline nowadays are required to take more responsibility for sustainable development and explore ways to tackle complex environmental problems in more synthesized ways. The supporting TLA is always evolving and optimized with the advancement of technologies, and its significance in LA practice and education cannot be ignored. Meanwhile, contemporary LA education tends to focus more on cultivating future LA talents with comprehensive and interdisciplinary skills [1]. To satisfy the requirements of future LA education, clarifying the theoretical framework and categorizing the current TLA is crucial. In terms of SDGs, sustainable design and planning are always among the most important tasks of LA education. Achieving sustainable development of both natural

and artificial living environments using landscape design is regarded as one of the key responsibilities of LA higher education. Therefore, clarifying the categories of TLA will benefit the SDGs of LA education as well.

There are various ways to categorize the current TLA in LA education, but many of them fail to examine the relationship between different categories comprehensively. Therefore, to refine the uncertain categorizations of TLA, this research aims to first establish an NMTLA using NA, expert interviews, and content analysis. Then, based on the findings drawn from the NMTLA, this research will develop an EFLA to explain, predict, and guide the expansion of discipline boundaries of LA. At the same time, this EFLA has the potential to offer solutions to the critical problems faced by LA education today and contribute to the advancement and development of future LA education.

1.1. Expansion of LA's Disciplinary Boundary

LA originated from Landscape Gardens. Versailles in Paris, the Taj Mahal in India, and Humble Administrator's Garden in China, for instance, are all categorized under "landscape garden" as a form of art [2]. While these examples are all from after the 15th century, the concept of landscape gardening is much older and has been an important part of many cultures throughout history. The aesthetic styles and scales of historic gardens were influenced by designers' efforts to turn landscapes that existed in people's fantasy into reality. By then, the field was greatly affected by local culture, religions, social ethos, and art movements. The design of the garden placed great emphasis on social status, religious tradition, personal cultivation, and taste.

These characteristics of landscape gardens shifted after entering the 19th century, successively due to the prevalence of modernism concept of "form and function" and post-modernism's focus on dialectics, individual expression, and personal cultural emotional value [3]. Since the discipline of LA was founded at Harvard University in 1900, landscape architects and scholars have been arguing whether LA belongs to science or art, given the coexistence of science, functional practicality, and artistic aspects in the design process. Via both rational and emotional perspectives, the subject is carrying the responsibility of opening dialogues and building a coexistence environment for humans and nature, individual and collective. Norman Newton defined LA in the book "Design on the Land" as "an art or science, mediating between nature and culture" [4]. More recently, as growing attention and exploration are given to social ecosystems, more and more scholars tend to consider LA to be an interdisciplinary subject. In 2012–2013, the 36th edition of Harvard Design Magazine was titled LA's Core; the collected articles aimed to explain the core of LA. Each article claimed expertise in a facet of LA, such as "Immanent Landscape", "Landscape Infrastructure", "Beyond Sustainable Landscapes", "Digital Landscape Now", "Landscape Navigator", etc. Such one-sided articles cannot explain the core of the landscape.

Apparently to see that during the past few decades, many ideas, methodologies, and technologies from various disciplines, such as ecology, environmental protection, agriculture, food science, computer science, and so on, have been employed as references throughout the practice of LA [5,6]. The increasing frequency of transdisciplinary communication leads to the appearance of many new terms, for example, landscape urbanism, ecological urbanism, sustainable design, etc. These new ideas do expand the boundary of LA and change what had previously been the traditional responsibility of practitioners. Nevertheless, the rise of these new terms is more of a grouping and simple overlapping of existing knowledge from LA and those from other fields. Hence, the field of LA needs to incorporate them into new creative and intelligent theories that integrate aesthetic design principles and scientific technologies [7]. In this way, people would gain a deeper understanding of what is meant and encompassed by the term LA in the 21st century.

It is also worth noting that this development of LA is what separates it from sister disciplines of study such as Urban Planning, Urban Design, and Architecture. The latter disciplines have different scopes in terms of the environment under their consideration and how much innovation and management are required. Urban Planning and Design takes care

of the urban and built environment in general to determine the best practices to promote sustainability, equity, and economic development through the design and management of urban systems and environments. Architecture is the design and construction of buildings and other physical structures. Architects work to create structures that are functional, aesthetically pleasing, and meet the needs of their occupants. Contrary to these disciplines, Landscape architects use their expertise in ecology, horticulture, and design to create functional and aesthetically pleasing outdoor environments that promote sustainability and enhance the quality of life for users.

1.2. *Blurry Definition of Technology in LA (TLA)*

The application of technology branches out in various disciplines; thus, technologies as tools gain further specialized developments and become expertise-led professional techniques [8]. Imaging has been used by various disciplines, such as art, biology, medical science, astronomy, and geology, due to its ability to reproduce and visualize real objects for different purposes. The needs and requirements of each field determine the evolution of imaging technology. For example, medical diagnosis, photography, and geological investigation all use optical and acoustic survey instruments, but they result in different imaging technologies due to factors such as the disease being tested, patient side effects, commercial value, aesthetic perspectives, and the clear presentation of soil types for identification. Each technology has its own unique parameters and operating rules.

For LA, the definition of TLA in current literature, most of which originates from the research about the classification of landscape design topics, remains a relatively huge difference. Some scholars believe that computer application software, such as AutoCAD, BIM, and geographic information system (GIS), is the core of TLA. Some scholars also believe that TLA is about construction details, plant design, and other construction details; other scholars argue that LA technology is the combination of technology and landscape design in the field of science [9–14]. A shared situation of these perspectives is that many of these “technologies” are borrowed directly from other academic fields, most of which are only viewed as a visualization tool to convey design concepts. LA practitioners find it challenging to keep up to date with and take full advantage of the potential of constantly upgraded modern technology directly to update subject knowledge [15]. Additionally, the knowledge renewal within the LA discipline has a relatively high dependence on innovation in other fields for the application of science and technology.

If no specialized transformation occurs while employing technology and theory from other subjects, LA will possibly lose its unique voice and irreplaceable position in combining scientific environment planning and human environmental design [16]. On the other hand, exploring scientific technology does not imply a reduction in the impact of aesthetic representation. In contrast, technology will make those representations more meaningful. The missing parts that connect “technique” and “technology” in landscape design and the vague boundary of LA discipline confuse practitioners from the discipline themselves, hinder the future development of landscape research, and further influence the effectiveness of design practice and education. Some questions still remain to be answered: “What is the core of LA?”; “What technologies belong to LA?”; and “What are the boundaries of LA?” Hence, it’s vital for the discipline to clarify “technology” with those has been transformed into “technique of landscape design”, meanwhile organizing their relationships with LA and reflecting current progress and effectiveness of knowledge transformation to define and expand discipline boundaries [17–19].

According to several studies on research trends and the theoretical development of LA, digital tools and certain techniques emerged as trends and were perceived as major ways to categorize TLA [9–14]. Compared to construction technologies in LA, nowadays, professional tools in LA are more related to digital tools. (Table 1). The table shows that most scholars combine digital tools and technology and visualized expression with TLA. Part of scholars regards landscape design technologies as the implementation and details of design. The LA Education Conference (CELA) released 14 hot topics of landscape

design in 2022, which “Geo-spatial and Digital Analytics”, “Climate Crisis and Ecological Restoration”, and “Landscape Design and Implementation” involve TLA relatively conform to the classification of “TLA” in Table 1.

Table 1. The definition of ‘TLA’ in landscape design thematic studies literature.

Author/Source	TLA Related Topics	Topic Related Terminology
Powers & Walker, (2009) [20]	Material and Construction	Vegetation/Horticulture/Innovative construction technology/Materials/practice
Gobster et al., (2010) [9]	Technology and Digital Tools	GIS/PC/Graphic/Visualization
Cushing et al., (2015) [10]	Technology and Digital Tools	Digital software/Technology/Skill
Meijerin et al., (2015) [11]	Technology and Digital Tools	Digital software/Skill/Technology
Vicenzott et al., (2016) [12]	Material and Construction	Ecological restoration/Planting
Langley et al., (2018) [13]	Technology and Digital Tools	Digital software/Technology/Skill
Newman et al., (2021) [14]	Technology and Digital Tools	Technology/Tool/Digital/GI/Environment/Software/Vocality/Reality/Geo-design/Application/Visualization/Virtual/Decision/Space/Scale/Enabling/Platform/Future/Detail/Soundscape

From the above illustrations, there are major gaps in the clarification, classification, and relationships among multiple categories of technology in LA. Thus, this study further refined categories of landscape design technology and built the relation model through the NA of technology categories with discipline technique and future research areas. Via critically reviewing the existing literature and archival materials on the development of LA, the research is also seeking to provide the foundation to identify the logic and method of building up inter-discipline knowledge by transdisciplinary communication to achieve the expansion of LA boundaries.

2. Materials and Methods

This research first collected the data by applying Secondary Research to clarify the scope and categories of TLA. The second step was to apply expert interviews [21] and NA [22] to analyze the relationships among each technology in LA, then generate EFLA Based on data analysis of NMTLA. Figure 1 can briefly show the framework of this research (Figure 1).

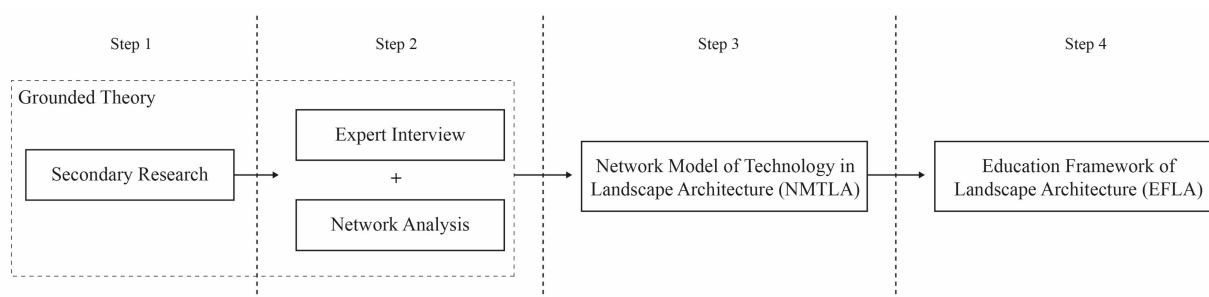


Figure 1. The analytical framework of the research.

2.1. Secondary Research

The data analysis, resolution, and comprehension of the categorization of current TLA require a multiplicity of perspectives that must dialogue, articulate, and integrate into an interdisciplinary, intelligent, and creative dynamic. Grounded Theory (GT) is a theory-building methodology from data collection developed by Glaser and Strauss in 1967 [23]. GT aims to formulate theoretical results that are derived from qualitative analysis of data. In this research, the GT is applied in the form of content analysis of Secondary Research to build the categories of TLA.

The secondary research of this study is built on the work by Powers and Walker (2009); Gobster et al. (2010); Cushing and Renata (2015); Meijering et al. (2015); Vincezotti et al. (2018)

and Newman et al. (2021) whose team explored the categorization of current TLA through a study of journal articles [9–12,14,20]. Based on their work, researchers developed preliminary categorization criteria for the current TLA. Meanwhile, this research reviewed journals that investigate TLA in LA education and industry, including *Journal of Digital LA* (2016–2021), *Landscape Research* (2015–2021), *Landscape Journal* (2013–2021), *Landscape Review* (2013–2021), *Journal of Landscape Architecture* (2013–2021), and CELA's *Landscape Research Record* (2011–2021), and Credential LA program syllabus from CELA. Researchers examined the title, keywords, and abstract of every article, then summarized the core LA knowledge of the articles. After that, the article was categorized into the relevant category based on the preliminary criteria mentioned above. If no category meets the core knowledge of the article, new categories will be generated using the method of content analysis. Through the journal review, the preliminary categorization criteria for TLA can be refined. Finally, 23 categories of TLA were developed.

2.2. Expert Interview

After developing the 23 categories of current TLA, semi-structured (open-ended) interviews with experts were adopted to further refine the categorization and study the relationship between each category; 40 experts in LA discipline were recruited to attend the interview. The qualified experts should have at least 20 years of experience in LA higher education and LA design practice. The interviewed experts in this research included faculties of many universities and landscape architects in professional design firms in the USA. Snowball sampling is adopted to recruit potential participants. Researchers contacted 15 experts based on their social network, then the 15 experts introduced this study to qualified people they know and invited them to the expert interview. Among all experts, 22 of them are male, while 18 of them are female. Their age is between 45 and 85 years old. The interviews were conducted remotely through Zoom meetings. The average duration of the interview is 25 min. Two researchers participated in the interview; one worked as an interviewer, while the other research focused on taking notes. During the interview, experts will review the 23 categories of current TLA and give their comments. In addition, they were asked to decide whether 2 categories have correlations or not using an evaluation matrix shown in Section 3.2.

2.3. Network Analysis (NA)

A comprehensive set of techniques known as NA is used to portray the relationships between examined targets and to investigate the mutual influences that result from the persistence of these relationships. In order to perform this analysis, relational data is gathered and arranged in a matrix. Actors can be represented as nodes, and their relationships can be shown as lines connecting pairs of nodes, transforming the idea of “a social network from a metaphor to a practical analytical tool that makes use of the mathematical terms from graph theory, matrix algebra, and relational algebra”. NA can be seen as a collection of approaches having a common methodological stance. By defining and measuring conventional all-purpose concepts, NA enables researchers to define empirical indicators and manage field hypotheses.

Based on the relationship within TLA generated through expert interviews, the experienced LA experts are further invited to finish a questionnaire of the relationship matrix among the sub-categories of TLA to gain the initial data for TLA Relationship Matrix. A visualization of this matrix will intuitively present the relationship, intensity, and status of influence among landscape design technologies. Subsequently, the analysis and the comparison of the degree centrality, closeness centrality, and betweenness centrality of the matrix will lead to the classification and development models of TLA.

3. Results

3.1. Categories of TLA

Based on the secondary research, this study divides contemporary TLA into three initial dimensions: “Geo-spatial and Digital Analytics”, “Landscape Design Implementation

and Construction”, and “Climate Crisis and Ecological Restoration”. These three initial aspects are subdivided by taking a literature review as the main method, supplemented by the expert interview

3.1.1. Geo-Spatial and Digital Analytics

For the initial dimension of “Geo-spatial and Digital Analytics”, nine categories (A1–A9) were identified through the research methods introduced in the previous section; 90 reviewed articles are related to the dimension of “Geo-spatial and Digital Analytics”. How they support the categorization is shown in Table 2.

Table 2. Summary of Topics of Geo-spatial and Digital Analytics from 2019 to 2021.

Geo-Spatial and Digital Analytics (A)	Subject (Sub-Category)	Source
A1	Geographical design method and GIS technology	[24–40]
A2	Landscape algorithmic design and analysis	[41–58]
A3	VR and AR in landscape design	[59–79]
A4	Information modeling (LIM and BIM) of landscape and building	[80–89]
A5	Landscape visualization and analysis	[90–98]
A6	UAV imagery and remote sensing	[99–105]
A7	Mobile devices, internet-of-things, and “smart” systems	[106–110]
A8	Social media in landscape design	[111–114]
A9	Point cloud applications in landscape design	[115–120]

3.1.2. Landscape Design Implementation and Construction

Scholars from this category argue that TLA is related to the landscape material and implementation, which have the ability to transform terrain, organize drainage, build roads and sites, reshape sites, and so on. This study finds there is little research in this area, with no record in the Landscape Research Record (CELA) in recent 10 years. However, the proposition of this category tends to be emphasized more in academic institutions and their curriculums. LA education in the USA has a long history, rich experience, and a high reputation around the world. At the same time, the research team of this study has better experience, network, and funding support in the USA’s LA discipline. Therefore, this study chose to analyze the syllabus of LA education from the top five academic institutions in the USA ranked by American Design Intelligence (DI). It is shown that the courses of TLA in these academic institutions mainly focus on Design and Implementation (Terrain, Drainage, Details, Materials, Standards, etc.) and Landscape Ecology (Vegetation, Planting design, Soil, Stormwater management, etc.) (Table 3). According to the definition and classification of “Landscape Design Implementation and Construction” by CELA, this study subdivides the dimension of “Landscape Design Implementation and Construction” into seven categories. Table 4 summarizes these technology types and the academic institutions which offer related technology courses.

Table 3. Summary of landscape design techniques courses from leading academic landscape institutions in the USA.

Academic Institution	Course	Number of Institution
University of Pennsylvania	Design Implementation (Grading, Planting Design, Construction Documents)	R1
Louisiana State University	Landscape Technology (Grading, Drainage, Detailing, Materials) Plant Materials	R2
Cornell University	Site Assembly (Construction Materials, Specifications, Cost Estimate, Construction Documentation) Creating the Urban Eden: Woody Plant Selection, Design, and Landscape Establishment	R3
The University of Georgia	Landscape Construction (Construction Details) Soil and Storm Management	R4
The Ohio State University	Ecology/Technology (Landscape Materials, Ecological Dynamics, Planting Design)	R5

Table 4. Summary of landscape design and implementation categories and academic institutions offering related courses.

Landscape Design and Implementation (B)	Subject (Sub-Category)	Number of Institutions
B1	Topographic design and earthwork	R1, R2, R3, R4, R5
B2	Planting design	R1, R2, R3, R4, R5
B3	Stormwater management and engineering	R1, R2, R3, R4, R5
B4	Landscape materials	R1, R2, R3, R4, R5
B5	Landscape construction details and management	R1, R3, R4
B6	Landscape development design and details	R1, R2, R3, R4, R5
B7	Landscape paving design	R1, R2, R3, R4

3.1.3. Climate Crisis and Ecological Restoration

Through the secondary research and expert interview explained in the previous section, the dimension of “Climate Crisis and Ecological Restoration” can be divided into seven categories (Table 5). Table 5 also shows some typical articles supporting this categorization, which were examined by researchers in the process of secondary research.

Table 5. Summary of the Climate Crisis and Ecological Restoration.

Climate Crisis and Ecological Restoration (C)	Subject (Sub-Category)	Source
C1	Plant communities and habitat restoration	[121]
C2	Landscape responses to climate change	[58,121–127]
C3	Urban greening and ecological restoration	[37,123,125,126,128,129]
C4	Disaster responses and technology in landscape design	[97,100,110,112,114]
C5	Wildlife habitat conservation strategies	[121,130,131]
C6	Brownfield remediation technology	[40,132]
C7	Ecological restoration of water environment	[37,122,126,131,133]

Only four sub-categories, including “Landscape responses to climate change”, “Urban greening and ecological restoration”, “Disaster responses and technology in landscape design”, and “Ecological restoration of water environment”, are the most appeared topics in the literature released on CELA. Technologies for “Plant communities and habitat restoration” and “Wildlife habitat conservation strategies” are the aspects that lack enough research and integration within the discipline.

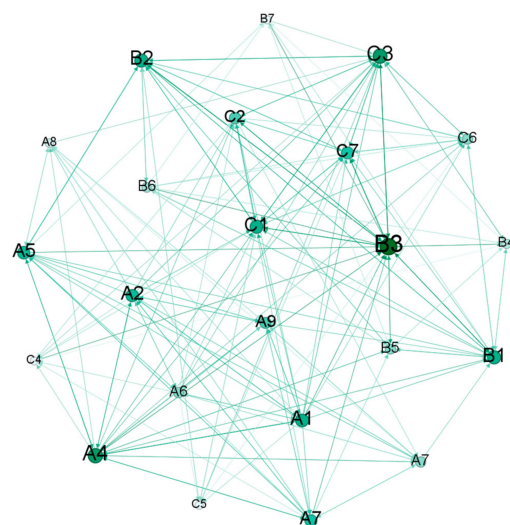
3.2. NMTLA

The relationship of 23 landscape design technologies is discussed using expert interviews; 40 experienced LA experts were invited to finish a questionnaire of the relationship matrix among the sub-categories of TLA. The TLA Relationship Matrix consists of 23 columns and 23 rows (Table 6); “0” refers to no correlations, while “1” refers to having correlations identified by experts, filled by experts, and adapted to indicate whether the technologies of the first row exert monodirectional impact on the technologies of the first column. For example, “1” in row 1, column 4 indicates that A4 has an effect on A1, while “0” in row 1, column 4 means A4 has no effect on A1. After collecting experts’ answers, if more than twenty experts give “0” for one relationship, then the final answer will be defined as “0”. On the contrary, if more than twenty experts answer “1”, the final results will be marked as “1”. This approach can be regarded as a simplified version of the Delphi Method [134]. Considering that all experts are quite busy and have limited time to participate in the survey, this research method can be a relatively efficient and feasible choice. Moreover, if the number of people answering “0” and “1” is the same, the research team will invite another expert to participate in the interview to obtain the final answer. However, this situation did not happen in the real study.

Table 6. TLA relationship matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	C5	C6	C7
A1	-	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	1	-	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	0	1	-	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
A4	1	1	1	-	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
A5	1	1	1	1	-	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
A6	1	1	1	0	1	-	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A7	1	1	1	1	1	1	-	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A8	1	1	1	1	1	0	1	-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A9	1	1	1	1	1	1	1	1	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B1	1	0	1	1	1	0	0	0	1	-	1	1	1	1	1	0	0	0	0	0	0	1	0
B2	0	0	0	0	1	0	0	0	0	1	-	1	0	1	1	0	1	0	1	0	1	1	1
B3	1	0	0	1	1	0	1	0	0	1	1	-	1	1	1	1	1	1	1	1	0	0	1
B4	0	0	0	0	0	0	0	0	0	1	0	1	-	1	1	1	0	0	1	0	0	0	0
B5	0	0	0	1	0	0	1	0	0	1	1	1	1	-	1	1	0	0	0	0	0	0	0
B6	0	0	0	0	0	0	0	0	0	1	1	1	1	1	-	1	0	0	0	0	0	1	1
B7	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	-	0	0	0	0	0	0	0
C1	1	1	0	1	0	1	0	0	0	1	1	1	0	0	0	0	-	1	1	0	1	1	1
C2	1	1	0	1	0	1	1	0	0	0	0	1	0	0	0	0	1	-	1	1	0	0	1
C3	1	1	0	0	0	1	0	1	0	0	1	1	1	0	0	1	1	1	-	1	1	1	1
C4	1	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1	1	0	-	0	0	0
C5	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	1	0	-	1	1
C6	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0	0	-	1
C7	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	0	1	1	-

The network model, which shows the relationship, intensity, and status of influence among landscape design technologies, is visualized based on the analysis of the relationship matrix (Figure 2). Each vertex represents a TLA, while the size and brightness of the vertex indicate the status of a certain technology in the whole TLA system. The brightness of the connection line between two vertices indicates the strength of the relationship between the two technologies, and the absence of the line means that there is no relation between them. Specifically, the arrow of a line means the direction of influence. For example, the one-way arrow between “Topographic design and earthwork” and “Landscape visualization and analysis” indicates that “Landscape visualization and analysis” has a monodirectional impact on “Topographic design and earthwork”.

**Figure 2.** NM and analysis of TLA categories.

3.2.1. Degree Centrality of NMTLA

Degree centrality represents the closeness of the relationship between one element and another. The values of degree centrality of 23 landscape design technologies were calculated and shown in Figure 3. The results indicate that “Stormwater management and engineering (B3)” and “Urban greening and ecological restoration (C3)” have the highest degree of centrality. This means that these two technologies have the closest connections with the other twenty-one categories of TLA. Meanwhile, according to the results, “Landscape paving design (B7)”, “Disaster responses and technologies in landscape design (C4)”, and “Wildlife habitat conservation strategies (C5)” have the weakest connections with other technologies.

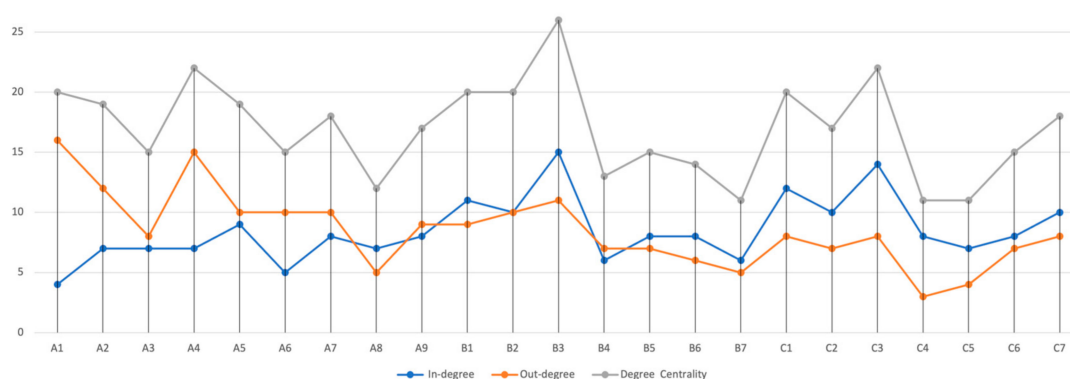


Figure 3. Degree centrality analysis of NMTLA.

In addition to degree centrality, two secondary indicators of degree centrality, in-degree centrality and out-degree centrality, should be discussed as well. In-degree represents the intensity of the influence exerted by another technology. Figure 3 shows that “Stormwater management and engineering (B3)”, “Urban greening and ecological restoration (C3)”, and “Topographic design and earthwork (B1)” are the top three technologies influenced by other technologies. “Geographical design method and GIS technology (A1)” and “UAV imagery and remote sensing (A6)” have the least possibility of being influenced by other technologies. Out-degree indicates the intensity of the influence that technology exerts on another. For example, “Geographical design method and GIS technology (A1)” and “Information modeling (LIM and BIM) of landscape and building (A4)” produce a great impact on other technologies, while “Disaster responses and technologies in landscape design (C4)” and “Wildlife habitat conservation strategies (C5)” have the least impact on other technologies.

Regarding the NA results of overall degree centrality, in-degree centrality, and out-degree centrality, this study finds that the geo-spatial and digital analytics technologies have more impact on other technologies than being impacted by other technologies. On the contrary, climate crisis and ecological restoration technologies are more likely to be affected by other categories of TLA.

3.2.2. Closeness Centrality of NMTLA

Closeness centrality indicates the difficulty that one element affects another. The higher value of closeness centrality indicates that technology can significantly and extensively affect other categories of TLA. The closeness centrality analysis (Figure 4) shows that “Geographical design method and GIS technology (A1)”, “Information modeling (LIM and BIM) of landscape and building (A4)” and “Landscape algorithmic design and analysis (A2)” have extensive and broad impacts on other technologies. (Figure 4).

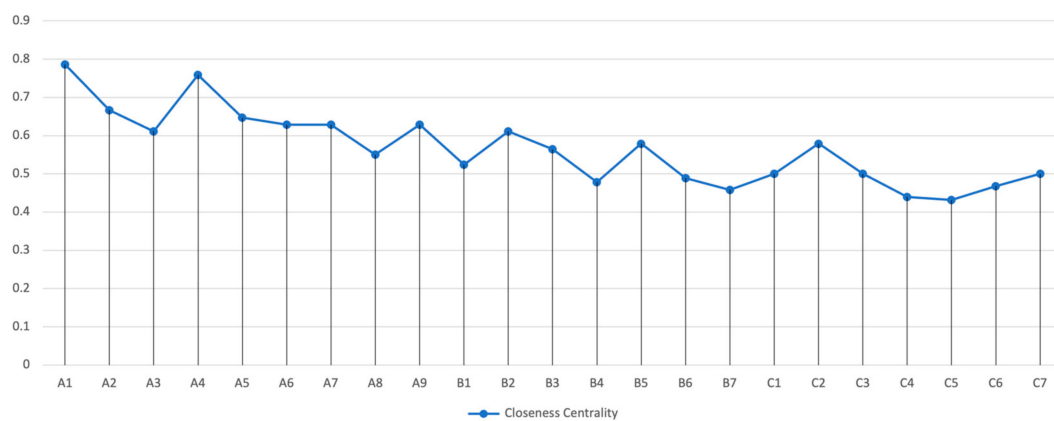


Figure 4. Closeness centrality analysis of NMTLA.

3.2.3. Betweenness Centrality of NMTLA

Betweenness centrality shows the number of shortest paths that relate one technology to another, representing how one technology can influence others through a specific path. The results (Figure 5) show that “Planting design (B2)”, “Landscape visualization and analysis (A5)”, and “Information modeling (LIM and BIM) of landscape and building (A4)” are the three categories that have the highest value of betweenness centrality, which indicates that these three categories play important roles in bridging various categories of TLA in the NMTLA. Although “Planting design (B2)” and “Landscape Visualization and Analysis (A5)” have low scores in degree centrality analysis, they are still essential in the TLA system.

3.2.4. Comparison of Degree Centrality, Closeness Centrality, and Betweenness Centrality

Comparing the analysis of degree centrality, closeness centrality, and betweenness centrality, it can be learned that “Planting design (B2)”, “Stormwater management and engineering (B3)”, “Landscape visualization and analysis (A5)”, “Information modeling (LIM and BIM) of landscape and building (A4)”, “Urban greening and ecological restoration (C3)”, “Landscape construction details and management (B5)”, and “Landscape responses to climate change (C2)” are seven important categories in NMTLA, they also can connect other categories together like bridges. On the other hand, “Wildlife habitat conservation strategies (C5)”, “Disaster responses and technologies in landscape design (C4)”, “Landscape paving design (B7)” and “Social media in landscape design (A8)” are four technologies with limited universality according to their low scores in the NA (Figure 6).

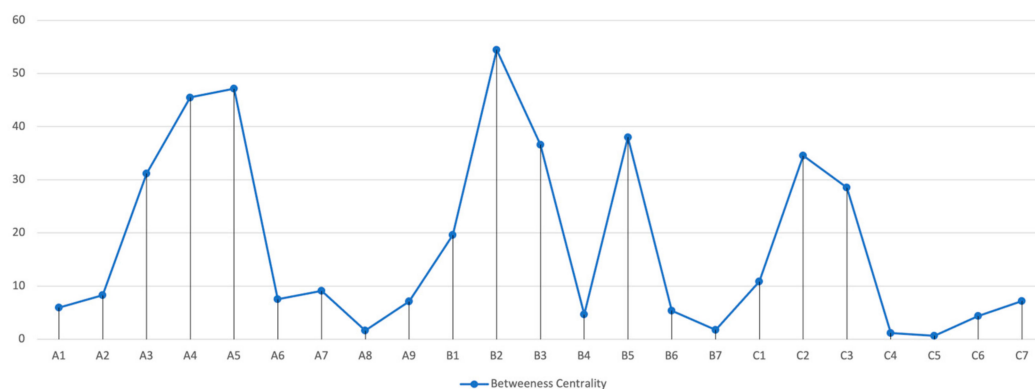


Figure 5. Betweenness centrality analysis of NMTLA.

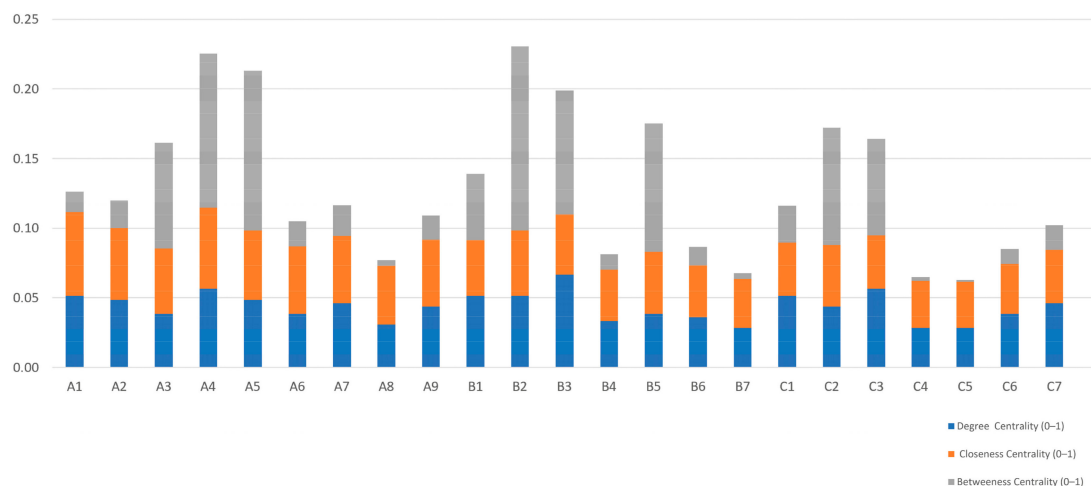


Figure 6. Comparison of degree centrality, closeness centrality, and betweenness centrality of NMTLA (the scales of all indicators are normalized between 0 and 1).

4. Discussion

4.1. Reflection on Categories of Current TLA

The research findings indicate that “Planting design”, “Stormwater management and engineering”, “Landscape visualization and analysis”, “Information modeling (LIM and BIM) of landscape and building”, “Urban greening and ecological restoration”, “Landscape construction details and management”, and “Landscape responses to climate change” are seven important categories in NMTLA. This result can be explained by recalling the development of LA discipline nowadays. Among the seven crucial categories of TLA, “Landscape construction details and management” and “Planting design”, “Information modeling (LIM and BIM) of landscape and building”, and “Stormwater management and engineering” are both practice-oriented technologies. They are closely connected to LA industry and could be utilized in every LA design project. In contemporary LA education, teaching students the professional skill that can be applied in work is an important task. Therefore, these technologies absolutely should be included in today’s LA higher education, especially in the first 2 years of college, since they serve as the foundation of other advanced courses.

Among the seven most important categories of TLA, “Landscape visualization and analysis”, “Urban greening and ecological restoration”, and “Landscape responses to climate change” are more research-based technologies. They might not be very necessary to LA design practice, but they can inspire potential solutions to critical social and environmental issues through academic research. Therefore, in LA education, these categories of TLA should be involved in the curriculum, possibly in the form of independent study, thesis, seminar, or lab section. Moreover, “Urban greening and ecological restoration” have become more and more critical in LA discipline since Ian McHarg proposed the ‘design with nature’ theory in 1995. Meanwhile, the technologies of “Landscape responses to climate change” starts to receive increasing attention in both LA practice and research. These two categories of TLA integrate the knowledge and techniques of ecology, climatology, geography, botany, zoology, and other disciplines into LA. With much more explicit goals compared with other TLA, “Urban greening and ecological restoration” and “Landscape responses to climate change” could easily transform the technologies of other disciplines to the field of LA while combining LA research with LA practice. For example, water processing (hydrology), site transformation (climatology and geography), and vegetation application (botany) have become fundamental aspects of “Urban greening and ecological restoration” and “Landscape responses to climate change”.

Considering that landscape design is a broad concept, none of the technologies of landscape design are isolated. For example, data from GIS, UAV imagery, AR, VR, landscape and building information modeling (LIM + BIM), landscape visualization, and algorithmic

design and analysis will be adopted when it comes to the ecological restoration of water environments in design projects [134,135]. In general, the larger the scale of the design, the more complexity of the system, the greater number of technologies would be involved, and the more integrated the technologies are referred to. Each of these technologies affects and supports others in the whole TLA system, while designers have to realize the hierarchy and relevance of the system through the whole process of design. Designers should not only design with the view of history, culture, and aesthetics but also conceive, promote, and implement the design with the thinking of technology.

4.2. EFLA Based on NMTLA

By analyzing the degree centrality, closeness centrality, and betweenness centrality of 23 categories of TLA, an NMTLA can be developed. Based on the NMTLA, an EFLA can be proposed (Figure 7). In this EFLA, all categories of TLA can be summarized into four domains. The first category is core technologies of landscape design, such as “Planting design” and “Landscape visualization and analysis”. Core technologies are indispensable in both LA education and practice. With high values of degree centrality and betweenness centrality, core technologies are able to affect and connect other technologies directly. The second category is applied technologies. Applied technologies indicate techniques from other disciplines that can be directly transformed into LA. Applied technologies, such as “UAV imaging and remote sensing”, are scientific and objective. With higher out-degree than in-degree, applied technologies affect other technologies a lot and are less likely to be impacted by others. The third category is integrated technologies, which combine technologies in multiple other industries with the core technologies in LA according to the specific needs of landscape design. Integrated technologies show a low degree of centrality and tend to be impacted by other technologies. The fourth category is the specific technologies that meet specific circumstances and needs, with a low degree of centrality and betweenness centrality. Specific technologies are not universal in landscape design, but they are not trivial. For example, “Wildlife habitat conservation strategies” is not suitable for most of the practices of landscape design, but it is a critical meaning for the protection and restoration of the human ecological environment.

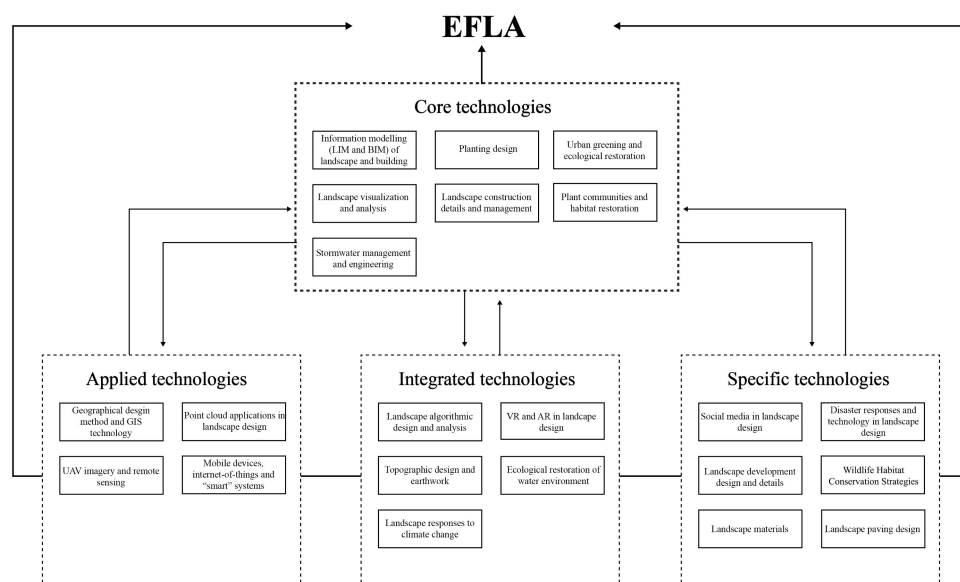


Figure 7. The summary of the EFLA model.

This EFLA suggests an appropriate use of different categories of TLA in LA higher education. Core technologies should be the focus of LA education and should be included in the first 3 years of college study. Since studio is the most important course for LA students, the learning of these core technologies can go with the studio or other basic courses.

For applied technologies, it requires students to have a fundamental understanding of LA then the techniques from other disciplines can be learned and applied in the contexts of LA. Therefore, applied technologies are not required only to be taught within the LA department but could also be taught in other departments or by teachers with different backgrounds. In this way, collaborative and interdisciplinary teaching and learning are necessary. A possible suggestion is to teach applied technologies in the form of elective courses and lab sections, where students can explore interdisciplinary knowledge spontaneously. Integrated technologies combine technologies in multiple other industries with the core technologies in LA according to the specific needs of landscape design. Therefore, learning integrated technologies requires LA students to understand the role of core technologies and applied technologies first. The instructors teaching integrated technologies should be authoritative in LA discipline while having some experience or resources in other fields. Considering this, seminars, lectures, thesis, and independent study are reasonable carriers of integrated technology teaching and learning. Finally, for the domain of specific technologies, considering its limited universality, courses related to these topics do not need to be complimentary in a common undergraduate curriculum. However, if students are interested in any of them, necessary elective courses and after-class tutorials introducing these technologies should always be available for students.

5. Conclusions and Limitations

With the goal of finding relationships among various categories of TLA and exploring their potential for LA education, this research first collected the data by applying Secondary Research to clarify the scope and categories of TLA. The second step was to apply expert interviews and NA to analyze the relationships among each technology in LA, then generate EFLA Based on data analysis of NMTLA. To build the NMTLA, this research identified 23 key categories through content analysis of secondary research. The expert interview and NA were then used to analyze and visualize the mutual influence and relationships among the categories. The NMTLA shows that “Planting design”, “Stormwater management and engineering”, “Landscape visualization and analysis”, “Information modeling (LIM and BIM) of landscape and building”, “Urban greening and ecological restoration”, “Landscape construction details and management”, and “Landscape responses to climate change” are seven important categories in NMTLA, they also can connect other categories together like bridges. On the other hand, “Wildlife habitat conservation strategies”, “Disaster responses and technologies in landscape design”, “Landscape paving design”, and “Social media in landscape design” are four technologies with limited universality.

Based on these findings, the study developed an EFLA which summarizes the twenty-three categories of TLA into four domains: core techniques, applied technologies, integrated technologies, and specific technologies. Inspired by the EFLA, this research proposed a series of suggestions for how to apply different categories of TLA in today’s and future LA education. For core technologies, this research suggests it to be taught in the first stage of college study and integrated with LA design studio course. For applied technologies, a possible suggestion is to teach applied technologies in the form of elective courses and lab sections, where students can explore interdisciplinary knowledge spontaneously. For integrated technologies, this research believes they should be taught after students have a comprehensive understanding of core technologies and applied technologies. Meanwhile, close communication and interaction with experienced instructors are important. This implies that seminars, lectures, thesis, and independent study are reasonable carriers of integrated technology teaching and learning. The domain of specific technologies has limited universality. Instead of setting related complementary courses, this research suggests that necessary elective courses and after-class tutorials introducing these technologies should be available for students.

The proposed NMTLA and EFLA in this research could explain, predict, and guide the expansion of the disciplinary boundaries of LA. They also contribute to the advancement and development of future LA higher education. The development of LA discipline

and education relies on understanding and clarifying the related topics, techniques, and applications. TLA always changes with the progress of technology and the development of relevant disciplines. Therefore, keeping abreast of The Times to explore the function, potential, and limitations of various categories of TLA as well as the relationship among them will significantly benefit today's and future LA education. Building an NMTLA can potentially address the Sustainable Development Goals (SDGs) in LA education and industry, especially SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). Among the 23 categories of TLA, 12 of them are closely related to SDGs. Categories such as "Stormwater management and engineering", "Urban greening and ecological restoration", and "Landscape responses to climate change" are important TLA that responds to SDGs. Discussing how to apply these categories of TLA in LA education also help inspire the ways in which LA discipline can contribute to the SDGs. The EFLA proposed in this research not only can be used in general LA higher education, but it also explores how to cultivate qualified landscape designers who can contribute to sustainable urban development in the future.

However, this research still has many limitations. The first is about the research scope and focus. The focus of this study is on LA education in the USA, as all the data and interviews are based on this context. Although the findings of this research can potentially be generalized to LA education worldwide, it's important to acknowledge that different countries and regions may have unique situations and cultural backgrounds that affect their LA education and practice. Therefore, this research is only a start rather than an endpoint of a related EFLA study. Further research should be conducted with consideration of LA education in various countries. The second limitation is about interview design and sample size. A total of 40 experts are the maximum sample size we can approach in this research due to the limited funding, resources, and time. However, a larger sample size is necessary to draw more valid conclusions. This problem needs to be addressed in future research if we expand the research scope to more countries and regions. At the same time, the interview design should be improved in future studies. The evaluation matrix in this research is straightforward but relatively arbitrary. Defining the correlation between categories of TLA as either "have no correlation" or "have correlation" is not enough. Diverse answers should be allowed and encouraged in future expert interview designs. The third limitation is the establishment of EFLA. The current framework is relatively conceptual and not comprehensive enough. Future research should enrich this EFLA by discussing the relationship between TLA and LA higher education in-depth.

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