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Exploring the Potential of 3D Printing Technology in Landscape Design Process

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Abstract: Advances in 3D printing technology are giving rise to attempts to utilize the technology in various fields, including landscape design. However, exploring the potential of 3D printing technology has been largely neglected in the context of landscape design and education. Therefore, this study aimed to examine the implication of 3D printing technology for both education and practice in landscape design. We analyzed the literature and examined the current state of 3D printing technology. We also conducted case studies with secondary school students and landscape practitioners to assess the implementation of the technology. Secondary school students demonstrated positive responses, such as increased interest and participation and improvement of understanding, through workshops using 3D-printed models. The semi-structured interviews with landscape practitioners on the implication of the technology confirmed the limitations of 3D printing in terms of cost, delivery time, scale, and level of detail.

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

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1. Introduction

3D printing technology, also known as digital fabrication, rapid prototyping, and solid freeform fabrication, is widely used by engineers and industrial designers to make physical prototypes that allow them to visualize and test new design proposals [1]. The recent popularization of 3D printing is expected to give rise to many corresponding and significant changes in various fields. For example, the use of a small-quantity production system in manufacturing allows the production of goods that conforms to consumer requirements, and is expected to yield large economic benefits [2]. The connection between 3D printing and design is also increasingly emphasized [2].

For its customizability potential, 3D printing has attracted the attention of the planning and design industry. According to Jung [3], 3D printing is actively implemented in sectors such as automobile, fashion, and architecture design. With the realization and development of 3D printers, the application areas are being expanded to sectors such as arts, medicine, aerospace, and design [3]. Thus, this design technology has a wide range of applications associated with virtually all industry fields. 3D printing can easily produce designs that would be challenging for other types of technology, at a significantly decreased time and economic cost. In addition, 3D printing allows production of early-stage supply to enable the assessment of early responses in the market, along with small-quantity batch production in response to changes, thereby enhancing the manufacturing system [3]. Therefore, 3D printing is envisaged to allow further developments in the design industry.

For the education sector, 3D printing is already being used in architecture, computing, ergonomics and human factors, and medicine. In the fields of computer graphics, engineering design, medical design, and product and industrial design, 3D printing is actively used in university curricula [4]. Moreover, 3D printing has been demonstrated to be an excellent technology for improving students' understanding of geological formations on a scale not achievable with the use of only 3D images [5]. Students' understanding of topography is improved by printing 3D models [6,7]. Indeed, this technology is helpful in improving the sense of space owing to the tactile and observation effects obtained by producing physical models [8,9].

3D printing technology has also been adopted for interdisciplinary training purposes. According to Eisenberg [8], the theory, concepts, and practical applications of 3D printing technology "relate to a range of subject areas including IT, art and design, science, engineering, robotics, mathematics and humanities." In a secondary school in Australia that implemented 3D printing technology as an educational tool [10], 3D printers are well incorporated in the curricula, popularizing the technology among the students, teachers, and parents. The school's 3D printers are used for projects such as playground design and production, character creation for use in stop-motion films and electronic books, and constructions. In more complex cases, a computer-aided design (CAD) program has been implemented to build solid objects. This engagement has yielded benefits across all subjects, because the school engages in considerable cross-curricula practice. In the UK, the Department for Education funded a small 3D printing project between 2012 and 2013 aimed at exploring the potential use of 3D printers to enrich teaching across science, technology, engineering, and mathematics, as well as design, subjects. Particularly, schools were asked to explore innovative ways of using the technology in teaching complex scientific and mathematical concepts [11]. The application of 3D printing technology has been shown to have positive effects in the education sector. For example, one study observed the improvement in students' oral presentation skills through education using 3D printing [12]. Teachers have reported that using 3D printing technology has helped motivate students and foster student-centered learning [13,14]. In the same manner, the education sector for landscape architectural planning and design could employ 3D printing technology in design workshops, procedural phases, and participation and community workshops, instead of utilizing fine finished output.

As discussed above, 3D printing technology has many potential applications in education and practice in various fields. However, in the landscape architecture field, practical discussions on 3D printing technology and its applicability in the educational field have been rare [15]. Meanwhile, 3D printing technology costs are likely to decrease in the future, which would encourage increased adoption of this technology in other fields. The technological tools are likewise expected to become more powerful, intuitive, and efficient. The opportunities likely to arise in practice therefore need to be evaluated, with due consideration for the risk of inappropriate application. As the lead author has worked on many visualisations, Landscape Visual Impact Assessments, and computer graphics, both professionally and academically, this study examines previous the literature on 3D printing and landscape architecture and intends to conduct a case study using 3D printing in education and an interview with landscape architects in order to prepare the basis for the application of 3D printing in the landscape architectural field. In this way, the paper intends to discover the direction of development in future 3D printing technology. Given this context, the present study examined the literature on 3D printing and landscape architecture. We also conducted a case study of 3D printing in education and interviews with landscape architects, the results of which were expected to prepare the basis for the application of 3D printing in the landscape architectural field.

2. 3D Printing Technology in Landscape Architecture: Literature Review

In conventional landscape architectural design and planning processes, drawings and photographic representations are commonly used [16–19]. The related image-based methods allow vital comparisons of the before and after situations of a design. However, from a practical perspective, the use of visualizations has been met with some degree of skepticism [20–23]. Unlike computerized visualizations, where a mismatch between key players' expectations and development outcomes is commonly experienced, there is less concern regarding the credibility and interactivity of physical models. That is, 3D models can offer a true reflection of the eventual construction. Implementation of the landscape architectural design process can be challenging with regards to design outcomes and decisions. The process of establishing appropriate understanding of the planning impact is often complex and subjective and involves many stakeholders [16]. Planning and design decisions can be made via conventional methods, such as drawings and plans; however, these approaches are oriented toward trained personnel or experts and are limited in terms of information communication. For example, in the case of maps, some users have difficulty interpreting the visual variables owing to their lack of training or familiarity.

Physical models are expected to overcome these limitations of 2D visualization. Over the past 50 years, physical models have been used for a range of purposes and have become gradually more versatile in a number of fields [24]. For instance, ship builders and car and aerospace engineers have implemented physical 3D models to represent their designs. Physical models have diverse purposes; they are used for education, testing, and sales generation within developments. Indeed, physical models are powerful tools, because they present 3D objects [24]. In particular, information in the third dimension is not lost, as is a common problem in cartography [24]. On 2D maps, the third dimension is represented by size, color, shading, texture, shape, and orientation. A 3D model would be better able to show geographic information. 2D technologies, such as imaging and video, have enabled a leap in expressive skills, but these technologies have limitations in that they can only interpret visually [25]. Physical models have the advantage over 2D drawings; slight movements of the head or body suffice to view parts of the model covered by obstacles in the line of sight, such as high prisms or mountains in the foreground. Thus, with 3D models, people can easily view and grasp what is presented. In other words, a 3D model shows the design proposal more realistically, making evaluation easier, helping to find design flaws, and facilitating communication between clients and planners [15]. In landscape architecture, 3D computer graphics are used to overcome the difficulties entailed with explaining with only a 2D plan; in many cases, 3D models are preferred [15].

Physical models also have the advantage of providing additional sensory experience. 3D-printed models provide opportunities for the simultaneous action of multiple senses [25]. Providing multi-sensory experiences is one of the important reasons for 3D printing drawing more attention recently [26]. Moreover, whenever haptic communication is required, conventional media cannot support the interaction among the stakeholders in landscape planning and design processes. The planning stakeholders, such as the community, planners, and designers, have different levels of technical understanding. In communication among stakeholders, drawings and computer visualizations have played an important role. As discussed above, physical models are intended for communication, and one essential and emergent role for physical models in landscape architecture is as components in public debate over alternative futures [27].

We considered the potential of 3D printing in landscape modeling in the context of physical models, which can be understood easily, as a major form of visualization used in landscape design practices. Physical models have often been used in the landscape field, and 3D printing technology can be used as one of the tools to produce such physical models. In particular, 3D printing technology has advantages compared with the existing physical modeling. At present, most physical models employed in civil engineering and architecture use clay, cardboard, foam, and/or wood. These physical models are typically cut by hand and subsequently assembled piece by piece. This process tends to be time consuming. In addition, as topographic terrain has complex geometry and is difficult to produce using such methods, large inaccuracies often occur as a consequence [24].

However, despite its benefits for design, the implementation of 3D printing technology in landscape architectural planning and design has not been investigated sufficiently. Various reasons and constraints may explain this phenomenon.

Landscape architectural planning and design incorporate natural materials, such as vegetation, and are often applied to large-scale areas. The current 3D printing technology cannot support such cases because of cost and size constraints. As mentioned in some studies, the speed of 3D printing—the time it takes to print a large-scale model—is one of its limitations, which makes it difficult to apply 3D printing technology in most fields [28,29]. In addition, as pointed out by Neumüller et al. [26], although developing at a considerably rapid pace, 3D printing technology still has limitations in color expression and application of materials, indicating palpable limits to printing complex landscape architectural models in particular. According to Ervin [27], the term "landscape" may be used to refer to a complex cultural construction, a simple aggregation of elements, such as landform, water, and vegetation, or a complex interaction of dynamic forces at work over time scales ranging from seconds to centuries. From a modeling perspective, landscapes are highly complex structures covering large areas. In the real landscape, the most important variables determining visual appearance are the following: terrain, vegetation, animals and humans, water, built structures, atmosphere, and light [30].

Steinhilp and Kias [15] analyzed several 3D printing technologies to find a suitable technology for the landscape field, and they reported that high speed and low cost are valued over high precision. These characteristics are suitable when the 3D printed model is used to show the overall target site rather than show the target site accurately, as is one of the roles of the physical models often used in the landscape architecture field. Depending on the target planning or design problem, or the landscape in question, a landscape architectural representation does not necessarily have to cover all elements. In addition, it is not always necessary for all elements to be represented in high detail. However, each element could act as a major obstacle to achieving a representation with a high degree of realism [30]. For example, real vegetation is extremely complex, as it consists of a large number of objects, such as leaves, flowers, and branches, and the vegetation elements of a landscape are also very diverse, potentially causing greater challenges [30]. Given the complexity of landscapes, the creation of landscape architectural 3D printing could be highly arduous. However, the omission of details of the real landscape from a virtual landscape would yield a certain sterility [31], and very abstract representations appear inappropriate for determining landscape aesthetic/scenic beauty values [32].

Overall, although a number of issues affect the implementation of 3D printing technology in the landscape architectural planning and design process, we categorized the current considerations into four items: level of detail, production cost, production time, and scale. This study also aimed to determine the relations between these issues. We adopted a holistic research approach to elucidate some of the complexities embedded in the practice of landscape planning and design. The main idea behind the approach mirrored the landscape practitioners' holistic handling of problem identification and solving, and their ability to synthesize and coordinate bits and parts into a whole without detailed knowledge of each. The approach was based on two elements: a descriptive framework and a storytelling technique. The descriptive multi-level framework could support the achievement of a better overview and understanding of the implementation and use of 3D printing technique in real-life projects. The framework was grounded on four dimensions of the implementation: cost, level of detail, time, and scale. Based on the main framework elements, different tools and models were introduced to provide an overview of the factors affecting the implementation and use of 3D printing technology. These tools operationalized the relations between the landscape planning and design process and 3D printing technology [33].

Although the importance of boundary work and potential for interactive design have been recognized within the industrial design application literature, this concept has been largely neglected in landscape planning and design implementation. In our work, the 3D printing technology literature and findings from landscape practitioner interviews were uniquely combined to shed light on the potential of 3D printing to enhance design communication and participation.

3. Methodology

Considering the advantages and disadvantages of 3D printing technology, this study aimed to investigate the potential of 3D printing techniques for the landscape architectural planning and design process, targeting improved communication within the industry and overall development. In particular, we sought to explore the possibility of using 3D printing in the landscape architectural education curriculum.

In order to investigate the aims and purposes of the study above, qualitative research and a case study are employed as the methodology. Semi-structured interviews are used to acquire data. The case study data have been gathered from several evidence sources, a strategy recommended by Yin [34] to ensure the validity of the qualitative study. Via surveys with secondary students and landscape practitioners, the benefits and disadvantages of this technology are analysed and methods of overcoming the problems associated with innovative technology are discussed.

3.1. Secondary School Workshop

Whilst the lead author has worked on many landscape planning and design projects involving 3D printing technology, the research described in this paper began with a landscape architectural design workshop study involving a secondary school student. From 2016 to 2019, 50 students were recruited each year to participate in the Major Experience program. The workshop was conducted for secondary school students to experience what they would learn at a university majoring in landscape architecture and to enhance their understanding of the major. Secondary school students are on the verge of choosing a major that they will learn in college. We recognized the need for their classes to improve the students' understanding of the landscape architecture major. During the day, students participated in a program consisting of three sessions: a general lecture for introducing landscape architecture, an experiential workshop (including a design workshop using 3D-printed models), and a conversation with senior students.

Experimental 3D printed models, which were physically printed in three dimensions, were developed for the proposed workshops. As time and the budget were limited, a simplified geometric approach using "lollipop-like" tree formation was implemented, simplified with modular toy blocks on 30 cm $\times$ 30 cm square boards. In particular, in this study 3D models could not provide various tree shapes and only two different types which were broadleaved and conifers shapes were 3D printed for the case study purpose. Vegetation, such as deciduous and evergreen trees, was created using a Da Vinci 1.0 AiO 3D printer, for fitting to the brick modules used in the workshop, ensuring appropriate size and scale in the modular system. This model was used in a landscape design workshop for secondary school students participating in a landscape course experience. Usability of 3D printing in education was central to the workshop discussion. Using the modular 3D-printed model, the students could install (plant) a garden as required by the assigned theme, as a design exercise within the workshop.

A brief survey conducted after the workshop, and the feedback from the participants was collected. As well as general questions (as shown in Table 1), the key question variables within the questionnaire were understanding of the subject 'landscape architecture' with 3D models workshops and how satisfying were the training processes. The outline of the questionnaire survey could be divided into two main question groups. In the first question group, the participants were asked about their most preferred program among lecturing, workshop, and talk sessions with current students. The other question group, asked how helpful the overall program was in understanding the subject of landscape design. These questions were provided with a 5 point Likert scale. At the end of the two question groups, the participants were asked to provide descriptive answers to explain the reason why or why not the program they chosen had been preferred and perceived to be helpful in understanding the subject of landscape design. We analyzed the survey results of 177 participants, excluding those who had values that were omitted from the survey conducted after the program (Table 1).

Table 1. Characteristics of the major experience program participants.

Division		**n**	**Ratio (%)**
Total		177	100
Year of participation	2016	49	27.7
	2017	46	26
	2018	45	25.4
	2019	37	20.9
Sex	Male	60	33.9
	Female	117	66.1
Age (years)	17	4	2.26
	18	53	29.9
	19	120	67.8

3.2. Practitioner Interviews

While the secondary school workshops to identify emerging issues in 3D printing technology implementation in education field were carried out, a series of semi-structured interviews with landscape practitioners was performed in order to discover the potential for 3D printing technology to enhance the landscape planning and design process in practical terms.

The findings were generated from six semi-structured and open-ended interviews conducted in 2018 with practitioners involved in landscape design and project management. To obtain broad insights into the studied project beyond the subjective world of the single respondent, we selected project actors who represented different backgrounds, experiences, and perspectives.

Through these interviews, reflections on the issues and challenges of implementing 3D printing technology in landscape practice were explored. The overall approach to the interviews was first piloted with landscape students at a university. Subsequently, six professional practitioners were interviewed (Table 2). Most of the interviewees had experience with a number of projects relating to landscape architectural planning, design, and management and planning policies, involving both the public and private sectors. They had often been members of community consulting group committees and had been required to communicate visual representations to broader audiences. A few participants within the landscape practitioners group had extensive experience with 3D printing, and had become well aware of this technology through their practice. All interviewees were known to the lead author (through previous work on a range of landscape architectural projects as a landscape designer). As such, a form of convenience sampling was used. However, the interviewees were selected to encompass a broad range of practices and experiences.

Table 2. Interviewee list.

	Title	**Organization**	**Field**	**Experience**
Interviewee A	Professor	University	Landscape education	13 Years
Interviewee B	Owner/head of landscape design	Landscape consultant	Landscape design	30 Years
Interviewee C	Landscape consultant	Multidisciplinary engineering consultant	Landscape design and planning	2 Years
Interviewee D	Team leader/landscape design department	Major construction company	Landscape planning and construction management	17 Years
Interviewee E	Owner/head of design	Street furniture manufacturer	Street furniture design	15 Years
Interviewee F	Senior landscape Consultant	Landscape consultant	Landscape design	11 Years

The outline of the semi-structured interviews started with questions about the interviewees. A total of six in-depth interviews was carried out with practitioners who have in field experience of between two to thirty years. Professionally, they worked in construction companies, multi-disciplinary practices, design studios, and the public sector. The interview questions were divided into five different groups. Each question group is as below.

1. Experiences in 3D printing in landscape design field
2. If any, describe the experience of using 3D printing technology
3. Pros and cons of implementing 3D printing technology; recommendations
4. Explain your knowledge about the technology, and the potential of implementing 3D technology in your field
5. Review of tradeoffs in 3D printing technology: Cost, scale, time, level of detail

The interviews lasted between one and two hours, beginning with general background questions on the interviewees' experience and previous use of 3D printing technology. This was followed by a demonstration of 3D printing technology samples. During the demonstrations, the interviewees were encouraged to explore and touch the samples and provide opinions on the technology. A more open discussion followed, in which issues relating to the comparative strengths/weaknesses of 3D printing technology were explored, along with the potential for wider implementation within the landscape architectural planning and design process in future. If required, further prompting was provided regarding the key issues of concern. However, this was rarely necessary. Thematic analysis was used, which was conducted by each author independently.

Moreover, thematic analysis was used, setting up four different issues relating to each other; cost, size, time, and level of detail. The individual themes could act supportively or as trade-offs and the analysis of the study was based on the four themes (Section 4.2).

4. Case Study Results: 3D Printing in Landscape Architectural Education and Landscape Design

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

4.1. Applicability of 3D Printing in Landscape Architecture Education

On questions regarding the most preferred session among the three conducted, experiential 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).

Table 3. 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

Regarding the reason for choosing the preferred session, the students mentioned having fun by making something "themselves." They also cited the creativity of the activity as a reason.

> "The activities to create a park with 3D models were good because I could design the village myself."

> "It was nice to be able to show off my creativity through a park-making workshop using 3D models."

In addition, some of the participants answered that they preferred the workshop because it was a class where they made something themselves and practiced what was taught, unlike general lecture classes.

> "It was nice to be able to do things, such as in the park and garden design workshop, that I couldn't experience anywhere else."

> "I liked the variety of the major experience sessions. The park-designing workshop was too short, and the one-sided lecture classes were boring."

Among the participants, several students stated that collaboration and discussion with other participants proved to be fun. The advantages of delivering presentations using 3D printing were also confirmed [12].

> "I had fun thinking for myself in designing the park and then presenting my work with other teams."

> "Creating a 3D park was what I really wanted to do, and the cooperation between the team members was brilliant."

In addition, 94.35% of students answered positively (Yes or Very much) to the question as to whether the major experience workshop was helpful in expanding their understanding of the major (Table 4). The participants reported that the reason they answered positively was that their understanding related to the major had been improved through the workshop.

Table 4. 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

> "It was great that I felt like I had experienced the things I would learn later through the garden and park design practice."

> "It seems that I was able to approach landscape architecture in an easier and more friendly way through the workshop experience."

> "After graduation, I want to work on designing and decorating cities based on their surrounding environments. I thought that the Department of Landscape Architecture literally only landscaped nature or forests, but it was fun to have an activity that matched what I wanted. By participating, I became more resolved about my career path."

In addition, among several workshop sessions, the design workshop using 3D models was evaluated as being easier to understand compared with the CAD workshop, which was about creating 2D design drawings. The participants responded that understanding what to plan and how to design was easier in the 3D design workshop. Meanwhile, many students answered that the CAD workshop, which dealt with 2D programs, was difficult and that they needed more help from senior students.

These results can be considered in conjunction with the research demonstrating that students can acquire knowledge beyond abstract concepts through the production of actual 3D printing models [4,35]. This point also demonstrated the effect of improving learning ability through the use of more than one type of sensory processing [25].

> "All other programs were good, but the CAD program was too difficult for the student level."

> "When I asked a question, the senior students explained the concepts kindly in an easy-to-understand manner. I wish there were more people who helped me in CAD practice."

> "Above all, it was nice to be able to learn about the department in detail, to experience what to learn, and to take classes, but it was a little disappointing because the CAD program was a difficult experience."

Based on the positive practice results, 3D printing technology was seen to have potential for improving the landscape design process. Although the potential of this technology has been demonstrated in a range of academic studies, as illustrated in the scientific and design interaction literature, realizing this potential through wide implementation in practice would be far from simple. Encouraged by the success of this project, we conducted semi-structured interviews with experienced landscape practitioners to investigate the implementation of 3D printing technology in landscape design.

4.2. Suitability of 3D Printing for Landscape Design: Cost, Size, Time, and Level of Detail

Computer visualization technology is often employed within the landscape planning and design field, but many organizations and professional bodies have worked to improve the credibility and interactivity of this method. 3D printing technology is recognized as one avenue for improving interactivity and credibility; however, it is not usually implemented by landscape professionals in South Korea, despite being commissioned by developers and governments following consultation with the relevant authorities. Physical 3D modeling constitutes a supplementary approach, and its use within planning permission processes is uncommon. Computer graphics are frequently produced. Implementation of 3D printing technology is a technical exercise with an emphasis on textual description of development impacts.

As noted above, the majority of the interviewees did not have empirical experience of the use of 3D printing technology in their own projects. Several reasons for this were given, examples of which are listed below:

> "It is quite difficult to use 3D printers. No one owns them. This must be an issue of high cost." (Interviewee D)

> "In my company, we do not have one." (Interviewee C)

> "I do not see any necessity to use 3D printers in my job." (Interviewee E)

> "Several reasons can be given, such as high cost and size limits. Therefore, 3D printing is only for street furniture and smaller site designs." (Interviewee F)

Based on the above responses, the implementation constraints could be summarized as high cost, size limits, and work relevance. Meanwhile, only one interviewee, with 30 years of professional experience, reported actual implementation experience:

> "I only used 3D printing models for decking design in a lakeside project in 2016. The outcome was of sufficient quality and was presented to my client." (Interviewee B)

Having this experience, the interviewee enquired whether the printing material could be changed and expressed a desire to use a variety of materials. Moreover, the interviewee commented on current size limitations and stated the usefulness of a technology that could easily print larger items.

In addition, the value of implementing 3D printing technology was considered. An interviewee, a street furniture designer, stated the following:

> "I only have knowledge of 3D printing from the news; therefore, I am not the person who decides on usage. However, I can say that the implementation of 3D printing technology in the street furniture industry could be successful. For instance, prototype fabrication with a 3D printer before manufacturing could save time and money." (Interviewee E)

Concerning the value of 3D printing implementation, another interviewee made an interesting point about the consultation process:

> "For smaller things, such as benches, entrances, and art features, 3D printing could be a great tool to aid client understanding during consultation. Although there are many 3D modeling software programs, such as Revit and SketchUp, seeing and touching physical models would be more useful." (Interviewee F)

Regarding cost issues of implementing digital manufacturing technology, all interviewees gave opinions despite their lack of actual experience.

> "I would like to see higher-durability material for 3D model production, such as metal. A robust material could preferably be used." (Interviewee A)

> "The cost of 3D printing is presumably high. Therefore, I would like to see that 3D models (printed) can be produced more cheaply than physical 3D models. Otherwise, digital manufacturing cannot be implemented in this field." (Interviewee B)

> "It is difficult for smaller firms to acquire 3D printing facilities." (Interviewee C)

> "In my experience as a street furniture manufacturer, 3D printing technology is only useful in the prototype fabrication stage. Street furniture quality is heavily dependent on manufacturer ability. If we used 3D printing methods, even less skilled manufacturers could produce final items; however, other skilled personnel would be required for the 3D printing process." (Interviewee E)

A comparison was made between current computer graphics and physical 3D modeling methods in the design process.

> "Average architecture and landscape architecture firms pay $500 - 700$ USD for computer graphics for their designs (per image); thus, the implementation of 3D printing technology relies on such price competitiveness." (Interviewee F)

Manufacturing size issues were also found to be critical. At the time of the interviews, 3D printed models were limited to dimensions of 20 cm × 20 cm × 20 cm. Most of the interviewees established links between size and cost issues.

> "To achieve wide use, larger-scale 3D printing, such as for real-sized benches and chairs, must be feasible." (Interviewee A)

> "In landscape architecture, everything is life scale. Therefore, if 3D printing can be used for detailed street furniture, it would be acceptable; otherwise, larger-scale printing technology must be developed." (Interviewee B)

> "Within the budget permitted, larger scale is preferable." (Interviewee F)

However, another interviewee claimed that size did not matter.

> "In practice, computer graphics are currently presented on monitors or pieces of paper, for which size issues remain. Therefore, size problems are encountered not only in 3D printing. All design media have the same issue." (Interviewee C)

Meanwhile, appropriate 3D printing sizes were suggested for landscape planning and design.

> "The size would depend on the purpose; however, for 3D printing, smaller products of A3 or A2 size, for example, would be more efficient as design aids rather than larger formats." (Interviewee D)

Manufacturing time was another key issue identified in this study. Most of the participants were aware of the long production time of 3D printing as a significant drawback.

> "Like a 3D scanner, 3D printing must be produced simultaneously with its order." (Interviewee A)

> "This technology should be compared with the production of hand-made physical models. If 3D printed model production is faster or better, then this technology could be widely used." (Interviewee B)

> "The problem I can see is that landscape design can be conducted in real time. Many design changes can be made, and 3D models must reflect those changes quickly." (Interviewee D)

Finally, the level of detail that can be supported by 3D printing technology was identified as a critical issue.

> "Unlike architectural design, landscapes have many natural forms. 3D printers must support those natural forms for them to be implemented in the industry." (Interviewee C)

> "At present, issues regarding materials exist. A single color or material cannot yield appropriate landscape designs. I think that, similar to hand-made models, 3D printing must support various materials and textures, such as vegetation and hardscapes." (Interviewee D)

The issue of detail was linked to cost and time. For example, greater detail would require longer manufacturing time, which would entail higher costs. Based on an analysis of the responses obtained in the case study, we determined the relations between the four main issues.

For some landscape architectural practitioners surveyed in this work, 3D printing technology was seen as simply another tool with its own strengths and weaknesses. Although this would appear to be an appropriate assessment and consistent with the idea that there is no universal landscape planning and design tool [36], as noted by Fleischmann [37], technology can also show agency in changing pre-existing processes. As noted above, two interviewees suggested that 3D printing technology could yield significant changes in current practices, particularly for street furniture design.

5. Discussion

In the case studies described above, we examined the applicability of 3D printing technology in the landscape architecture field through landscape design workshops for students using 3D printed models and interviews with landscape practitioners. Through design workshops for students, our study confirmed the positive aspects of the application of 3D printing technology in landscape education. The students indicated that the class using 3D models was interesting and that the use of printed models helped improve their understanding of the landscape architecture major and the design process. In particular, some students compared the 3D design workshop with the 2D CAD design class that was held separately and said that the former was easier, more interesting, and stimulated creative work. In addition, some students stated that they had fun in the process of making things by hand and discussing the results using 3D models. As confirmed in the literature [12,25,26], these responses can be attributed to the tactile effect of classes using a 3D printed model and the effect of improving oral presentation skills.

In the interviews with landscape practitioners, we examined their opinions on cost, level of detail, time, and scale, which are major issues arising when applying 3D printing technology in the landscape field. Generally, most of the interviewees did not have much experience in implementing 3D printing technology, which proves that 'unfamiliarity' led to a lack of technology adaptation in not only educational area but professional practices, as Krassenstein [5] claimed. Moreover, they evaluated the high cost and size limits as the main factors for the slow reception of 3D printing technology in the landscape architecture field. Indeed, landscape practitioners, as in other fields [4], have expressed concern about the high cost of 3D printing technology. In addition, one interviewee who had used 3D-printed models in practice, pointed out the limited size and types of material as problems. The scale issue was also pointed out as a limitation of 3D printing technology, although a number of the interviewees claimed this issue to exist in other modeling media. The experts interviewed also identified the time-related issue as a hindrance to the application of 3D printing in the landscape architecture sector. In particular, they said that 3D printing should be faster compared with the production of physical models by hand. In addition, regarding the level of detail, they responded that for this technology to be applied in the landscape field, it should be able to express various natural forms, textures, and materials of landscape elements. Despite these limitations, the landscape practitioners generally positively evaluated the use of 3D printing models for customer consultation.

Overall, 3D printing technology is achieving positive reactions across the landscape architecture field both in education and practice. In particular, in both education and practice fields (especially in relation to customer consulting), a common possibility was confirmed: understanding and interest levels could be enhanced with the use of 3D-printed models. As mentioned above, traditionally, physical models were widely used in landscape architecture; therefore, the study was positive about the possibility of producing physical models by 3D printing technology. However, such beneficial 3D printing technology in landscape architecture has not been explored sufficiently, particularly within landscape planning and design.

The paper portrays current trends in 3D printing technology implementation in the landscape field and produces evidence of what limits the implication of the technology, and why. In particular, the paper illustrates empirically the views of student participants and professional practitioners. While students appreciate the technology in terms of interest and learning efficiency, interestingly, professional practitioners point out realistic limits of implementation. Furthermore, from the practical landscape design point of view, the experts indicated that cost issues and level of detail were main drawbacks in using the technology. However, there is a possibility of using the technology more if production time was reduced. Moreover, there are several issues to be resolved in order to implement 3D printing technology. Although education related to 3D printing is becoming increasingly common in various fields, research indicates that the related support for education, such as educational books and materials, is insufficient [4,38]. To increase the application of 3D printing technology and maximize its various advantages in the landscape architecture field, stakeholders should develop educational curriculums for the use of 3D printing in the landscape field and undertake further research on overcoming the limitations suggested in the interviews with practitioners. Currently, there is a number of research activities in adaptation of the technology; therefore, this paper predicts that many drawbacks in implementing the technology will be resolved through training and technological advancements in the future.

6. Conclusions

Despite the recognized importance of 3D printing technology within planning, design, and education literature, it has largely been neglected in the context of the landscape architecture field. In this study, we combined technological literature and findings from landscape practitioner interviews to explore the potential of 3D printing technology in enhancing the landscape design process. Hence, the possible contribution of 3D printing in enhancing the level of detail, cost, scale, and time within the process of landscape planning and design was explored, along with its potential to improve the translation of scientific and technical understanding into the policy arena, and to encourage better communication, understanding, and negotiation among key actors.

The design workshop conducted for secondary students in this study positively confirmed the applicability of 3D printing in the current curricula. In particular, design workshops using 3D models can help students understand 3D design, and above all, are effective in enhancing students' interest and inducing participation. The 3D models were also useful in the process of explaining and discussing designs. The interviewed practitioners emphasized the importance of employing a secure methodology; however, this focus on credibility and interactivity may significantly limit the salience of 3D printing in practice. The adoption of such a methodology would imply limiting the model to landscape architectural features that can be justified using recognized sources and extrapolation methods. Any features that may distract from this focus would need to be removed. In contrast, lay people are likely to require detailed impressions of the landscape planning and design of a development, and game-like apparent realism may be more salient in such cases.

Nevertheless, a large number of issues require resolution for the active implementation of 3D printing technology within landscape architectural design processes, such as the capabilities of the technology in terms of level of detail, cost, time, and production size. These issues had strong correlations. In particular, 3D printing technology could be efficiently used in small-scale landscape design objects, such as to produce street furniture. The present study could not incorporate a detailed analysis of each relation between detail, time, cost, and scale for 3D printing in the context of landscape architecture. Further research must be conducted to investigate the relations of some important factors separately, such as cost-to-detail, detail-to-size, size-to-time, and time-to-cost problems.

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References

1. Walters, P.; Davies, K. 3D printing for artists: Research and creative practice. *Rapp. J. Nor. Print Assoc.* **2010**, *1*, 12–15.
2. Jin, S.Y.; Oh, C.S. A Study on the Effects of 3D Printing on Design Business. *J. Korean Soc. Des. Cult.* **2014**, *20*, 75–86.
3. Jung, J.W. A Study on the way of revitalization for design Industry of 3D Printing Technology. *J. Korea Des. Knowl.* **2014**, *31*, 43–52.
4. Ford, S.; Minshall, T. Invited review article: Where and how 3D printing is used in teaching and education. *Addit. Manuf.* **2019**, *25*, 131–150. [CrossRef]
5. Krassenstein, E. Why 3D Printing Needs to Take Off in Schools around the World. Available online: https://3dprint.com/27743/3d-printing-benefits-schools (accessed on 10 January 2021).
6. Corum, K.; Garofalo, J. Using digital fabrication to support student learning. *3D Print. Addit. Manuf.* **2015**, *2*, 50–55. [CrossRef]
7. Huleihil, M. 3D printing technology as innovative tool for math and geometry teaching applications. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2017; Volume 164, No. 1; p. 012023.
8. Eisenberg, M. 3D printing for children: What to build next? *Int. J. Child-Comput. Interact.* **2013**, *1*, 7–13. [CrossRef]
9. Chen, M.; Zhang, Y.; Zhang, Y. Effects of a 3D printing course on mental rotation ability among 10-year-old primary students. *Int. J. Psychophysiol.* **2014**, *2*, 240. [CrossRef]
10. Gray, C.; Hughes, W. *Building Design Management*; Routledge: London, UK, 2001.
11. 3D Printers in Schools: Uses in the Curriculum. Available online: https://www.gov.uk/government/publications/3d-printers-in-schools-uses-in-the-curriculum (accessed on 5 August 2020).
12. Schelly, C.; Anzalone, G.; Wijnen, B.; Pearce, J.M. Open-source 3-D printing technologies for education: Bringing additive manufacturing to the classroom. *J. Vis. Lang. Comput.* **2015**, *28*, 226–237. [CrossRef]
13. Fernandes, S.C.; Simoes, R. Collaborative use of different learning styles through 3D printing. In Proceedings of the 2016 2nd International Conference of the Portuguese Society for Engineering Education (CISPEE), Vila Real, Portugal, 20–21 October 2016; pp. 1–8.
14. Loy, J. eLearning and eMaking: 3D Printing Blurring the Digital and the Physical. *Educ. Sci.* **2014**, *4*, 108–121. [CrossRef]
15. Steinhilp, W.-M.; Kias, U. Comparison of 3-D Printing Techniques Usable in Digital Landscape Architecture. 2009. Available online: http://193.25.34.143/landschaftsinformatik/fileadmin/user_upload/_temp_/2010/Proceedings/Buhmann_173-181.pdf (accessed on 10 January 2021).
16. Lai, P.C.; Kwong, K.-H.; Mak, A.S. Assessing the applicability and effectiveness of 3D visualisation in environmental impact assessment. *Environ. Plan. B Plan. Des.* **2010**, *37*, 221–233. [CrossRef]

17. Berry, R.; Higgs, G.; Fry, R.; Langford, M. Web-based GIS Approaches to Enhance Public Participation in Wind Farm Planning: Web-based GIS Approaches to Enhance Public Participation. *Trans. GIS* **2011**, *15*, 147–172. [CrossRef]
18. Danese, M.; Las Casas, G.; Murgante, B. 3D simulations in environmental impact assessment. In *International Conference on Computational Science and Its Applications*; Springer: Berlin/Heidelberg, Germany, 2008; pp. 430–443.
19. Palmer, J.F.; Hoffman, R.E. Rating reliability and representation validity in scenic landscape assessments. *Landsc. Urban Plan.* **2001**, *54*, 149–161. [CrossRef]
20. Kitchen, T. *Skills for Planning Practice*; Palgrave Macmillan: London, UK, 2007.
21. Appleton, K.; Lovett, A. GIS-based visualisation of development proposals: Reactions from planning and related professionals. *Comput. Environ. Urban Syst.* **2005**, *29*, 321–339. [CrossRef]
22. McQuillan, A.G. Honesty and Foresight in Computer Visualizations. *J. For.* **1998**, *96*, 15–16. [CrossRef]
23. Sheppard, S.R.J. Guidance for crystal ball gazers: Developing a code of ethics for landscape visualization. *Landsc. Urban Plan.* **2001**, *54*, 183–199. [CrossRef]
24. Jacobs, L. Terrain Modeling Using Rapid Prototyping. Available online: https://www.researchgate.net/profile/Laura-Jacobs-7/publication/251798764_TERRAIN_MODELING_USING_RAPID_PROTOTYPING/links/54866c470cf268d28f045011/TERRAIN-MODELING-USING-RAPID-PROTOTYPING.pdf (accessed on 10 January 2021).
25. Horowitz, S.S.; Schultz, P.H. Printing space: Using 3D printing of digital terrain models in geosciences education and research. *J. Geosci. Educ.* **2014**, *62*, 138–145. [CrossRef]
26. Neumüller, M.; Reichinger, A.; Rist, F.; Kern, C. 3D printing for cultural heritage: Preservation, accessibility, research and education. In *3D Research Challenges in Cultural Heritage*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 119–134.
27. Ervin, S.M. Trends in Landscape Modeling. Available online: http://193.25.34.143/landschaftsinformatik/fileadmin/user_upload/_temp_/2003/2003_Beitraege/05ervin.pdf (accessed on 10 January 2021).
28. Easley, W.; Buehler, E.; Hurst, A.; Salib, G. Fabricating Engagement: Benefits and Challenges of Using 3D Printing to Engage Underrepresented Students in STEM Learning. In Proceedings of the 2017 ASEE Annual Conference & Exposition, Columbus, OH, USA, 24 June 2017.
29. Plemmons, A. Building a culture of creation. *Teach. Libr.* **2014**, *41*, 12.
30. Lange, E. Visualization in Landscape Architecture and Planning: Where We Have Been, Where We Are Now and Where We might Go from Here. Available online: https://www.semanticscholar.org/paper/Visualization-in-Landscape-Architecture-and-%3A-Where-Lange/085dc0ca8fd28d0b71cdf9cb5a63871ef8559215 (accessed on 10 January 2021).
31. Ervin, S.M. Digital landscape modeling and visualization: A research agenda. *Landsc. Urban Plan.* **2001**, *54*, 49–62. [CrossRef]
32. Daniel, T.C.; Meitner, M.M. Representational validity of landscape visualizations: The effects of graphical realism on perceived scenic beauty of forest vistas. *J. Environ. Psychol.* **2001**, *21*, 61–72. [CrossRef]
33. Kyungjin, A.N. Implementation of Computer Visualisation in UK Planning. Ph.D. Thesis, Newcastle University, Newcastle upon Tyne, UK, 2012.
34. Yin, R.K. *Case Study Research and Applications: Design and Methods*; Sage Publications: Thousand Oaks, CA, USA, 2017.
35. Kostakis, V.; Niaros, V.; Giotitsas, C. Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece. *Telemat. Inform.* **2015**, *32*, 118–128. [CrossRef]
36. Appleton, K.; Lovett, A.; Sünnenberg, G.; Dockerty, T. Rural landscape visualisation from GIS databases: A comparison of approaches, options and problems. *Comput. Environ. Urban Syst.* **2002**, *26*, 141–162. [CrossRef]
37. Fleischmann, K.R. Boundary Objects with Agency: A Method for Studying the Design–Use Interface. *Inf. Soc.* **2006**, *22*, 77–87. [CrossRef]
38. Paudel, A.M.; Kalla, D.K. Direct digital manufacturing course into mechanical engineering technology curriculum. In Proceedings of the ASEE's Annual Conference & Exposition, New Orleans, LA, USA, 26–29 June 2016; p. 26848.