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DIGITAL TECHNOLOGY AND DISRUPTIVE EDUCATION: AN APPLIED CASE FOR FOUNDATION ENGINEERING

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ABSTRACT

Breaking paradigms in teaching methods has become increasingly necessary for student development, as implementing more interactive, practical, and collaborative teaching approaches is essential for fostering critical, creative, and adaptive skills—key to comprehensive academic formation. It is worth highlighting that the new national curricular guidelines for engineering (DCNs) recommend that undergraduate engineering programs should equip graduates with appropriate techniques for observing, understanding, recording, and analyzing users' needs and their social, cultural, legal, environmental, and economic contexts. Furthermore, they should be able to broadly and systematically formulate engineering problems, considering the user and their context, devising creative solutions, and applying suitable techniques. Within this context, this activity aims to present the effects of a disruptive experience in an elective course of the Civil Engineering program. Using the Maker Culture and additive manufacturing (3D printing), different spacers for foundation elements were fabricated and tested to identify relationships between infill percentage and compressive failure load. The results reveal the impact of certain printing variables on the compressive strength of the spacers, while also providing quantitative data to support the alternative and autonomous production of spacers with higher cover requirements.

Keywords: Education. DCNs. Maker Culture. 3D Printing. Foundations.

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INTRODUCTION

Over the past decades, education has undergone a major transformation, primarily driven by the emergence of new technologies that have revolutionized life experiences and communication. In this context, it is essential to break pedagogical paradigms, and disruptive education emerges precisely to enhance the learning process in contemporary society.

Researchers Macedo and Sapunaru (2016) highlight the historical link between engineering and military interests, such as map recognition and description, land surveying, topography, fortifications, defense, and other constructions.

The École Nationale des Ponts et Chaussées (ENPC), founded in France in 1747, was the first formal engineering school and trained builders. According to Macedo and Sapunaru (2016), the ENPC most closely resembles modern engineering schools.

In Brazil, the authors state that the Royal Academy was the precursor to the Polytechnic School of UFRJ and the Military Institute of Engineering (IME). The Royal Academy aimed to train a military elite to develop the exact sciences and was modeled after the École Polytechnique of Paris (MACEDO; SAPUNARU, 2016).

According to Abed (2014), most educational institutions are guided by the valorization of what has been defined as knowledge and the transmission of content deemed valid. The educational policy focuses on transferring curricular content from a knowledgeable teacher to an unknowing student.

As a result, for years, educational institutions have been structured around curricula that often prove inadequate for addressing local problem situations (FREIRE, 1987).

In 2019, Brazil's Ministry of Education (MEC), through the Higher Education Chamber of the National Education Council (CNE), revised the National Curricular Guidelines (DCNs) for engineering programs, paving the way for significant changes in the education system.

Today, with the continuous advancement of technology and the rapid evolution of knowledge, it is crucial to develop skills to deal with the pace of change—one of the key points in the new DCNs. Engineers must increasingly be able to consider the complexity and social integration of their projects, recognizing and analyzing their historical, cultural, environmental, and social impacts, aiming for positive outcomes. To achieve this, they must continually learn and engage in dialogue with the various stakeholders involved in their projects. Brazilian universities have until 2024 to implement these new guidelines in their curricula.

The new DCNs, established by Resolution CNE/CP No. 2/2019, introduce several important innovations, such as:

- **Broad Education**: Emphasis on the comprehensive formation of graduates, encompassing technical, scientific, ethical, and social aspects;
- **Competencies and Skills**: The guidelines prioritize developing competencies beyond technical knowledge, including problem-solving, teamwork, and communication skills;
- **Disciplinary Integration**: They encourage interdisciplinarity by promoting integration among different areas of knowledge and fostering more practical and contextualized approaches;
- **Practical Experience**: They value hands-on training and interaction with real-world work environments, recommending internships and practical activities during the program;
- **Sustainable Education**: They address the importance of sustainability and environmental issues in engineering education;
- **Innovation and Technology**:

They recognize the need to prepare graduates for a constantly evolving technological environment, with a strong focus on innovation.

Foundation engineering has several specific characteristics. Typically, foundation projects must consider two aspects: geotechnical and structural.

The geotechnical aspects relate to two requirements: (i) adequate safety concerning failure in the soil-foundation system, and (ii) settlements compatible with the displacement of the superstructure. The structural component involves designing foundation elements, including specifying concrete quality and section dimensions. Based on these factors, the reinforcement is calculated, taking into account the type of steel used.

NBR 6122/2022 – Design and Execution of Foundations – refers to NBR 6118/2023 – Design of Concrete Structures – for guidelines on structural foundation design.

Rebar cover refers to the minimum distance between the concrete surface and the reinforcement. It is essential for protecting the rebar against corrosion and ensuring proper bonding between concrete and steel. NBR 6118/2023 establishes different nominal cover requirements depending on the structure type and environmental exposure class, as outlined in Table 1.

Table 1 – Nominal reinforcement coverage according to NBR 6118.

Type of structure	Component or element	Environmental aggressiveness class (table 6.1)			
		I	II	III	IV3)
		Nominal coverage mm			
Reinforced concrete	Slab2)	20	25	35	45
	Beam/Column	25	30	40	50
Prestressed concrete1)	All	30	35	45	55
1) Nominal coverage of the passive reinforcement that surrounds the sheath or wires, cables and strands, always higher than that specified for the reinforced concrete element, due to the risks of embrittlement corrosion under stress.					
2) For the upper face of slabs and beams that will be covered with subfloor mortar, with dry final coverings such as carpet and wood, with covering and finishing mortar such as high-performance floors, ceramic floors, asphalt floors and many others, the requirements of this table can be replaced by 7.4.7.5, respecting a nominal covering ≥ 15 mm.					
3) On the lower faces of slabs and beams of reservoirs, water and sewage treatment plants, sewage pipes, effluent gutters and other works in chemically and intensely aggressive environments, the reinforcement must have a nominal covering ≥ 45 mm.					

It should be noted that the requirements of NBR 6118/2023 do not specify foundations. They only mention conventional reinforced or prestressed concrete structures, such as slabs, beams and columns. Regarding the environmental aggressiveness class, Table 2 presents them according to the type of environment and the risk of deterioration of the structure in the projects.It should be noted that the requirements of NBR 6118/2023 do not specify foundations. They only mention conventional reinforced or prestressed concrete structures, such as slabs, beams and columns. Regarding the environmental aggressiveness class, Table 2 presents them according to the type of environment and the risk of deterioration of the structure in the projects.

Table 2 – Environmental aggressiveness classes for concrete structure projects, according to NBR 6118.

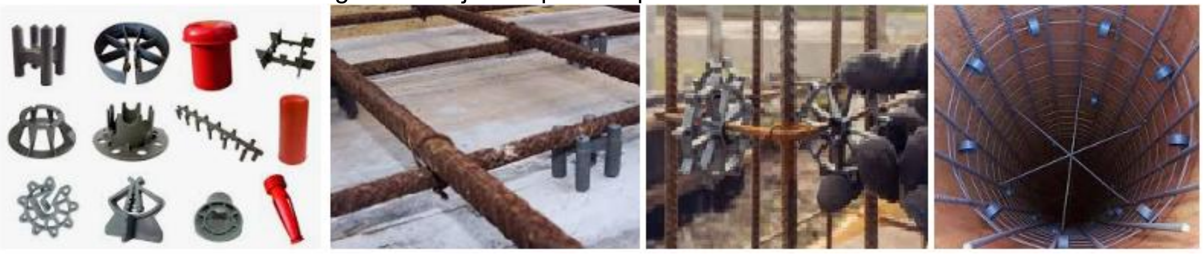
Environmental aggressiveness class	Aggressiveness	General classification of the type of environment for design purposes	Risk of structural deterioration
I	Weak	Rural	Insignificant
		Submerged	
II	Moderate	Urban 1), 2)	Small
III	Strong	Navy1)	Big
		Industrial1), 2)	
IV	Very strong	Industrial 1), 3)	High
		Tide splash	
1) A microclimate with a milder aggressiveness class (one level higher) may be permitted for dry indoor environments (living rooms, bedrooms, bathrooms, kitchens and service areas of residential apartments and commercial complexes or environments with concrete coated with mortar and paint).			
2) A milder aggressiveness class (one level higher) may be admitted in: works in dry climate regions, with relative air humidity less than or equal to 65%, parts of the structure protected from rain in predominantly dry environments, or regions where it rarely rains.			
3) Chemically aggressive environments, industrial tanks, electroplating, bleaching in pulp and paper industries, fertilizer warehouses, chemical industries.			

Foundation design practice shows that in these cases the cover is usually greater than 4 cm due to contact with the soil. Several shallow foundation designs (e.g.: footings or rafts) recommend minimum covers of 5 cm and, for deep foundations (e.g.: piles or caissons), covers of up to 7.5 cm have recently been recommended.

Plastic spacers are traditionally used to ensure that the reinforcement covers recommended in the designs are achieved during the execution of the foundations. The most common method for manufacturing these spacers is plastic injection, where the plastic resin is melted and injected into molds that shape the spacer. After cooling, the spacers are demolded.

Figure 1 shows some types of plastic spacers used to ensure reinforcement cover during the execution of concrete structures.

Figure 1 – Injected plastic spacers for the armor.



Lobo (2022), Carvalho (2023) and Pinto (2024) report that in recent years there has been difficulty in acquiring (ready-to-deliver) spacers that allow foundations to have nominal covers greater than 5 cm in the market in the northern region of Rio de Janeiro.

In this context, by integrating the new DCNs and the disruptive education approach, civil engineering can introduce new practices for the execution of structures, such as the use of 3D printing to manufacture specific spacers for foundation reinforcement..

2 DISRUPTIVE EDUCATION

Disruption can be understood as the sudden interruption or rupture of something. Therefore, the term, which appears to have a complex meaning, is actually quite easy to understand.

Disruptive education is nothing more than the transformation undergone by the teaching and learning process, which has been simplifying, improving and modifying the dynamics of teaching and the learning structure.

The traditional teaching model, centered on the figure of the teacher as the holder of knowledge, has been questioned over the last few decades, especially with the arrival of new generations of young people, who are already born within a social model where the technological revolution dominates.

A British man, Ken Robinson, a leading thinker in education, sought to compare the evolution that the world has undergone in the last 50 years using society and education as a reference. While society has undergone a profound transformation, education has remained with the same structure as it was in the last century.

Therefore, in order to reach these new generations of children, it was necessary to emerge with new educational approaches and new pedagogical practices.

Disruptive education emphasizes this and mainly advocates the need to transform conventional and traditional forms of education.

ADVANTAGES

These new educational approaches promote many benefits for teachers and students, and among their advantages, the following can be highlighted:

- Personalizes the educational experience and encourages diversity

One of the main concepts of new teaching practices is the personalization of the educational experience. Each student is a unique individual, with their own personal needs and potential that is different from everyone else's.

Disruptive education seeks to move away from this traditional model that treats students as something standardized.

Therefore, teachers and educators seek to create practices using technologies that benefit each student in a different way, varying according to the needs of each one of them.

- Increasingly multidisciplinary learning

Current thinking promotes the idea that everything can be interconnected, mathematics with history, geography with physics, biology with chemistry.

Therefore, the pedagogical training of students must be developed based on this idea of multidisciplinarity, which is one of the foundations of disruptive education. Technology, in this sense, can only contribute.

- Practical knowledge

Not that theory is not important, but disruptive education promotes a teaching model based on practical activities that aim to offer knowledge in a more direct and independent way. In other words, the student has all the tools at hand to acquire knowledge, and the teacher is responsible for mediating, assisting and helping the student.

- Digital revolution and process optimization

Disruptive education presents new models of pedagogical management, improving a large part of the educational management processes.

Using intelligence systems to manage all the bureaucratic or technical aspects greatly favors this new educational model, since the time that was wasted by teachers on technical tasks is now directed to the production of more content and practical knowledge activities.

● Stimulates skills of the future

One of the primary functions of the educational process has always been to prepare our children for the future. Well, disruptive education by definition already presents this idea, since its dynamics involving the use of technologies and means of communication provide students with the knowledge necessary to succeed in the job market.

A series of skills, such as emotional intelligence, the ability to think critically and easily adapt to needs are promoted within a current teaching structure, which seeks to give students more independence, autonomy and choices.

CHALLENGES

It is clear that not everything is rosy when it comes to disruptive education. Even though its concept is presented as an evolution and a profound transformation in pedagogical practices, there are still many challenges and obstacles.

● Virtual reality

Virtual reality has already been considered one of the great partners of this new teaching model. Technology that simulates a new reality, it favors the student in school practice, and facilitates the understanding of subjects, generating more interaction, engagement and a feeling of curiosity in the teaching process.

● Augmented reality

Augmented reality has also been widely used in classrooms or in pedagogical practices. Technology, which inserts virtual elements into real environments, facilitates and gives a new dimension to the learning process.

● Gamification

Gamification has gained a new approach with the technological revolution, and is now used to facilitate the teaching of children and young people, generating greater engagement and understanding of the content offered by educators.

● Maker culture

A culture that is widespread among admirers of disruptive education,The maker culture is based on do-it-yourself, that is, the student is the owner of his/her pedagogical experience. In this case, the teacher's role is to offer the instruments and tools so that the student can independently and autonomously develop his/her skills and acquire new information and knowledge. ● Hybrid teaching Hybrid teaching is a good example of how education has evolved and transformed with new technologies. Nowadays, teachers and students are not only hostages of the physical classroom and pedagogical practices can be carried out using both defined physical spaces and virtual spaces or different spaces. This hybrid model, which combines these two perspectives, has been widely used by schools that work with this concept of disruptive education. ● Lifelong learning The concept of lifelong learning has been used in new educational approaches and promotes the idea that knowledge should be absorbed throughout life and not only at a specific moment, in a specific phase of life. This concept is gaining followers and is yet another example of how education is improving.

● Machine learning

Machine learning is a technology that will also play a very important role in disruptive education. It will bring significant changes to the learning process and to society as a whole, as it directly contributes to the student's continuous learning through practical interventions in a more intelligent and productive way.

● Active methodologies

This is based on the concept that the teacher is no longer the center of the pedagogical process, but rather the student himself. The student will be responsible for his own learning experience, with the teacher acting as a mediator and tutor in this new teaching journey.

Active methods take place in practice and encourage students to seek knowledge autonomously, with the guidance of a teacher, but never as a mere spectator.

CONTEMPORARY EPILOGUE

It can be concluded that the changes that have occurred in the world in recent times have had a profound impact on society, but it took a while to affect pedagogical processes. From this reflection, the need for education to be updated and improved was created, seeking to reach an audience that now dominates new technologies and that no longer accepts that teaching format based on the figure of the teacher sitting in the classroom ready to offer knowledge.

Knowledge is now everywhere and technologies are essential for information to be generated at all times. The teacher is now the mediator and the student is the owner of his or her educational experience.

Disruptive education starts from this break with the old education model and presents the student with a new era of learning.

CASE STUDY

SPECIAL TOPICS IN FOUNDATIONS

The elective course Special Topics in Foundations at UFRJ/Macaé has a broad syllabus, and its main purpose is to analyze and study unconventional cases already covered in the mandatory courses Foundations 1 (superficial) and Foundations 2 (deep).

Since the course is offered in the last period and is elective, the number of students is reduced, allowing the introduction of a differentiated approach in the educational process. In this way, and supported by the new DCNs, students, in groups or individually, are encouraged to research and prepare papers on specific topics for publication in journals or conferences.

Among the innovations applied in this elective course are the maker culture, active methodologies, project-based learning and hybrid teaching. GOMES (2022) mentions that these new ways of "teaching and learning" can truly transform engineering education.

The latest research conducted in the discipline was aimed at identifying the types of devices used in the northern market of the state of Rio de Janeiro for the execution of foundations to ensure the covering of the reinforcement.

Some construction sites in Rio das Ostras, Macaé and Campos dos Goytacazes were visited and monitored to understand the needs and practices adopted during the execution of foundations, both superficial (raft) and deep foundations (continuous helix piles).

Figure 2 shows a raft foundation in a construction site in Rio das Ostras using an improvised spacer, since it was not possible to find a spacer on the local specialized market that met the requirements of the geotechnical project. Figure 2 also shows a construction site in Campos dos Goytacazes with the execution of foundations using continuous helix piles where injected plastic spacers purchased in São Paulo were used.

Figure 2 – Examples of foundation execution with spacers.

USE OF 3D PRINTING TECHNIQUE

3D printing, also known as additive manufacturing, is an innovative technology for producing three-dimensional objects by depositing material in successive layers of a digital (virtual) model, thus having the potential to be an alternative method for manufacturing customized products that are difficult to access or have complex geometries.

Thus, with the help of the multidisciplinary team of Maker educators from the #inovareaprender laboratory at SEMED – Macaé City Hall, and the guidance of the teacher of the elective course Special Topics in Foundations, it was possible for the student, with no prior knowledge, to develop the ability to act autonomously and perform several experiments, expanding her practical knowledge.

The tests carried out by the student, based on the application of the maker culture, consisted of several 3D prints in different materials using the Creality CR-10 SE printer from the Civil Engineering Laboratory of the Polytechnic Institute of UFRJ/Macaé. Figure 3 shows the student's first contacts with the laboratory's 3D printer..

Figure 3 – The student's first contact with the 3D printer.

Furthermore, it was possible to learn about the programs required for its operation and the variation in the final quality and printing results due to several factors such as printer settings, filament type, calibration, environment and maintenance.

The materials used in the research were polylactic acid (PLA) filament and acrylonitrile butadiene styrene (ABS) filament, although there are many other types. These two materials differ in characteristics such as strength, durability, cost and environmental aspects, such as toxicity and energy consumption during printing. Figure 4 shows a roll of PLA filament and another of ABS..

Figure 4 – Filaments used.

For printing, the Thingverse website was used to obtain the model in STL (Stereolithography file) format, followed by the Ultimaker Cura software version 5.8.1, which converts the 3D model into a G-code file that can be decoded by the printer. In the software, it is also possible to adjust the various parameters and settings that directly influence the final quality of the products. The parameters used in slicing are listed in Figure 5.

Figure 5 – Printing parameters.

0.4mm nozzle

Draft - 0,2mm

QUALITY		WALLS		TOP/BOTTOM	
Layer Height	0,2 mm	Wall Thickness	0.8	Upper Layers	3
First Layer Height	0,3 mm	Number of Wall Fillets	2	Lower Layers	3
Extrusion Width	0,3 mm	External Wall Penetration	0,05 mm	Top/Bottom Pattern	Lines
Wall Extrusion Width	0,3 mm	Minimum Wall Fillet Width	0,3 mm		
Fill Extrusion Width	0,3 mm	Horizontal Expansion	0,0 mm		
SPEED		ROUTE		COOLING	
Print Speed	60 mm/s	Enable Retraction	(Marked)	Enable Cooling Printing	(Marked)
Fill Speed	60 mm/s	Retraction Speed	40 mm/s	Fan Speed	100%
Travel Speed	120 mm/s	Z Jump When Retracting	(Unchecked)		

FILLING		MATERIAL	
Fill Density		Printing Temperature	195ºC
Fill Pattern	Cubic	Print Table Temperature	60ºC
Connect Fill Lines	(Unchecked	Flow	100%
Filler Fillet Directions	[ ]		
Layer Thickness			
Padding	0,2 mm		
SUPPORT		TABLE ADHERENCE	
Generate Support	(Unchecked	Printing Table Adhesion Type	None

difficulties encountered

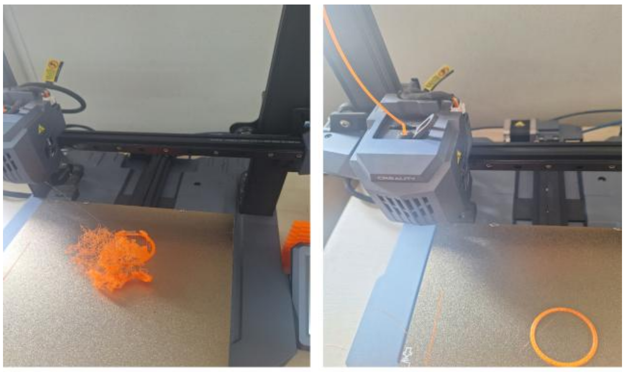
When trying to reproduce the model with ABS material, which is superior to PLA in terms of mechanical properties, problems occurred with the layers coming off and filament accumulating on the inside, as illustrated in Figure 6. This occurred because the use of ABS is not recommended for open printers, because fluctuations in ambient temperature can harm the printing process.

Figure 6 – ABS spacer.

After research, some adjustments were made to the settings, resulting in an ABS print with fewer visual flaws, as shown in Figure 7. However, a satisfactory result was not obtained, which could affect, in addition to the visual aspect, the mechanical properties, making it unfeasible for the manufacture of spacers, which must support a certain load of the concrete weight.

Figure 7 – ABS spacer after adjustments.

During the learning process, errors also occurred when working with PLA, as shown in Figure 8a, suggesting that the temperature of the table used, 210ºC, was high. Figure 8b shows an interruption in printing due to the breakage of a section of the filament, which may have been caused by excess humidity, since one characteristic of polymeric materials is that they are hygroscopic, that is, they absorb moisture from the air.

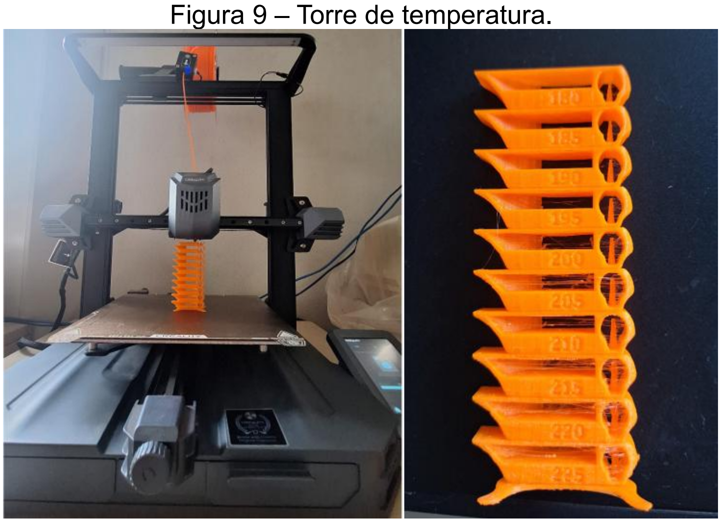


(a) (b)

Figure 8 – PLA printing problems.

To solve the problem of the bed temperature, a test print called a temperature tower (illustrated in Figure 9) was performed, configured to be printed with temperature variations in the same print. This tower serves to visually evaluate different filament temperatures and determine the ideal temperature for printing, which was set at 195ºC..

Figura 9 – Torre de temperatura.



the use of the pla

After initial testing, it was realized, through the Maker culture, that the ideal material to work with the type of printer in the Civil Engineering laboratory would be PLA, which is a biodegradable and non-toxic thermoplastic. Thus, four types of spacers of the same model were printed, varying only the density of filament used (10%, 30%, 60% and 100% filling).

The Ultimaker Cura program allows you to know in advance the time and amount of material to be used during printing. Table 3 shows the weight and length of PLA filament, in addition to the printing time of each spacer, associated with the density of material used.

Table 3 – Printing characteristics of PLA spacers.

Density	10%	30%	60%	100%
Weight (g)	6	7	8	9
Length (m)	1.93	2.23	2.66	3.17
Time (min)	45	52	59	67

Figure 9 shows the 3D model of the spacers designed in the Ultimaker Cura Software for 5 centimeters of reinforcement coverage of shallow foundations in footing or raft.

Figura 9 – 3D model in Ultimaker Cura software

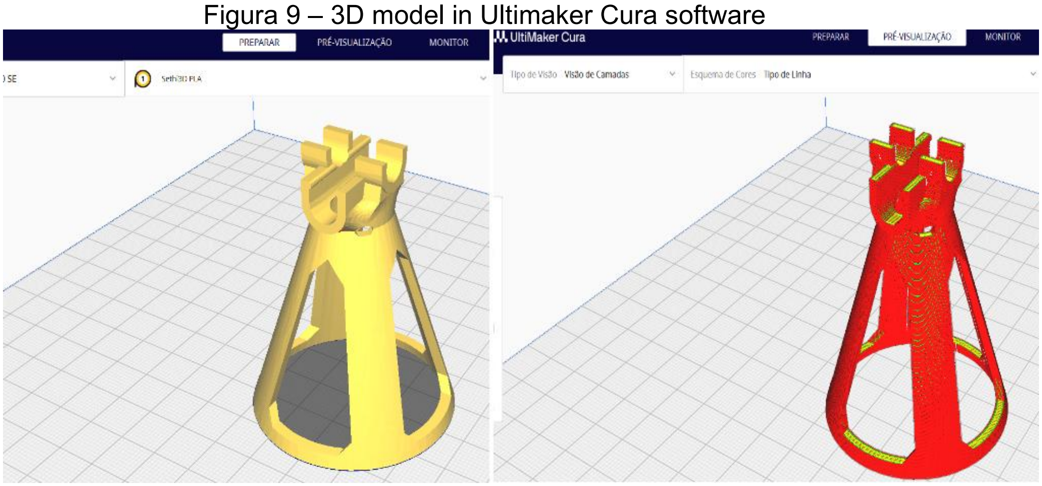
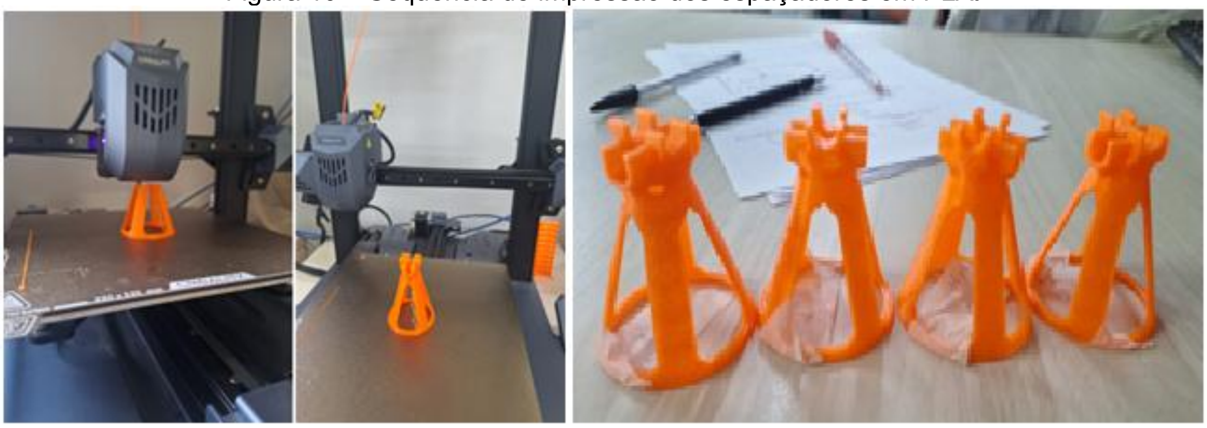


Figure 10 shows the sequence of printing the PLA spacers, carried out on the printer at the Civil Engineering laboratory of the Polytechnic Institute of UFRJ/Macaé. One of the illustrations shows the spacers with the four densities used. It is worth noting that it is not visually possible to perceive the difference between them, so it was necessary to use an identification label for each of them.

Figura 10 – Sequência de impressão dos espaçadores em PLA.



COMPRESSION TESTS ON MANUFACTURED PARTS

To verify the influence of the filling percentage on the mechanical properties of the spacers, simple compression resistance tests were performed on samples with 10%, 30%, 60% and 100% filling.

To determine the speed of application of the load (moving jaw displacement), the ASTM D695 standard - Standard test method for compressive properties of rigid plastics was followed. The American standard establishes that the standard test speed should be 1.3 ± 0.3 mm/min for rigid plastics, both unreinforced and reinforced, with thicknesses from 1 to 14 mm.

The printed spacers were tested on the EMIC Universal Testing Machine of the Mechanical Engineering laboratory of the Polytechnic Institute of UFRJ/Macaé, at a speed of 1 mm/min. It is important to mention that the press used records the compression efforts and the displacements associated with them. Figure 11 shows the automated press in the Mechanical Engineering laboratory and one of the samples positioned to begin the compression test..

Figure 11 – Compression test of spacers

Figure 12 shows some of the spacers after the compression test, where their rupture had already been proven during the test.

Figure 12 – Test specimens ruptured under compression

Figure 13 shows the load versus displacement curves of the PLA spacers with fillings of 10%, 30%, 60% and 100%.

Figure 13 – Load vs Displacement graph for different fill percentages.

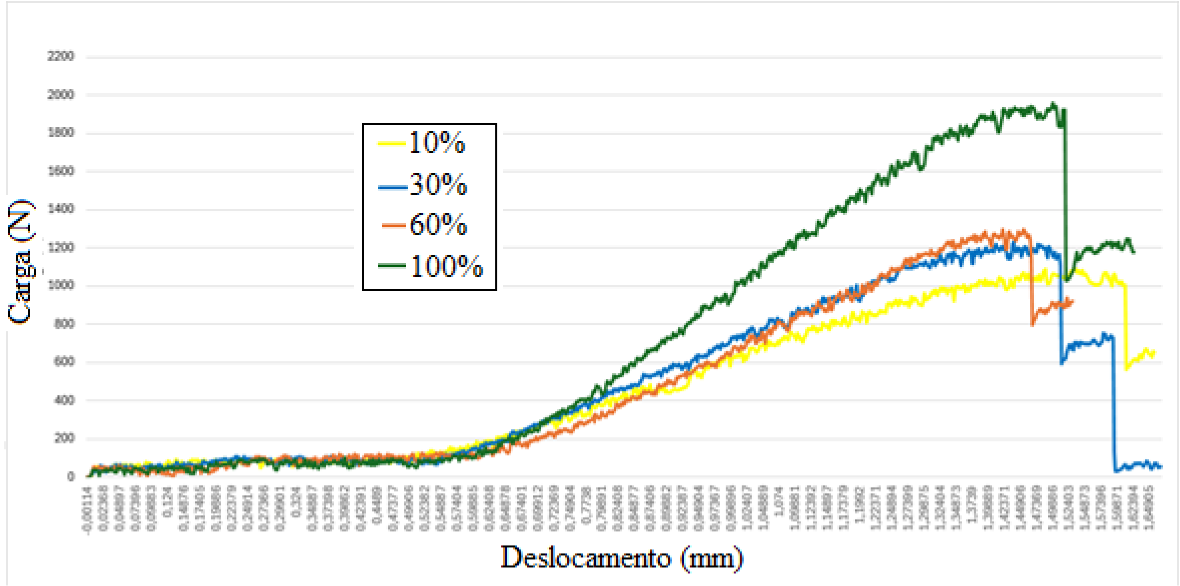


Table 4 presents a summary of the maximum load reached and its corresponding displacement for the four spacers, of different densities. In addition to the time each test took to reach rupture.

Table 4 – Data obtained from uniaxial compression test.

Density	10%	30%	60%	100%
Maximum load supported (N)	1088.70	1229.65	1299.26	1962.45
Displacement at failure (mm)	1.55	1.44	1.46	1.51
Test duration (s)	100.4	100.6	90.4	94.8

The results indicated that the higher the filling percentage, the higher the compressive strength of the spacers. The test times and the displacements until rupture were not greatly influenced by the variation in the density of the tested parts..

FINAL CONSIDERATIONS AND CONCLUSIONS

Using a disruptive methodology based on the Maker culture, four PLA plastic reinforcement spacers with filling densities of 10%, 30%, 60% and 100% were printed using digital 3D technology. Simple compression tests carried out in the laboratory provided results that showed that the spacers with 100% filling achieved compression loads almost twice as high as the spacers with 10% filling. In terms of the amount of filament (weight) and printing time, other very important variables, the spacers with 100% filling outperformed the spacers with 10% filling by approximately 50%. Thus, it can be concluded that if there is a need to obtain a spacer for a shallow foundation reinforcement that needs to support more weight, it is worth investing in a higher filling density for the part. In fact, at the end of the research, it can be said that manufacturing these devices with a 3D printer can be an alternative to the difficulty of finding them on the market with the appropriate coating for foundation elements.

On the other hand, it is worth highlighting that engineering courses can create a curriculum that prepares students for the contemporary challenges of foundation engineering. This includes the use of emerging technologies, sustainability and agile design methodologies.

This connection strengthens the training of engineers, making them more adaptable and innovative. As the construction industry evolves, well-trained engineers will not only apply technical knowledge, but will also excel in creating innovative and sustainable solutions.

These guidelines aim to ensure that trained engineers are better prepared for contemporary challenges and contribute significantly to society. It is important to highlight that during the learning and teaching, the difficulties that arose helped to understand the importance of studying the parameters that cause errors and minimizing their effects, seeking better results and a greater understanding of the uncertainties that arise in 3D printing.

Finally, it can be concluded that, in addition to gaining knowledge about foundation engineering, which is essential for the training of engineers, practical and personalized knowledge was achieved through more attractive, active and meaningful teaching using new technologies and contemporary methodologies..

REFERENCES

1. ABED, A. L. Z. (2014). *O desenvolvimento das habilidades socioemocionais como caminho para a aprendizagem e o sucesso escolar de alunos da educação básica*. São Paulo.

2. ASTM International. (2015). *ASTM D925-15: Standard test method for compressive properties of rigid plastics*. West Conshohocken, PA: ASTM International.

3. Associação Brasileira de Mantenedores de Ensino Superior. (2019). Resolução CNE/CES nº 02, de 24 de abril de 2019 (alterada pela Resolução CNE/CES nº 01, de 26 de março de 2021). *Diretrizes Curriculares Nacionais do Curso de Graduação em Engenharia*. Brasília.

4. Carvalho. (2023). Comunicação pessoal.

5. Coonectse. (s.d.). *Educação disruptiva: O que é? Quais vantagens? Conceitos e exemplos*. Recuperado em 15 de setembro de 2024, de https://coonectse.com.br/blog/educacao/educacao-disruptiva

6. Freire, P. (1987). *Pedagogia do oprimido*. Rio de Janeiro: Paz e Terra.

7. Gomes, R. C. (2022). *Metodologias de ensino para mecânica dos solos e geotecnia – Visão tradicional e contemporânea: Estudo de caso a partir de uma pesquisa exploratória* [Trabalho de Conclusão de Curso, Universidade Federal do Rio de Janeiro]. Macaé, RJ.

8. Lobo. (2022). Comunicação pessoal.

9. Associação Brasileira de Normas Técnicas. (2023). *NBR 6118: Projeto de estruturas de concreto*. Rio de Janeiro: ABNT.

10. Associação Brasileira de Normas Técnicas. (2022). *NBR 6122: Projetos e execução de fundações*. Rio de Janeiro: ABNT.

11. Macedo, G. M., & Sapunaru, R. A. (2016). Uma breve história da engenharia e seu ensino no Brasil e no mundo: Foco Minas Gerais. *REUCP, 10*(1), 39–52. https://doi.org/10.2318/0692

12. Pinto. (2024). Comunicação pessoal.