Exploring the Potential of 3D Printing Technology

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**Abstract:** The emergence of 3D printing technology has led to its exploration across various domains, including landscape design. However, its potential in the context of landscape design and education has been relatively overlooked. This study aims to investigate the implications of 3D printing technology for landscape design education and practice. We conducted a thorough review of the existing literature and analyzed the current state of 3D printing technology. Additionally, we conducted case studies involving secondary school students and landscape practitioners to assess the practical implementation of the technology. The workshops with secondary school students using 3D-printed models resulted in positive outcomes, including heightened interest, increased participation, and improved understanding. Furthermore, semi-structured interviews with landscape practitioners confirmed certain limitations of 3D printing, such as cost, delivery time, scale, and level of detail.

**Keywords:** digital fabrication technology; 3D printing; landscape design; landscape architecture education; landscape practitioners

# Introduction

3D printing technology, referred to as digital fabrication, rapid prototyping, and solid freeform fabrication, has found extensive application among engineers and industrial designers for creating physical prototypes to visualize and test novel design concepts [1]. The growing popularity of 3D printing is anticipated to bring significant transformations across various industries. In manufacturing, for instance, the adoption of small-quantity production systems enables the customization of goods according to consumer preferences, leading to substantial economic advantages [2]. Moreover, the relationship between 3D printing and design is gaining increased attention [2].

Due to its adaptability, 3D printing has garnered attention in the planning and design industry. Various sectors, including automobile, fashion, architecture design, and more, have actively implemented 3D printing technology [3]. As 3D printers continue to evolve, their applications are expanding to fields like arts, medicine, aerospace, and design, making this technology relevant across industries [3]. 3D printing offers significant advantages, enabling the production of complex designs with reduced time and cost compared to other methods [3]. It allows for the creation of early-stage prototypes, facilitating market assessment and small-quantity batch production to enhance the manufacturing system [3]. Consequently, 3D printing is expected to foster further developments in the design industry.

In the education sector, 3D printing is already being integrated into various disciplines, such as architecture, computing, ergonomics, human factors, and medicine. Universities actively use 3D printing in subjects like computer graphics, engineering design, medical design, and product and industrial design within their curricula [4]. Moreover, 3D printing has proven to be a valuable tool for enhancing students' understanding of geological formations, as it provides a level of detail not achievable through 3D images alone [5]. Printing 3D models aids in improving students' comprehension of topography [6][7]. The technology also contributes to a better sense of space through tactile and observational experiences obtained from physical models [8][9].

3D printing technology is widely adopted for interdisciplinary training in various subject areas, as described by Eisenberg [8]. Its practical applications span across IT, art and design, science, engineering, robotics, mathematics, and humanities. In one secondary school in Australia [10], 3D printing technology has been successfully integrated into the curriculum, gaining popularity among students, teachers, and parents. The school uses 3D printers for diverse projects, including playground design and production, character creation for stop-motion films and electronic books, as well as various constructions. The incorporation of 3D printing has resulted in cross-curricular benefits across all subjects at the school. Similarly, the UK's Department for Education funded a 3D printing project between 2012 and 2013 with the aim of enriching teaching in science, technology, engineering, mathematics, and design subjects. Schools were encouraged to explore innovative ways of using 3D printing technology to teach complex scientific and mathematical concepts [11].

The application of 3D printing technology in education has shown positive effects. For instance, one study demonstrated improvement in students' oral presentation skills through education using 3D printing [12]. Teachers have reported that the use of 3D printing technology has motivated students and promoted student-centered learning [13][14]. In the context of landscape architectural planning and design, the education sector can also benefit from incorporating 3D printing technology in design workshops, procedural phases, and participation and community workshops, instead of relying solely on finished outputs [14]. This application of 3D printing can further enhance the learning experience and engagement of students in landscape design education.

# As highlighted earlier, 3D printing technology offers numerous potential applications in education and various fields. However, in the landscape architecture field, practical discussions concerning 3D printing technology and its applicability in education have been limited [15]. Nonetheless, with the expected decrease in 3D printing technology costs and the anticipated advancements in its tools and efficiency, opportunities for its implementation in other fields are likely to emerge. Nevertheless, it is essential to assess these opportunities carefully to avoid inappropriate applications.

# The lead author, with experience in visualizations, Landscape Visual Impact Assessments, and computer graphics, undertakes this study to explore the existing literature on 3D printing and landscape architecture. Additionally, a case study on 3D printing in education and interviews with landscape architects are conducted to lay the groundwork for the potential application of 3D printing in the landscape architectural field. The aim is to discover the future direction of 3D printing technology's development. This study evaluates the literature on 3D printing and landscape architecture, along with the insights gained from the case study and interviews with landscape architects, to prepare the basis for the future application of 3D printing technology in landscape architecture.

# Literature Review

In conventional landscape architectural design and planning processes, the use of drawings and photographic representations is widespread [16–19]. These image-based methods allow for crucial comparisons between the before and after scenarios of a design. However, there has been some skepticism surrounding the practicality of using visualizations [20–23]. Unlike computerized visualizations, which often lead to discrepancies between stakeholders' expectations and actual outcomes, physical models are considered to be more credible and interactive. 3D models provide a true reflection of the eventual construction. Implementing the landscape architectural design process can be challenging, especially when it comes to making design decisions. Understanding the planning impact is often complex and subjective, involving multiple stakeholders [16].

Traditional methods, such as drawings and plans, are primarily tailored for trained personnel or experts, and they have limitations in terms of effectively communicating information. For instance, users without sufficient training or familiarity with maps might find it challenging to interpret the visual variables presented in them. In contrast, physical models, such as 3D models, can overcome these limitations and provide a more accessible and tangible representation of the design, facilitating better communication and decision-making in the landscape architectural planning process.

Physical models have the potential to overcome the limitations of 2D visualization. Over the last 50 years, physical models have found applications in various fields and have become increasingly versatile [24]. For example, shipbuilders, car manufacturers, and aerospace engineers have used physical 3D models to represent their designs. These models serve multiple purposes, including education, testing, and sales generation within development projects. Physical models are powerful tools because they present objects in three dimensions, retaining crucial information that can be lost in 2D representations like maps [24].

In contrast to 2D technologies such as imaging and video, which can only interpret visually, physical models have advantages over 2D drawings. By making slight movements of the head or body, viewers can easily observe different aspects of the model that may be obstructed in the line of sight, such as high prisms or mountains in the foreground. As a result, 3D models provide a more realistic representation of the design proposal, making evaluation easier, assisting in identifying design flaws, and facilitating communication between clients and planners [15].

In the field of landscape architecture, 3D computer graphics are often used to overcome the limitations of explaining a design solely with a 2D plan. However, in many cases, 3D models are preferred due to their ability to provide a more comprehensive and tangible representation of the design proposal [15].

Physical models offer additional sensory experiences that contribute to the growing interest in 3D printing [25]. 3D-printed models allow for multi-sensory experiences, which is a significant factor behind their increasing popularity [26]. Moreover, when haptic communication is required, conventional media fall short in facilitating interaction among stakeholders involved in landscape planning and design processes. Communication between stakeholders, such as the community, planners, and designers, often relies on drawings and computer visualizations. As mentioned earlier, physical models are specifically designed for communication, and they play a crucial role in public debates concerning alternative futures in landscape architecture [27].

In the context of landscape modeling, we explored the potential of 3D printing technology as a valuable tool to create physical models, which are widely used in landscape design practices. Traditional physical models in civil engineering and architecture are typically crafted by hand using materials like clay, cardboard, foam, or wood. This manual assembly process is time-consuming and can lead to inaccuracies, especially when dealing with complex topographic terrain [24].

By leveraging 3D printing technology, these challenges can be addressed more efficiently and accurately. Compared to conventional physical modeling, 3D printing offers advantages such as faster production, greater precision, and the ability to create intricate geometries. With 3D printing, the process of building physical models can be streamlined, reducing time and effort while ensuring higher accuracy in representing complex landscapes.

However, despite the advantages it offers for design, the full implementation of 3D printing technology in landscape architectural planning and design has not been thoroughly explored. Several reasons and constraints may contribute to this phenomenon.

Landscape architectural planning and design involve incorporating natural materials, such as vegetation, and often encompass large-scale areas. Current 3D printing technology faces limitations in supporting such cases due to cost and size constraints. Studies have pointed out that the speed of 3D printing, particularly for large-scale models, is one of the limitations that hinder its widespread application across various fields [28,29]. Additionally, researchers like Neumüller et al. [26] have highlighted that despite rapid developments, 3D printing technology still has limitations in terms of color expression and the range of applicable materials, which presents challenges when attempting to print complex landscape architectural models. According to Ervin [27], the term "landscape" can encompass various interpretations, including a complex cultural construction, a simple arrangement of elements like landform, water, and vegetation, or a dynamic interaction of forces over different timescales, ranging from seconds to centuries. From a modeling perspective, landscapes are highly intricate structures that cover extensive areas. In the actual landscape, critical variables that determine its visual appearance include terrain, vegetation, animals and humans, water, built structures, atmosphere, and light [30].

Steinhilp and Kias [15] conducted an analysis of various 3D printing technologies to identify a suitable one for the landscape field. They emphasized the importance of high speed and low cost over high precision, especially when using 3D printed models to represent the overall target site rather than achieving absolute accuracy, which aligns with the typical role of physical models used in landscape architecture. Depending on the specific planning or design problem and the nature of the landscape under consideration, a landscape architectural representation does not necessarily have to encompass all elements, nor does every element need to be represented in high detail. However, each element can pose a significant challenge when striving for a representation with a high degree of realism [30]. For instance, real vegetation is inherently complex, comprising a multitude of objects like leaves, flowers, and branches, and the diverse nature of vegetation elements in a landscape can create additional difficulties [30]. Given the complexity of landscapes, the creation of landscape architectural 3D printing can indeed be highly demanding.

However, it is essential to acknowledge that omitting real landscape details from a virtual representation might result in a certain lack of richness [31], and overly abstract representations may not be suitable for accurately determining landscape aesthetic and scenic beauty values [32].

# In summary, the implementation of 3D printing technology in landscape architectural planning and design involves several key considerations: level of detail, production cost, production time, and scale. To gain a comprehensive understanding of these factors and their interrelations, our study adopted a holistic research approach. This approach was inspired by the way landscape practitioners tackle problem-solving, synthesizing various elements into a cohesive whole without requiring detailed knowledge of each part. The approach utilized a descriptive framework and a storytelling technique to provide a better overview and comprehension of how 3D printing technology is applied in real-life landscape projects. The framework focused on four dimensions of implementation: cost, level of detail, time, and scale. By employing different tools and models based on this framework, we aimed to analyze the factors influencing the utilization of 3D printing technology in landscape planning and design, effectively operationalizing the connections between the design process and 3D printing technology [33].

# Notably, while the significance of boundary work and interactive design has been acknowledged in the context of industrial design, it has been relatively overlooked in landscape planning and design implementation. In our research, we aimed to bridge this gap by integrating insights from the literature on 3D printing technology with the findings from interviews with landscape practitioners. This unique approach shed light on the potential of 3D printing to enhance communication and participation in landscape design.

# Methodology

Considering the potential benefits and drawbacks of 3D printing technology, this research aims to explore its applicability in the landscape architectural planning and design process, with a focus on enhancing communication within the industry and fostering overall development. Additionally, the study seeks to investigate the integration of 3D printing into the landscape architectural education curriculum.

To achieve these objectives, a qualitative research methodology and case study approach are adopted. The data collection process involves conducting semi-structured interviews with landscape practitioners and surveys with secondary students. This combination of methods ensures the validity of the qualitative study, following the recommendations by Yin [34]. Through these interviews and surveys, the study analyzes the advantages and disadvantages of 3D printing technology and explores potential strategies to address challenges associated with this innovative technology.

The research described in this paper originates from a landscape architectural design workshop involving secondary school students. Over the span of 2016 to 2019, 50 students were recruited each year to participate in the Major Experience program. The workshop aimed to provide secondary school students with a glimpse of what they would learn in a university landscape architecture major and improve their understanding of the subject. The program consisted of three sessions: an introductory lecture on landscape architecture, an experiential workshop that included a design activity utilizing 3D-printed models, and an opportunity to engage in conversations with senior students. This initiative was undertaken to cater to the needs of secondary school students who were on the verge of choosing their college majors and enhance their understanding of landscape architecture.

Experimental 3D printed models were developed for the workshops, utilizing a simplified geometric approach with "lollipop-like" tree formations created from modular toy blocks on 30 cm x 30 cm square boards. Due to limited time and budget, the models were restricted to two types of trees, broadleaved and conifers, using a Da Vinci 1.0 AiO 3D printer. These models were used in a landscape design workshop for secondary school students participating in a landscape course experience. The workshop aimed to explore the usability of 3D printing in education, with students using the modular 3D-printed models to design and install gardens based on assigned themes.

Following the workshop, a brief survey was conducted to collect feedback from the participants. The survey included questions about their understanding of the subject of landscape architecture with the aid of 3D models, as well as the satisfaction level with the training processes. The questionnaire used a 5-point Likert scale for responses. Two main question groups were included: the participants' most preferred program among lecturing, workshop, and talk sessions with current students, and how helpful the overall program was in understanding the subject of landscape design. The survey results from 177 participants were analyzed, excluding any responses with omitted values (Table 1).

# The semi-structured interviews conducted for this study involved six practitioners with field experience ranging from two to thirty years in various sectors, including construction companies, multi-disciplinary practices, design studios, and the public sector. The interviews aimed to gather insights into their experiences with 3D printing in the landscape design field and to explore the pros and cons of implementing this technology, along with their recommendations.

# The interviews were divided into five question groups as follows:

# Experiences in 3D printing in the landscape design field.

# Description of any previous experience using 3D printing technology.

# Evaluation of the advantages and disadvantages of implementing 3D printing technology and any recommendations.

# Explanation of their knowledge about the technology and its potential for implementation in their field.

# Review of tradeoffs in 3D printing technology, including cost, scale, time, and level of detail.

# Each interview lasted between one and two hours, starting with general background questions about the interviewees' experience and previous use of 3D printing technology. The interviewees were then shown samples of 3D printed technology and encouraged to explore and provide their opinions on the technology. The discussions covered the strengths, weaknesses, and potential applications of 3D printing technology in landscape architectural planning and design.

# Thematic analysis was employed to analyze the interview data. Each author independently conducted the thematic analysis, focusing on four interconnected issues: cost, size, time, and level of detail. The study's analysis was based on these four themes (Section 4.2).

# Case Study Results: 3D Printing in Landscape Architectural Education andLandscape Design

To investigate the potential of 3D printing technology, we conducted a case study based on project experience.

On questions regarding the most preferred session among the three conducted, experi- ential workshops were ranked the highest at 83.1%, followed by general major introduction lectures at 10.2%, and conversation sessions with senior students at 6.8% (Table [3](#_bookmark0)).

Most preferred session.

|  |  |  |
| --- | --- | --- |
| **Sessions** | n | Ratio (%) |
| Total | 177 | 100 |
| Lecture for introducing the major | 18 | 10.2 |
| Experiential workshop | 147 | 83.1 |
| Conversation with senior students | 12 | 6.8 |

The students mentioned that they chose the preferred session because they enjoyed the hands-on experience of creating something themselves. They found the activity of designing a park with 3D models to be engaging and allowed them to showcase their creativity. Some students expressed that they appreciated the opportunity to do practical work and apply what they had learned, which was different from the traditional lecture classes.

They also mentioned that the workshop provided a unique experience that they couldn't find elsewhere, and they liked the variety of activities offered during the major experience sessions. They found the park-designing workshop to be enjoyable, but they felt it was too short, and they found one-sided lecture classes to be boring in comparison.

Several students who participated in the workshop expressed that they enjoyed collaborating and discussing ideas with other participants. They found it fun to work together as a team and appreciated the opportunity to present their park designs using 3D printing technology.

Furthermore, when asked about the helpfulness of the major experience workshop in expanding their understanding of the landscape architecture major, 94.35% of the students answered positively (Yes or Very much). The participants stated that their understanding of the major had significantly improved as a result of the workshop.

Was the workshop helpful in expanding your understanding of the major?

|  |  |  |
| --- | --- | --- |
| **Division** | **n** | Ratio (%) |
| Total | 177 | 100 |
| Not at all | 1 | 0.56 |
| No | 0 | 0 |
| Neither helpful nor unhelpful | 9 | 5.08 |
| Yes | 84 | 47.46 |
| Very much | 83 | 46.89 |

The feedback from the participants highlighted the positive impact of the garden and park design practice during the workshop. Students expressed that the experience allowed them to gain a practical understanding of landscape architecture and made the subject more approachable and enjoyable.

One student mentioned that the workshop helped them realize their career aspirations, as it aligned with their interest in designing and decorating cities based on their surrounding environments.

Moreover, the design workshop that involved 3D models was perceived as easier to understand compared to the CAD workshop that focused on 2D design drawings. The students found the 3D design workshop more straightforward in terms of planning and designing, while they faced challenges with the 2D CAD workshop and needed more assistance from senior students.

The findings from the workshop align with previous research that indicates students can gain deeper knowledge and understanding through hands-on experiences, such as creating actual 3D printing models. The use of multiple sensory processing methods in the workshop also contributed to enhancing learning ability.

Feedback from students indicated that while most of the programs were enjoyable, the CAD program proved challenging for some due to its complexity. However, the guidance and assistance provided by senior students were appreciated.

Based on the positive outcomes of the workshop, 3D printing technology was recognized as having the potential to improve the landscape design process. Although academic studies have demonstrated the potential of this technology, its widespread implementation in practice would require careful consideration and planning. To explore the implementation of 3D printing technology in landscape design further, semi-structured interviews were conducted with experienced landscape practitioners.

In the landscape planning and design field, computer visualization technology is commonly used, but there have been efforts to enhance its credibility and interactivity. Although 3D printing technology is recognized as a potential avenue to improve interactivity and credibility, it is not frequently employed by landscape professionals in South Korea, even though it may be commissioned by developers and governments after consulting with relevant authorities. Physical 3D modeling is considered a supplementary approach, and its use in planning permission processes is uncommon. Instead, computer graphics are more commonly used. The implementation of 3D printing technology is often viewed as a technical exercise with a focus on textual descriptions of development impacts.

During the interviews with landscape professionals, it was found that the majority of them had not yet used 3D printing technology in their own projects. Several reasons were cited for this, some of which are as follows:

"It is quite challenging to use 3D printers, and the cost is a significant concern." (Interviewee D)

"In my company, we don't have a 3D printer." (Interviewee C)

"I don't see a compelling need to use 3D printers in my work." (Interviewee E)

Based on the responses from the interviews, several constraints for the implementation of 3D printing technology in landscape planning and design can be identified. These constraints include high cost, size limitations, and relevance to the work. One interviewee, with 30 years of professional experience, reported having used 3D printing models for a decking design in a lakeside project in 2016. The outcome was of sufficient quality and was well-received by the client. This interviewee expressed interest in using a variety of materials and highlighted the usefulness of a technology that could easily print larger items.

Another interviewee, a street furniture designer, acknowledged having knowledge of 3D printing from news sources but stated that they were not the decision-maker for its usage. However, they mentioned that implementing 3D printing technology in the street furniture industry could be successful. For instance, using a 3D printer for prototype fabrication before manufacturing could save time and money.

Regarding the value of implementing 3D printing technology, one interviewee emphasized its usefulness in aiding client understanding during consultation for smaller items such as benches, entrances, and art features. They suggested that while there are various 3D modeling software programs available, having physical models to see and touch would be more beneficial.

In terms of cost issues, the interviewees expressed their opinions despite their lack of actual experience with 3D printing. One interviewee expressed a desire to see higher-durability materials, such as metal, for 3D model production. Another interviewee mentioned that the cost of 3D printing could be a concern and that for it to be feasible in the field, 3D models should be produced more cheaply than physical 3D models. They also noted that smaller firms might find it challenging to acquire 3D printing facilities.

Furthermore, an interviewee with experience in street furniture manufacturing stated that 3D printing technology could be useful in the prototype fabrication stage. However, they pointed out that the final quality of street furniture heavily relies on the manufacturer's ability. While 3D printing might enable less skilled manufacturers to produce final items, skilled personnel would still be required for the 3D printing process.

In comparing current computer graphics and physical 3D modeling methods in the design process, one interviewee emphasized the price competitiveness of 3D printing technology compared to computer graphics. They mentioned that average architecture and landscape architecture firms typically pay around 500 to 700 USD per image for computer graphics, making 3D printing a potentially cost-effective alternative.

The size of 3D printed models was identified as a critical factor during the interviews. At the time of the interviews, 3D printed models were limited to dimensions of 20 cm x 20 cm x 20 cm, which posed challenges for larger-scale applications. Interviewees linked size to cost issues and expressed the need for larger-scale 3D printing to be feasible for widespread use in landscape architecture.

However, one interviewee argued that size was not a major concern, as size limitations are encountered not only in 3D printing but in other design media, such as computer graphics presented on monitors or paper.

Despite the discussions on size constraints, appropriate 3D printing sizes were suggested for landscape planning and design. An interviewee mentioned that the size would depend on the purpose, and smaller products of A3 or A2 size, for example, would be more efficient as design aids compared to larger formats.

Manufacturing time emerged as another key issue in the study. Participants acknowledged the long production time of 3D printing as a significant drawback. They compared it to the production of hand-made physical models and expressed the need for 3D printing to be faster and more efficient to compete effectively. One interviewee pointed out the challenge of reflecting design changes quickly in 3D models, which is essential in landscape design.

The level of detail supported by 3D printing technology was identified as a critical concern. Unlike architectural design, landscapes involve many natural forms, and 3D printers must be able to support these natural forms for practical implementation in the industry. The use of various materials and textures, such as vegetation and hardscapes, was highlighted as essential for creating realistic landscape designs using 3D printing.

The issues of detail, cost, and time were interrelated. More intricate details would require longer manufacturing times and could increase costs. This observation underscores the need for finding a balance between detail and practicality in implementing 3D printing technology in landscape architectural planning and design.

Some landscape architectural practitioners viewed 3D printing technology as just another tool with its own strengths and weaknesses. However, two interviewees recognized the potential for significant changes in current practices, especially in street furniture design, indicating that technology can drive transformative shifts in the industry.

Based on the case study's findings and the interviews, the study aimed to identify the relationships between the four main issues: cost, size, time, and level of detail, and their implications for the implementation of 3D printing technology in landscape design.

# Conclusions

3D printing technology has been widely recognized for its potential in planning, design, and education literature. However, in the context of landscape architecture, it has been relatively neglected. This study aimed to bridge this gap by combining insights from technological literature and landscape practitioner interviews to explore the potential of 3D printing in enhancing the landscape design process. Specifically, the study looked into how 3D printing could contribute to improving the level of detail, cost, scale, and time in landscape planning and design. Additionally, it investigated how 3D printing could facilitate the translation of scientific and technical understanding into the policy arena and improve communication, understanding, and negotiation among key stakeholders.

A design workshop conducted for secondary students in this study provided positive results, confirming the applicability of 3D printing in the current landscape architecture curricula. The workshop, which utilized 3D models, helped students grasp 3D design concepts effectively and sparked their interest, encouraging active participation. The 3D models were found to be valuable tools for explaining and discussing design ideas.

During the interviews with practitioners, the importance of credibility and interactivity was emphasized. However, this focus on methodology and justification might limit the potential impact of 3D printing in practice. Implementing a secure methodology could restrict the model to features that can be supported by recognized sources and extrapolation methods, leaving out potentially important elements. On the other hand, laypeople and clients often require more detailed and realistic impressions of landscape planning and design, where a more game-like apparent realism could be more effective.

In conclusion, the study highlights the promising prospects of 3D printing in the landscape architecture field, both in educational settings and in professional practice. It emphasizes the need to strike a balance between a secure methodology and the desire for more realistic and immersive representations to effectively communicate design ideas to various stakeholders.

Nonetheless, the active implementation of 3D printing technology in landscape architectural design processes requires resolution of several critical issues, including the technology's capabilities concerning level of detail, cost, time, and production size. These issues were found to be strongly interconnected. Notably, 3D printing technology shows great potential in efficiently producing small-scale landscape design objects, such as street furniture. However, the present study could not delve into a detailed analysis of each relation between detail, time, cost, and scale for 3D printing in the context of landscape architecture. Further research is needed to investigate these relationships separately, examining factors like cost-to-detail, detail-to-size, size-to-time, and time-to-cost problems in more depth.

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