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Article

The Role of 3D Printing Technology in Landscape Architecture Teaching and Learning Practices

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Abstract

3D printing technology has many known advantages in the education field. However, the utilization of 3D printing in landscape architecture teaching practices has not been fully explored. The potential of 3D printing in landscape architecture and graphic design is valuable to the teaching and learning process. This study examined the effects of 3D printing technology through 3D modelling, 3D creativity and effectiveness on teaching landscape architecture projects and design practices. The survey-based approach was adopted in present study and data was gathered by the respondents through questionnaires. The usable response rate of the present study was 71.4%. The researcher in present study used smart PLS for the analysis of gathered data. The result showed the students' positive responses to the inclusion of 3D printing and the use of 3D modeling techniques that had increased the student's interest and participation in their projects and improved their understanding and visualization of space and design concepts. The students' survey responses revealed that 3D printing made them feel happy, curious, and enthusiastic about their tutorials and helped them improve their learning processes. The study showed the advantage of incorporating 3D printing technology in teaching landscape architecture course.

Keywords

3D modeling; 3D printing; landscape architecture teaching; digital design; pedagogical practices

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The need for better landscape design is increasing because cities are growing and forcing their inhabitants' daily lives to become modern, busy, and highly technological. Therefore, improving the quality of their lives is crucial to maintaining their mental health and lifestyles. To support local communities, landscape design should be integrated with the urban fabric to reflect its regional features. Furthermore, to provide enjoyment to and fulfill the needs of inhabitants, aesthetic values should be included in their urban environment. The landscape architecture field is known for its interdisciplinary nature, and it provides design spatial solutions to social, environmental, and urban problems. Consequently, many landscape designers have incorporated green, ecological, and suitable concepts to create aesthetical, functional, and ecological value in their designed spaces (Ma, Hauer, & Xu, 2020).

Designers can integrate digital design tools and techniques into their landscape design and planning processes to deal with complex environments and design problems. Additionally, designers can creatively benefit from the added computer power, which provides graphical proficiencies, analyses, and spatial evaluations. By using computers, designers can visualize and conceptualize their designs to better express their intentions. Ultimately, landscape architecture represents the successful integration of science, art, the environment, and social values, and education in landscape architecture and design must therefore be interdisciplinary and varied (Gottfredson, 2014).

As educators, we are responsible for training and preparing our students to meet the needs of future generations. Moreover, we must upgrade and integrate the available advanced tools for our students to keep up with the current demand for technological skills. In this case study, students used hand modelling as well as computer-aided modelling (Tinker cad) and 3D printing to explore the added value of 3D printing in transferring and applying their classroom knowledge as Figure 1 displaying an example of the student's 3D printing work (Ng & Chan, 2019).

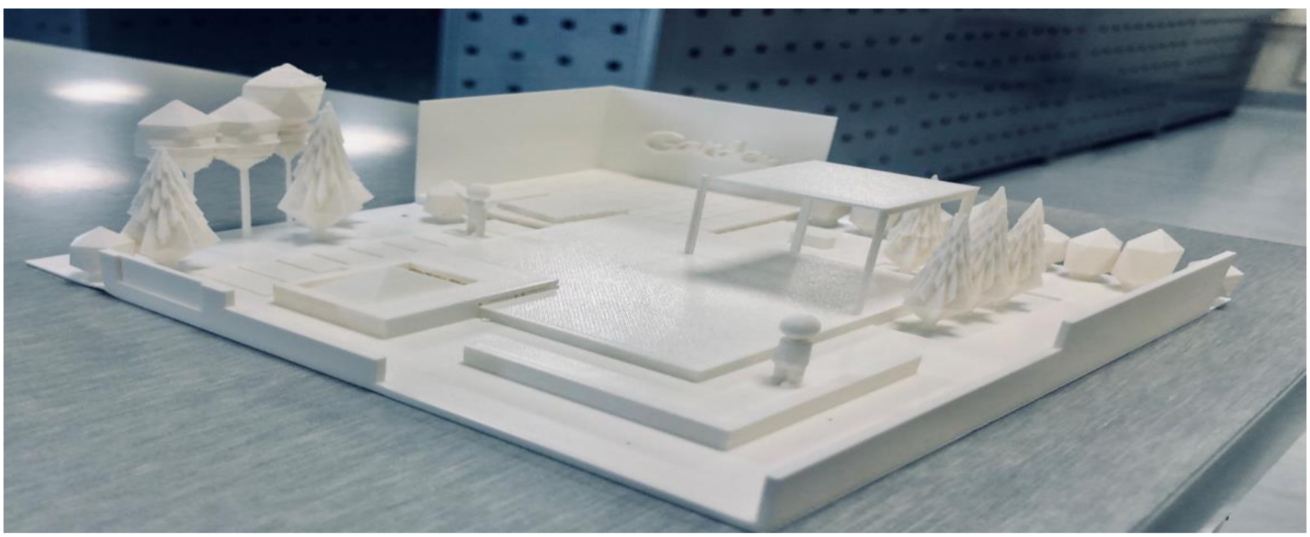

Figure 1. A sample of a 3D-printed project by a student participant – Graphic Lab, College of Education, Sultan Qaboos University

3-Dimensional printing – the virtual designs to Additive manufacturing; turns digital 3D models into solid objects. However, in the last decade, 3D printing has additionally started to evolve into the educational systems around the globe, but in developments 3D printing technology continue to accrue most of the STEM (Science, Technology, and Engineering & Math) institutes especially in developing countries like Pakistan. The focus of this study is to explore the current and futuristic range of applications of 3D printing technology in the revolutionary educational era (Waseem, Kazmi, & Qureshi, 2017).

Literature Review

3D Printing Technology

3D printing produces a three-dimensional object based on a digitally developed computer model. The produced object consists of material that has been successively printed in layers. Since its invention, 3D printing technology (i.e., digital fabrication) has been widely used by engineers and industrial designers to easily create physical prototypes and to visualize and test their proposed designs. As 3D printing becomes more accessible and popular due to its potential customizability, different fields, especially the design and planning fields, are adapting it to solve their problems. For example, applications of 3D printing can be seen in fields concerned with automobiles, fashion, architecture, art, medicine, and design (Bull, Haj-Hariri, Atkins, & Moran, 2015).

3D printing has already been applied as an educational tool in areas such as architecture, computing, and medicine. For instance, Physics of Materials, an educational course, used 3D printing to considerably enrich learning outcomes and maximize the experiences of its students. In addition, the use of 3D printing helped provide teachers with the tools to increase student involvement and improved the teaching environment by diversifying the learning process (Ishutov, Hodder, Chalaturnyk, & Zambrano-Narvaez, 2021).

Currently, there are about 10 different 3D printing technologies, each with its strengths and limitations. In this study, we used fused deposition modelling (FDM), which relies on a process known as material extrusion. Notably, this type of technology is inexpensive and uses some widely available material extrusion devices (Kristiawan, Imaduddin, Ariawan, & Arifin, 2021).

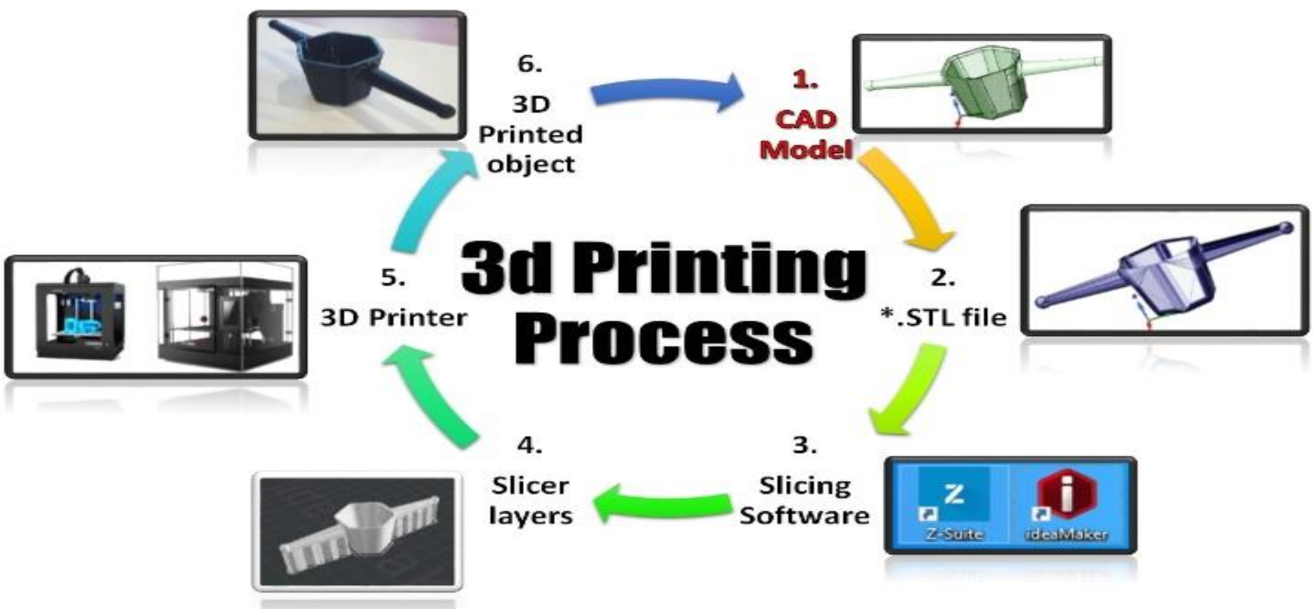

Figure 2. An explanation of the 3D printing process (www.recreate3d.co.za)

In art and architectural courses, 3D printing has significantly helped designers and artists expand various aspects of their designs. One study found that because students no longer depended on 2D screens to view their 3D models, they could bring their designs to life and feel them in real-time. 3D printing will certainly similarly benefit landscape architecture classes as art and architectural classes by enabling the landscape student to have a clear 3D view and experience of their design proposal (Kim, Shin, Park, Lee, & An, 2021). For instance, another study determined that 3D printing improved students' understanding of geological formations, as 3D images could not be used for this purpose (Horowitz & Schultz, 2014). The 3D-printed models also increased the quality and accessibility of science materials. Furthermore, a different study determined that 3D printing helped to improve students' sense of space by providing them with a physical model (Ford & Minshall, 2019).

The integration of 3D printing induced improvements across all subjects, including science, technology, engineering, mathematics, and design. However, while the application and the potential of 3D printing are especially notable in education, 3D printing is rarely used in landscape architecture practice and education. In the U.K., one school incorporated 3D printers into its curriculum to create various projects, such as designs for architecture and construction (Kim et al., 2021).

3D Modelling

To represent anything visually, models are the key. Past studies have focused on 3D models in the context of architectural design and research. In the aspect of research, these 3D models are the key. In 3D modelling, there are three kinds of steps that make 3D modelling crucial. The first phase is the analysis of the present situation so the accessible information may be gathered which is required to make the decisions regarding designs. The second phase is the generation of design which is key for the development of new ideas. In the end, the important phase is the presentation of the design to all the stakeholders. At this stage, the people involved in the manufacturing of design must present the prepared model to the stakeholders (Zaman, Mokhtar, Ibrahim, Huddin, & Beng, 2020).

The usage of 3D modelling is very important in the education sector as well. The usage of 3D modelling is described in three different aspects. Firstly, it is used to teach the students. Secondly, teachers can also use it for education. Thirdly, it can be used for the support purpose during teaching, fourthly, it has a main role in aid learning. At the later stage, 3D modelling has the main role in the creation of advanced technology. In the end, 3D modelling plays important role to support outreach activities (Yildirim, 2018).Scholars have mentioned that 3D modelling is also important to develop 3D learning and teaching skills among students. Students need to understand the difference between 3D literature and its integration to develop the skills through 3D curricula. For the active integration of 3D modelling, there is a need to develop projects and courses that are key to develop 3D modelling skills (Ford & Minshall, 2019).

Presently, 3-dimensional space is used at different levels to represent visual information. Sight sense is used by the viewer for the processing of visual information present in the surrounding. The most important aspect is to provide visual models with maximum accuracy for the perception of information. 3D information is lost by the brain when the 2D model is presented to the brain because every person processes the information at the subjective level. Thus, the use of 3D modelling is very important in the education sector. Teachers must use it effectively to develop skills and knowledge among the students (Lebamovski & Gospodinov, 2019).

3D Technology Creativity

To develop creativity among the students, digital technology plays a very important role by providing a new environments and tools for learning. In this way, students learn different skills in a creative manner. In several countries, technology is used by the teachers in the education sector to promote learning and creativity. It has a main role in the situation of Covid 19 where students are mainly dependent on the technology for learning. 3D tools can be used by the teacher to improve learning among the students. Past researchers used 3D technologies to improve interaction among the students. Thus, their creativity and cooperation were strengthened. 3D technology is a very valid option to strengthen creativity among the students. Several studies reported that creativity among the students can be promoted by using different software. It will later lead to the develop critical thinking among the students which will help in solving the problems related to the industry (Bereczki & Kárpáti, 2021).

3D Technology Effectiveness

Artificial Intelligence is one of the important aspects of today's life. 3D technology is used by industrialists and teachers so the students can undertint the usage of software at different levels. As a result, the learning process becomes very easy and interesting as well. Through 3D visualization, students can view the objects through different angles, altitudes, and directions. Past studies have revealed that the effectiveness of 3D GIS plays a very important role in the planning phase of buildings and landforms. On the other hand, scholars also reported that 3D technology and images play an important role to develop confidence and creativity among students. Moreover, interpretation becomes easy through 3D modelling as well (Xing & Marwala, 2017).

Satisfaction

High instructional quality is offered by the satisfied teacher. Moreover, better support is also provided by the teacher to the student as well. The impact of the process which is taken by the teacher is known as satisfaction. This impact is taken by the teacher during different teaching sessions and student participation. Satisfaction is also considered as the emotional reaction of teachers developed during lectures. If the teacher is satisfied, it will also play an important role to make students satisfied. Moreover, it has a key role to play to develop loyalty among students (Toropova, Myrberg, & Johansson, 2021).

- **Satisfaction and Teaching & Learning**

The main purpose of good quality of teacher is to develop good quality of skills among the students. For this purpose, a teacher needs to be satisfied so he or she can use teaching skills. As a result, the positive perceptions among students regarding the quality of teaching and learning may be developed among the students. Past researchers conducted studies to assess the relationship between satisfaction and teaching and learning. They mentioned that the quality of teaching and learning plays an important role to develop a perception regarding teaching and learning among students. Scholars also mentioned different five items for the development of satisfaction which will later affect teaching and learning perception. These five items include quality of instructional design, quality of the curriculum, quality of services, quality of the process of learning and quality of facilities (Aziz & Yasin, 2013).

- **3D Modelling and Satisfaction**

To derive the learning process, motivation plays a very important role. The students who are motivated have better performance, engagement, and interest. Scholars researched the usage of 3D models in a zoology class. They found that engagement, satisfaction, and interest of the students is increased through the usage of 3D models (Ho, Sun, & Tsai, 2019). Several studies have reported that 3D models play a very important role in the creation of satisfaction among students as they provide better visualization of the real object or anything that is under consideration (Castro, Amado, Bidau, & Martinez, 2021).

On the other hand, students can enjoy the dynamic environment with the help of 3D models during the classes. As a result, the level of satisfaction and interest among students to get the class is increased. Furthermore, effective communication among students is developed through 3D modelling as well (Ho et al., 2019).

- **3D Technology Creativity and Satisfaction**

A high level of creativity, innovation and thinking is required in 3D printing. The humans can develop imagination with the help of 3D technology. As a result, students get the opportunity to visualize 3D objects, two-dimensional shapes, and numbers. The combined power of production, design and thinking is massive to enhance satisfaction and create motivation. Moreover, the exploration of customers regarding several objects can be increased through 3D technology. Researchers argued that 3D technology enhances the exploration of the students regarding different options. As a result, the creativity of students is positively affected, and satisfaction is developed among the students. Researchers also concluded that 3D technology and creativity play a very important role in the educational sector. It plays an important role to provide a supportive environment (Lin, Wang, Kuo, & Luo, 2017).

Several different researchers in past studies have assessed the effect of technology adoption on satisfaction from several different perspectives. Scholars pointed that with the help of IT adoption, the productivity of the firm is enhanced through learning and knowledge creation. Researchers also mentioned that competitive advantage is also enjoyed by the construction organization as satisfaction is developed among stakeholders using 3D technology and creativity. Researchers also mentioned that operations of the organizations are enhanced through 3D technology creativity (Hossain, Zhumabekova, Paul, & Kim, 2020).

- **3D Technology Effectiveness and Satisfaction**

The research on 3D printing and its effectiveness is increasing at a rapid level in the last few years. Researchers have reported the growth of 3D technology in Asian countries, the growth and application of 3D technology effectiveness are exponential in some areas. Members of different societies are using it because of its effectiveness. The effectiveness of 3D technology has empowered educators a lot in their sectors. 3D printing and its effectiveness play a critical role in the development of satisfaction among the students. The results are more improved in classes when 3D technology is used instead of 2D technology (Hoyek, Collet, Di Rienzo, De Almeida, & Guillot, 2014). As a result, satisfaction among the students is enhanced (Li et al., 2017). It is because 3D technology is one of the enhancing technologies and its effectiveness is enhanced.

Based on the above literature, the following hypotheses and framework are developed:
H1: 3D modelling and satisfaction are positively related
H2: 3D modelling and Teaching and learning are positively related.
H3: 3D technology creativity and satisfaction are positively associated with each other.
H4: 3D technology creativity and teaching and learning are positively associated.
H5: 3D technology effectiveness positively affects satisfaction.
H6: 3D technology effectiveness positively affects teaching and learning.
H7: Satisfaction positively affects teaching and learning.
H8: Satisfaction positively mediates the relationship between creativity and teaching and learning.
H9: Satisfaction positively mediates the relationship between 3D modelling and teaching and learning.
H10: Satisfaction positively mediates the relationship between 3D technology effectiveness and teaching and learning.

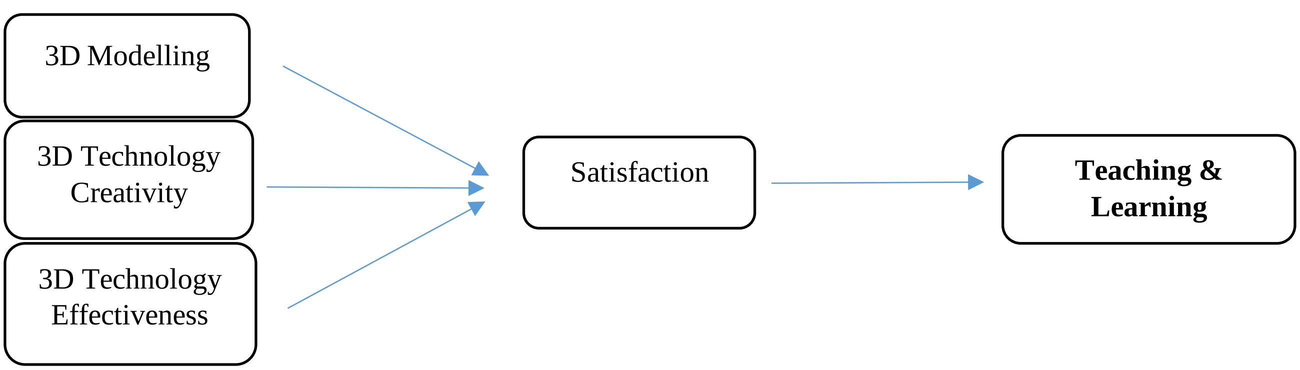

Figure 3. Framework

Method

To get the needed information, the present study relied on the primary data. For this purpose, the questionnaire was developed through Likert 5 Scale. On this scale 1 represent strongly disagree whereas 5 represent strongly agreed. The questionnaire was distributed among the respondents. For this purpose, 425 questionnaires were distributed. The usable questionnaire returned was 317. Thus, the usable response rate was 71.4 percent. The collected data was assessed through Smart PLS 3.3.2.

Results

Scholars have mentioned that usage of Smart PLS for the implementation of PLS-SEM is applicable in a number of industries (Sarstedt, Ringle, & Hair, 2014). Therefore, based upon the recommendations of Marcoulides (1998). The present study has opted to use PLS-SEM for the analysis of data collected through data collection. The measurement model is the first step for the analysis through PLS. The measurement model is also known as the outer model describes the relationship among the indicators. On the other hand, the second step which is the structural model describes the association among the latent constructs. Thus, past researchers have recommended using Smart PLS to assess the probability of the proposed model.

In the first step of the Smart PLS analysis, composite reliability, AVE, and factor loading are calculates. Moreover, the discriminant validity and validity of the data was assessed in the present study as well. The composite reliability and Cronbach Alpha are proposed by past studies for the measurement of reliability. On the other hand, average variance extracted (AVE) is used by the researcher for the quantification of variance among the variables. Moreover, AVE is also employed by the researchers to assess the convergence of factors used in the present study which is further used to assess the discriminant validity. Table 1 below shows the factor loading of the variables used in the study. Whereas Table 2 represent the CR, AVE and Cronbach alpha values that are important to establish convergent validity of the data.

Table 1. *Factor Loading*

	3D Modelling	*3D Technology Creativity*	*3D Technology Effectiveness*	*Satisfaction*	*Teaching & Learning*
3DM1	0.881				
3DM2	0.901				
3DM3	0.824				
3DT&C1		0.865			
3DT&C2		0.875			
3DT&C3		0.854			
3DT&C4		0.897			
3DT&C6		0.831			
3DT&C7		0.726			
3DTE1			0.875		
3DTE2			0.883		
3DTE3			0.863		
3DTE4			0.856		
SAT1				0.912	
SAT2				0.886	
SAT3				0.916	
SAT4				0.853	
T&L1					0.826
T&L2					0.869
T&L3					0.854
T&L4					0.815

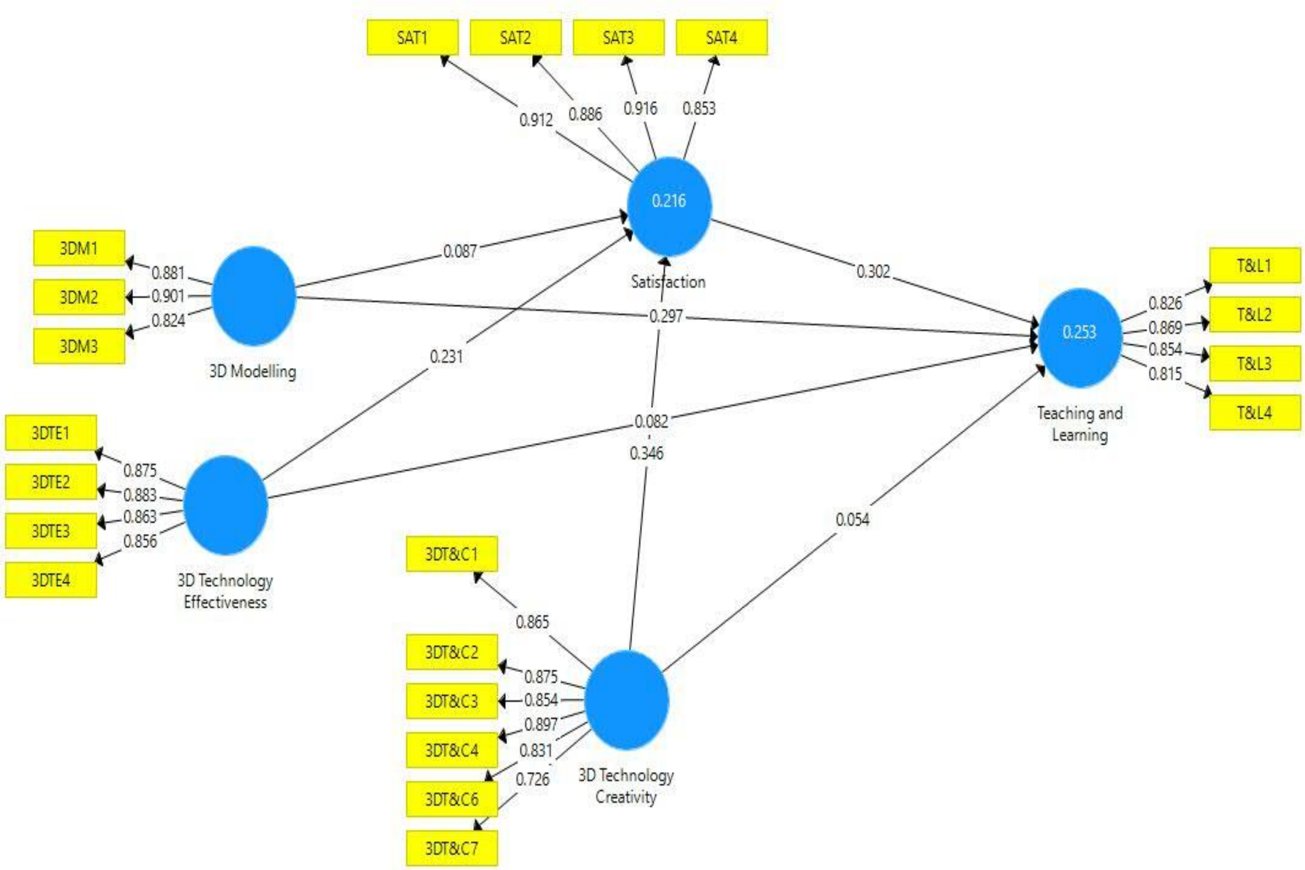

Figure 4**.** Measurement Model

As mentioned earlier that AVE, factor loading reliability is important to assess the convergent validity of the data. The values of factor loading mentioned in Table 1 are above the value of 0.60 as recommended by (Hair Jr, 1998). Moreover, the values of Cronbach alpha and CR are more than 0.70 as proposed by (Nunnally & Bernstein, 1978). On the other hand, studies have proposed the values of AVE should be more than 0.50. the values of AVE as mentioned in Table 2 are in the proposed range.

Table 2. *Reliability and Validity*

	Cronbach's Alpha	*rho_A*	*Composite Reliability*	*Average Variance Extracted (AVE)*
3D Modelling	0.841	0.877	0.903	0.756
3D Technology Creativity	0.918	0.918	0.936	0.711
3D Technology Effectiveness	0.892	0.895	0.925	0.756
Satisfaction	0.914	0.916	0.940	0.796
Teaching and Learning	0.862	0.862	0.906	0.708

After the establishment of convergent validity, the present study established discriminant validity through Fornell and Larcker (1981) method and HTMT criteria. According to Fornell and Larcker (1981) method, the values of the variable must be more than the square root of the AVE or remaining variables. Table 3 shows that the values at the horizontal are more than the remaining values. Thus, discriminant validity of the data is established through Fornell and Larcker (1981) criteria.

Table 3. *Discriminant Validity; Fornell and Larcker (1981)*

	3D Modelling	*3D Technology Creativity*	*3D Technology Effectiveness*	*Satisfaction*	*Teaching & Learning*
3D Modelling	0.869				
3D Technology Creativity	0.138	0.843			
3D Technology Effectiveness	0.070	0.151	0.869		
Satisfaction	0.151	0.393	0.290	0.892	
Teaching & Learning	0.356	0.226	0.199	0.392	0.841

Later, the present study employed HTMT as well for the establishment of discriminant validity. According to Kline (2011), the threshold values must be less than 0.85 for the establishment of discriminant validity through HTMT. As mentioned in Table 4, the present study has established discriminant validity through HTMT as well.

Table 4. *HTMT*

	3D Modelling	*3D Technology Creativity*	*3D Technology Effectiveness*	*Satisfaction*	*Teaching & Learning*
3D Modelling					
3D Technology Creativity	0.149				
3D Technology Effectiveness	0.084	0.169			
Satisfaction	0.162	0.424	0.319		
Teaching & Learning	0.407	0.253	0.225	0.438	

Before the assessment of the structural model, the present study has also estimated the values of R square. This value shows the dependency of the outcome variable on the independent variable. To assess the predictive accuracy of the model, the present study also assessed the values of R square. On the other hand, the values of the R square also show the dependency of the outcome variable on the independent variable. according to the values of R square in Table 5, satisfaction is affected 21.6% and teaching & learning is affected 25.3 % on the IVs of the present study.

Table 5. *R Square*

	R Square
Satisfaction	0.216
Teaching and Learning	0.253

After the evaluation of the measurement model, the present study assessed the structural model. For this purpose, the bootstrapping procedure was adopted with subsamples of 5000. With the help of this method, all proposed direct and indirect results were calculated. According to the values mentioned in Table 6, the values gathered, H1, H2, H3, H5, H6 and H7 of the proposed hypothesis are statistically supported. Whereas H4 of the present study is not supported in the present study.

Table 6. *Direct Results*

HYP		*Beta*	*SD*	*T Statistics*	*P Values*	*Decision*
H1	3D Modelling -> Satisfaction	0.087	0.048	1.814	0.035	Supported
H2	3D Modelling -> Teaching and Learning	0.297	0.054	5.454	0.000	Supported
H3	3D Technology Creativity -> Satisfaction	0.346	0.057	6.052	0.000	Supported
H4	3D Technology Creativity -> Teaching and Learning	0.054	0.061	0.893	0.186	Not Supported
H5	3D Technology Effectiveness -> Satisfaction	0.231	0.055	4.220	0.000	Supported
H6	3D Technology Effectiveness -> Teaching and Learning	0.082	0.046	1.796	0.037	Supported
H7	Satisfaction -> Teaching and Learning	0.302	0.046	6.535	0.000	Supported

Table 7 below shows the results of the mediation hypothesis proposed in the present study. According to the values, all proposed hypotheses namely H8, H9 and H10 are supported statistically. Thus, the relationship of all proposed mediating hypotheses is confirmed in the present study.

Table 7. *Indirect Results*

HYP		*Original Sample (O)*	*Standard Deviation*	*T Statistics*	*P Values*	*Decision*
H8	3D Technology Creativity -> Satisfaction -> Teaching and Learning	0.104	0.021	4.858	0.000	Supported
H9	3D Modelling -> Satisfaction -> Teaching and Learning	0.026	0.015	1.728	0.042	Supported
H10	3D Technology Effectiveness -> Satisfaction -> Teaching and Learning	0.070	0.020	3.411	0.000	Supported

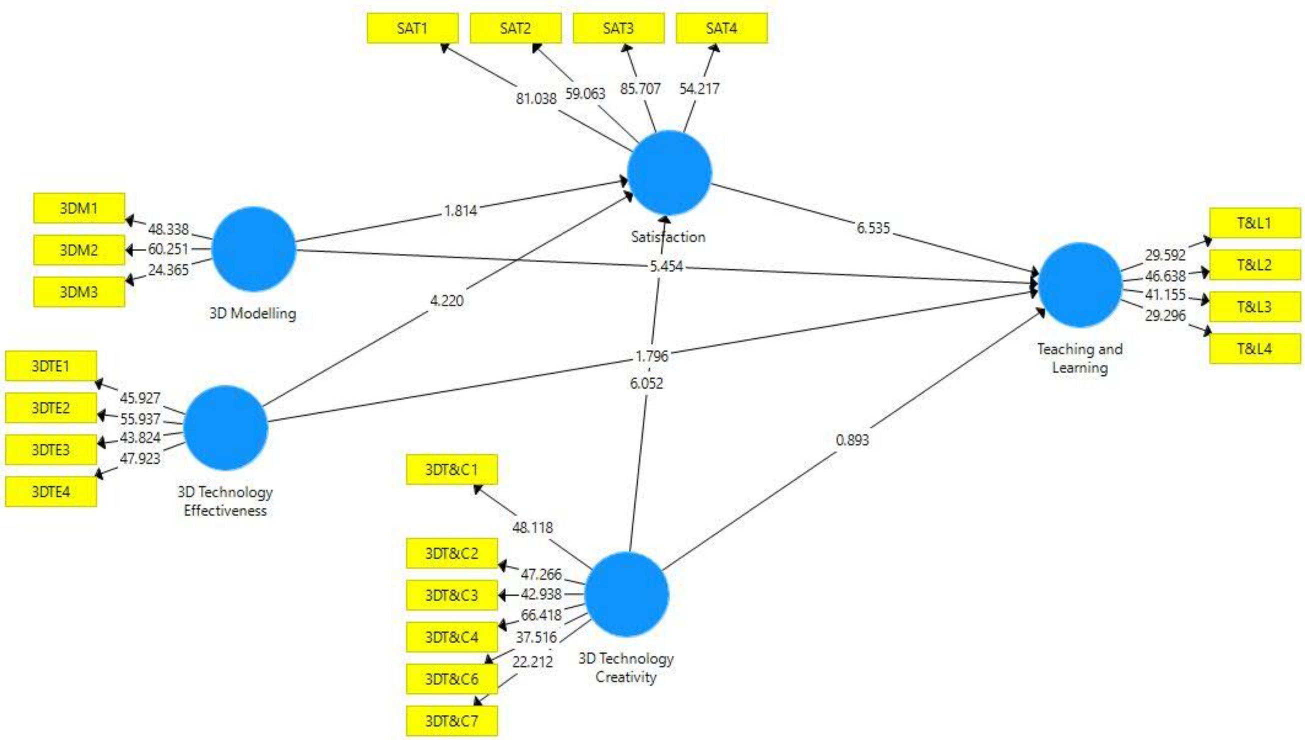

Figure 5. Structural Model

Discussion

The results support the use of 3D printing technologies in landscape architecture education and practice to provide additional tools and options for visualizing, teaching, and experiencing the product of a given design. It is stated that there is no universal tool or technique for landscape planning and design. Notably, the technology always has the potential to shift preexisting landscape design, planning, and visualization processes. Results revealed that digital 3D modelling is a very important aspect of teaching. Moreover, the students may prefer Tinkercad over SketchUp. The results also mentioned that respondents had more fun producing and visualizing their designs by "themselves." As a result, they also reported increased creativity and enjoyment

The findings of the study pointed that 3D design and 3D printing helped respondents to improve their design ideas, visualize the design as the respondent was going through the design process, determine the measurements, and obtain a clearer image, and they also provided respondents with opportunities to avoid potential errors. 3D modelling and 3D printing made respondents think differently and more realistically because respondents were able to navigate and live the experience from all sides. The results also revealed that the students enjoyed building 3D models in Tinkercad because it was easy and helped them a lot in making an excellent 3D model by themself. On the other hand, they enjoyed building the 3D model and visualizing with 3D printing because respondent was able to view my designs easily, extend my creativity, and see design details. In addition, some of the students addressed the class's unique learning style and the software used to build the 3D model. They enjoyed making something by themselves and practicing what they had been taught. Statistical results show that it was nice to be able to model the design. Respondents pointed that they liked the variety of experiences that I was exposed to. Modelling in 3D for my project that was based on my 2D plan view was an exciting and new experience for them. Due to the COVID-19 pandemic and the class's online learning style, the students cannot collaborate and freely discuss their designs with each other. However, the instructor can provide one-to-one feedback to each student, and each student could share their screen so that they could see and learn from the others' techniques and experiences. Based on their results, the students liked this format and had fun. 3D modelling helped the students visualize and experience the space before using 3D printing.

The present research found the class helpful because they learned and practiced new styles in 3D that expanded their understanding of landscape design. Because they could visualize and produce their designs in different ways, they could also improve their design knowledge. It was great that they felt like they had learned new techniques that they would learn later in landscape design. In addition, the 3D-printed models made it easier to visualize and understand the function of the space than the digital 3D models. The results mentioned that it would be helpful if they could convert their 2D plans into 3D digital models, and they found 3D printing of their design was more helpful in enhancing their learning outcomes and skills than other techniques.

This study's results support the notion that students can obtain knowledge beyond abstract concepts by producing 3D-printed models (Trust & Maloy, 2017). Hence, the results emphasize the need for and the impact of adopting new technologies in teaching, as this can enable learning using multiple types of sensory processing. The results of the study showed that 3D printing technology added valuable knowledge and skills to the students' experiences and learning of landscape design processes. In the literature, 3D printing has been applied in disciplines ranging from mechanical design architecture to archelogy, which demonstrates this technology's potential to accelerate and improve outcomes (Trust & Maloy, 2017).

3D digital modelling and computer visualization are often used within landscape architecture processes, planning, and design. 3D printing technology provides a new channel for improving interactivity, sensory involvement, and reliability. 3D printing is not commonly implemented in landscape architecture in Oman. Physical 3D modelling is used as a supplementary approach in education due to the required building time, cost, and labor. Thus, computer graphics are frequently used to produce 3D digital models and 2D plans. 3D-printed models have a unique sensual experience, real-time space experience, and visualization that cannot be obtained from digital models alone. In this study, the 3D-printed models provided the students with an exceptional experience that was fun, unique, and educational. Furthermore, the students were able to scale down their design models and have hands-on experiences with their designs before they were constructed and built-in real life.

Landscape architects deal with life-sized, natural forms. Therefore, 3D printing must be capable of producing detailed objects, such as street furniture, floor textures, and trees. During this study, several possible limitations of the use of 3D printing in landscape design education were observed: the cost of the filament, the restricted printing size (e.g., the students' designs needed to be a maximum of 20x20x20 cm to fit the printer's features), the significantly long time needed to produce the 3D models, the loss of fine details (e.g., while the 3D printer could print objects with no fine details, it struggled to create trees with leaves, grasses, and different floor textures), and the lack of easily displayed colours on the models. Regardless, the 3D-printed models were successful as objects and provided sufficient visualization quality.

While there are many potential advantages of 3D printing, the landscape architecture field has only started to investigate this technology. 3D printing could be used to produce small objects to share, see, and touch with clients, such as unique benches, entrances, and art features. Plus, 3D-printed models could help designers communicate their design ideas and concepts very easily to their clients in a fun way. For example, in this study, the students used web-based design software to share their designs and products between themselves.

Modern higher education requires flexible teaching and learning practices that can incorporate new technologies and improve knowledge and learning (Mykhailyshyn, Kondur, & Serman, 2018). This is because innovation in teaching is crucial to student motivation (Yilmaz, 2017). Incorporating technology into a class can change classroom involvement and experience. In landscape architecture education, computer-aided design software is used to provide efficient and convenient design platforms that effectively accelerate design production. Landscape educators understand the processes needed to conceptualize and analyze designs, and students are encouraged to use various design software to supplement their landscape design work.

Conclusion

This case study demonstrated the benefits of integrating 3D printing technology with landscape planning, design, and education, which is a unique approach within the landscape architecture context. Moreover, this study also explored the potential of 3D printing technology to improve and enrich landscape design learning processes and practices. Following the results, 3D printing of the designs may improve communication, understanding, and negotiation between designers and their clients. This study also provided evidence for the potential applicability of 3D printing in landscape design education. The 3D-printed models helped the students understand, sense, and envision their designs in real-time before their construction. This added value to the students' experiences. Furthermore, the 3D-printed models enhanced the students' interest, learning, and enthusiasm. The 3D-printed models were also useful tools for detecting mistakes and obstacles in the design and thus provided a venue for discussion and problem-solving.

This study showed the advantage and benefits of using 3D printing technology in landscape architecture teaching and learning practices. Modern higher education requires flexible teaching and learning practices. However, the study also detected some limitations in the 3D printing model. The limitation is in regarding the production of fine details, cost, and size, the common use of 3D printing in landscape architecture practices may be restricted. Both communication and visualization in landscape architecture necessitate detailed illustrations, especially for conveying a design's solutions, intentions, and aesthetic values. Therefore, to actively incorporate 3D printing into landscape architecture design processes, planning, and education, 3D printing technology requires improvements in terms of the level of detail, cost, time, and production size. 3D printing technology may be an effective tool if used to produce small-scale landscape design objects, such as hardscape furniture. Further research could investigate other values and benefits of 3D printing applications in landscape architecture design, planning, and processes.

This study found that 3D printing, 3D modelling, 3D creativity and effectiveness could be used to motivate and encourage student learning. 3D printing contributed positively to improved engagement, thinking, and proactivity. As a result, the teaching environment was fun, enthusiastic, and creative, and including different methodological styles in the learning process helped create this classroom experience. Overall, educators should consider the benefits of varied learning styles and tools. To help students solve real-time design problems and challenges, educators should focus on creating up-to-date teaching approaches, strategies, tools, and resources. Moreover, they should ensure effective teaching and learning outcomes for students that respond to their personalized learning styles.

The current study showed that using 3D printing technology in landscape design education benefited the students and increased their interest in the subject. Therefore, this study highlighted that teaching approaches and tools should focus on expanding students' skills and imaginations. Because our society embraces new technologies every day, we are responsible for educating a technology-savvy generation that is eager to explore, learn, and try new things that are only capable of advanced technologies.

References

Aziz, Z., & Yasin, R. M. (2013). THE IMPACTS OF CERTIFICATION POLICY ON TEACHERS'WORKING PERFORMANCE: A CASE OF RIAU. doi:http://dx.doi.org/10.5539/ass.v9n12p252

Bereczki, E. O., & Kárpáti, A. (2021). Technology-enhanced creativity: A multiple case study of digital technology-integration expert teachers' beliefs and practices. *Thinking Skills and Creativity*, *39*, 100791. doi:https://doi.org/10.1016/j.tsc.2021.100791

Bull, G., Haj-Hariri, H., Atkins, R., & Moran, P. (2015). An educational framework for digital manufacturing in schools. *3D Printing and Additive Manufacturing, 2*(2), 42-49. doi:http://doi.org/10.1089/3dp.2015.0009

Castro, K. M. d. S. A., Amado, T. F., Bidau, C. J., & Martinez, P. A. (2021). Studying natural history far from the museum: the impact of 3D models on teaching, learning, and motivation. *Journal of Biological Education*, 1-11. doi:https://doi.org/10.1080/00219266.2021.1877774

Ford, S., & Minshall, T. (2019). Invited review article: Where and how 3D printing is used in teaching and education. *Additive Manufacturing*, *25*, 131-150. doi:https://doi.org/10.1016/j.addma.2018.10.028

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of marketing research, 18*(1), 39-50. doi:https://doi.org/10.1177/002224378101800104

Gottfredson, J. A. (2014). Design process in landscape architecture: Developing a learning guide for the design workshop archives at Utah State University. doi:https://doi.org/10.26076/1ea1-f460

Hair Jr, J. (1998). Anderson, RE Tatham, RL & Black, WC 1998. Multivariate Data Analysis, Fifth-Edition. In: Upper Saddle River, New Jersey: Prentice-Hall.

Ho, L.-H., Sun, H., & Tsai, T.-H. (2019). Research on 3D painting in virtual reality to improve students' motivation of 3D animation learning. *Sustainability, 11*(6), 1605. doi:https://doi.org/10.3390/su11061605

Hossain, M., Zhumabekova, A., Paul, S. C., & Kim, J. R. (2020). A Review of 3D Printing in Construction and its Impact on the Labor Market. *Sustainability, 12*(20), 8492. doi:https://doi.org/10.3390/su12208492

Hoyek, N., Collet, C., Di Rienzo, F., De Almeida, M., & Guillot, A. (2014). Effectiveness of three-dimensional digital animation in teaching human anatomy in an authentic classroom context. *Anatomical sciences education, 7*(6), 430-437. doi:https://doi.org/10.1002/ase.1446

Ishutov, S., Hodder, K., Chalaturnyk, R., & Zambrano-Narvaez, G. (2021). A 3D printing Short Course: A Case Study for Applications in the Geoscience Teaching and Communication for Specialists and Non-experts. *Frontiers in Earth Science, 9*, 427. doi:https://doi.org/10.3389/feart.2021.601530

Kim, S., Shin, Y., Park, J., Lee, S.-W., & An, K. (2021). Exploring the Potential of 3D Printing Technology in Landscape Design Process. *Land, 10*(3), 259. doi:https://doi.org/10.3390/land10030259

Kline, R. B. (2011). Convergence of structural equation modeling and multilevel modeling. In: na.

Kristiawan, R. B., Imaduddin, F., Ariawan, D., & Arifin, Z. (2021). A review on the fused deposition modeling (FDM) 3D printing: Filament processing, materials, and printing parameters. *Open Engineering, 11*(1), 639-649. doi:https://doi.org/10.1515/eng-2021-0063

Lebamovski, P., & Gospodinov, M. (2019). *3D Innovation Technologies in Education.* Paper presented at the CBU International Conference Proceedings.

Li, K. H. C., Kui, C., Lee, E. K. M., Ho, C. S., Wong, S. H., Wu, W., . . . Liu, T. (2017). The role of 3D printing in anatomy education and surgical training: A narrative review. *MedEdPublish, 6*.

Lin, M. T.-Y., Wang, J.-S., Kuo, H.-M., & Luo, Y. (2017). A study on the effect of virtual reality 3D exploratory education on students' creativity and leadership. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(7), 3151-3161. doi:https://doi.org/10.12973/eurasia.2017.00709a

Ma, B., Hauer, R. J., & Xu, C. (2020). Effects of design proportion and distribution of color in urban and suburban green space planning to visual aesthetics quality. *Forests, 11*(3), 278. doi:https://doi.org/10.3390/f11030278

Marcoulides, G. A. (1998). *Modern Methods for Business Research*: Taylor & Francis. Retrieved from https://books.google.com.pk/books?id=EDZ5AgAAQBAJ

Mykhailyshyn, H., Kondur, O., & Serman, L. (2018). Innovation of education and educational innovations in conditions of modern higher education institution. *Journal of Vasyl Stefanyk Precarpathian National University, 5*(1), 9-16. Retrieved from https://philosophical.pu.if.ua/index.php/jpnu/article/view/3481

Ng, O. L., & Chan, T. (2019). Learning as Making: Using 3D computer-aided design to enhance the learning of shape and space in STEM-integrated ways. *British Journal of Educational Technology, 50*(1), 294-308. doi:https://doi.org/10.1111/bjet.12643

Nunnally, J. C., & Bernstein, I. (1978). Psychometric Theory McGraw-Hill New York. *The role of university in the development of entrepreneurial vocations: a Spanish study*, 387-405.

Sarstedt, M., Ringle, C. M., & Hair, J. F. (2014). PLS-SEM: Looking back and moving forward. In: Elsevier.

Toropova, A., Myrberg, E., & Johansson, S. (2021). Teacher job satisfaction: the importance of school working conditions and teacher characteristics. *Educational review, 73*(1), 71-97. doi:https://doi.org/10.1080/00131911.2019.1705247

Trust, T., & Maloy, R. W. (2017). Why 3D print? The 21st-century skills students develop while engaging in 3D printing projects. *Computers in the Schools, 34*(4), 253-266. doi:https://doi.org/10.1080/07380569.2017.1384684

Waseem, K., Kazmi, H. A., & Qureshi, O. H. (2017). Innovation in Education--Inclusion of 3D-Printing Technology in Modern Education System of Pakistan: Case from Pakistani Educational Institutes. *Journal of Education and Practice, 8*(1), 22-28. Retrieved from https://eric.ed.gov/?id=EJ1131562

Xing, B., & Marwala, T. (2017). Implications of the fourth industrial age for higher education. *The_Thinker__Issue_73__Third_Quarter_2017*. Retrieved from https://ssrn.com/abstract=3225331

Yildirim, G. (2018). Opinions of Secondary School Students on 3D Modelling Programs and 3D Printers According to Using Experiences. *Turkish Online Journal of Educational Technology-TOJET, 17*(4), 19-31. Retrieved from http://files.eric.ed.gov/fulltext/EJ1192786.pdf

Yilmaz, R. (2017). Exploring the role of e-learning readiness on student satisfaction and motivation in flipped classroom. *Computers in Human Behavior, 70*, 251-260. Retrieved from https://www.sciencedirect.com/science/article/pii/S0747563216309141

Zaman, M. H. M., Mokhtar, M. H. H., Ibrahim, M. F., Huddin, A. B., & Beng, G. K. (2020). Integration of 3D Printing in Computer-Aided Design and Engineering Course. *International Journal of Evaluation and Research in Education, 9*(4), 934-938. Retrieved from http://files.eric.ed.gov/fulltext/EJ1274766.pdf