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Research into The Design of Sustainable Ceramic Compositions for use in Additive Manufacturing Processes

Eklemeli Üretim Süreçlerinde Kullanılmak Üzere Sürdürülebilir Seramik Bünye Bileşimlerinin Tasarımına Yönelik Araştırma

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RESEARCH INTO THE DESIGN OF SUSTAINABLE CERAMIC COMPOSITIONS FOR USE IN ADDITIVE MANUFACTURING PROCESSES

ABSTRACT

In this research, it is aimed to carry out a practice-based research on ceramic filaments that can be used in 3D printing. Therefore, the main objective was to expand the current selection of materials for ceramic 3D printing and to investigate how material selection and utilisation affect the qualities of the 3D printed object. In parallel with the new developments in the field of 3D printing, our research was carried out to reveal the issues that are needed and have the potential to be developed in ceramic art and design. Egyptian paste, which has the character of a self-glazed ceramic body, is a blend that is difficult to shape by hand, but may be more possible to shape with additive manufacturing. Therefore, the main idea of the research was to find the best Egyptian tile paste recipe suitable for delta-type ceramic 3D printer. Experimenting with Egyptian paste has also led to an interest in other ceramic materials that have not previously been used in ceramic 3D printing. Therefore, various clay compositions were developed. The experimental processes of the research were carried out in the Ceramics Department of the Latvian Academy of Arts using a Delta-type Ceramic 3D printer. Then firing processes were carried out. The result of our research shows that; additive manufacturing proposes a different production philosophy than other traditional production methods, on the other hand, it provides new opportunities especially for ceramic printing and guides future research.

Keywords: Ceramics, Additive Manufacturing, 3D printing, Sustainability, Recycled Day, Egyptian Paste.

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EKLEMELİ ÜRETİM SÜREÇLERİNDE KULLANILMAK ÜZERE SÜRDÜRÜLEBİLİR SERAMİK BÜNYE BİLEŞİMLERİNİN TASARIMINA YÖNELİK ARAŞTIRMA

ÖZ

Bu araştırmada, üç boyutlu baskıda kullanılabilecek seramik filamentler üzerine uygulamaya dayalı bir araştırma yapılması amaçlanmıştır. Bu nedenle, seramik üç boyutlu baskı için mevcut malzeme seçimini genişletmek ve malzeme seçimi ve kullanımının 3D baskılı nesnenin niteliklerini nasıl etkilediğini araştırmak temel amaç olmuştur. Araştırmamız, 3D baskı alanındaki yeni gelişmelere paralel olarak seramik sanatı ve tasarımında ihtiyaç duyulan ve geliştirilme potansiyeli olan konuları ortaya çıkarmak amacıyla gerçekleştirilmiştir. Kendinden sırlı seramik bir bünye karakterine sahip olan Mısır hamuru, elle şekillendirilmesi zor ancak eklemeli imalat ile şekillendirilmesi daha mümkün olabilecek bir karışımdır. Bu nedenle araştırmanın ana fikri delta tipi seramik 3D yazıcıya uygun en iyi Mısır hamuru tarifini bulmak olmuştur. Mısır hamuru ile yapılan denemeler, daha önce seramik baskıda kullanılmamış diğer seramik malzemelerin de olanaklarının araştırılmasını sağlamıştır. Bu nedenle çeşitli kil bileşimleri geliştirilmiştir. Araştırmanın deneysel süreçleri Letonya Sanat Akademisi Seramik Bölümü'nde Delta tipi bir seramik üç boyutlu yazıcısı kullanılarak gerçekleştirilmiş, pişirim işlemleri yapılmıştır. Araştırmamızın sonucu göstermektedir ki; eklemeli üretim diğer geleneksel üretim yöntemlerinden farklı bir üretim felsefesi önermekle birlikte özellikle seramik baskı için yeni fırsatlar sunmakta ve gelecekçi araştırmalara yön vermektedir.

Anahtar Kelimeler: Seramik, Eklemeli Üretim, 3 Boyutlu Baskı, Sürdürülebilirlik, Geri Dönüştürülmüş Kil, Mısır Pastası.

INTRODUCTION

Additive manufacturing or three-dimensional printing is a technology that has been frequently mentioned in production technologies for more than 40 years, preferred in prototype production and started to take place in the industry. The method of obtaining products by removing the parts to be used from the main material such as cutting, drilling, moulding, gluing, screwing, etc. used in traditional production is described as substractive manufacturing. In additive manufacturing, the final product is sent to the printer of the three-dimensional model designed in a digital environment. The product becomes three-dimensional by placing the raw material on top of each other in layers or by hardening the powder particles. Since the main material in plastic or powder structure is added to each other by various methods, this method is called additive manufacturing.

It is known that the development and first examples of this production technology date back to the mid-70s. However, the commercialisation and patented production of printers was in 1984. Today, three-dimensional printers are used for both prototyping and industrial production purposes, and find a place in many fields such as architecture, construction, industrial design, automotive, aviation, space, defence, engineering, dentistry, medical, biotechnology (artificial tissue), fashion, footwear, jewellery, accessories, education, food. Today, polymer, ceramic and metal materials can be widely produced with three-dimensional printers, and designers continue to search for alternative materials and products to expand the limits of this production technology.

Different forming methods have been developed under the name of additive manufacturing. Basically, they all take the form of the construction of layers. However, depending on the design and material, there are differences in terms of solidification of the material to be built and bonding of the layers. In general, three-dimensional printing processes can be classified into two main groups. The first group (binding processes) is based on the principle that the printer head hardens the powder laid in layers in the z-axis by sintering or melting according to the x and y axes each time. In deposition processes, the printer head deposits the material in layers on top of each other. Both groups of production methods are used in ceramic production.

Printers based on material deposition build the liquefied or plastic filament material layer by layer with the use of an extruder in the print head. In the other group of methods based on binding, the product does not require support. However, in the material deposition method, the product may require additional support in order to survive without collapsing as it is formed in layers.

Fused Deposition Modelling (FDM) is a system based on the melting of fibre thermoplastic materials and the bonding of the layer formed by melting the layer to the previous layer by sudden cooling. In experimental research, thermoplastic hardening materials can be mixed with wood, metal and ceramics to make composites.

Paste extrusion technique is the most widely used production technique especially by designers working in studio style artistic and experimental ceramic applications. The material used in this technique has a paste consistency. The product is deposited layer by layer by pressurising the material from an injection-like nozzle. Our research focussed on this form of production and the compositions we used in our experiments were prepared in paste form.

FUSED DEPOSITION MODELLING, SUSTAINABLE RAW MATERIAL DESIGNS

Besides plastic, which is the most used material for 3D printing on the market, today there is a long list of materials that are possible to use in 3D printing - metal, wood (mixed with plastic), wax, sandstone, ceramics and others. In addition, today sustainability has become an important element of production. When designing new objects, the quality of sustainability is taken into account and even becomes the starting point of a new idea as a source of inspiration. Different industries are increasingly using recycled materials for production and artistic works. In the field of 3D printing, designers are also looking for ways to replace plastic with more sustainable materials.

One of the sustainable examples is the use of algae. Dutch designers Eric Klarenbeek and Maartje Dros have developed a bioplastic made of algae, which they believe could completely replace synthetic plastics over time. Klarenbeek and Dros grow algae, which are aquatic plants, and then dry them into a material that can be used in 3D printing objects. (Morris, A. 2017)

Another interesting example of the use of sustainable materials in 3D printing, which also creates unique visual objects, is the pulp printer. Design Academy Eindhoven graduate Beer Houthis created the pulp printer to combat the amount of waste plastic generated through 3D printing. After discovering that paper is one of the most wasted materials in the world, Houthis took on the task of making a 3D printer that can use recycled pulp. (Winston, A. 2018)

Figure 1. 3D printed bioplastic made from algae

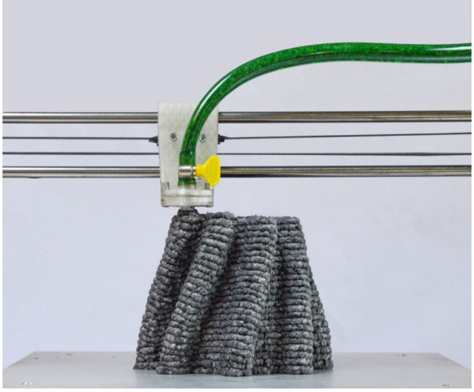

Figure 2. 3D printer that uses recycled paper

Ceramics has always been a discipline where material plays a big role. It already offers a range of different materials, clays each with its own characteristics, visual and tactile properties that have been field of exploration between artists and craftsman. 3D printing is one of ways that can help to extend the limitations of shapes and designs and using different ceramic materials adds more choice of visual preferences.

A leading exponent of studio-based ceramic 3D printing Jonathan Keeps in his article "Potting in a Digital Age" describes 3D printing as digital age pottery and compares this new technology to one of the first clay forming techniques, the coil building.The best way to think about extrusion 3D printing is as computerised coil building. Clay is extruded from a syringe; the syringe is moved around by electric motors guided by computer software, the clay coming out of nozzle forms the horizontal cross section of the form layer by layer. (Keeps, J. 2014, p.32)

UNFOLD, the Belgian design duo of Dries Verbruggen and Claire Warnier were the first to hack a 3-D printer kit by attaching a clay-filled syringe rather than the plastic printer head. Then using compressed air to pressurize the syringe, they extruded a thin line of clay—and so we had it, computer-guided coil building. (Keeps, J. 2014, p.18)

Today on the market there are a wide range of 3D printer types available. The simplest build 3D printers are available at a moderate price and even detailed descriptions of how to build 3D printers are available on the Internet. Therefore, 3D printer as a tool has become available to a wider range of people and with the greater accessibility it has the potential to become part of a ceramic studio's equipment.

CERAMIC 3D PRINTER EXPERIENCE AS A TOOL FOR CREATIVE EXPRESSION IN THE CASE OF ART ACADEMY OF LATVIA

The use of this technology in the field of ceramics at the Art Academy of Latvia, the centre where the research and practice was carried out, dates back to 2018. The Ceramics Department purchased a 3D printer and included it in their education programme in order for students to keep up with technological developments in the field of ceramics. However, this technology initially did not attract much interest in the student environment. Therefore, the teachers decided to set an example and the academic staff of the Ceramics Department developed designs for this technology. The designs were printed with the help of a 3D printer and an exhibition called 'Clone' was created. This exhibition was a creative experiment of the lecturers of the Latvian Academy of Arts and at the same time an incentive for students to try this new technology.

Figure 3. Exhibition "Clone" at Riga Porcelain Museum in 2018

Teachers created their own portraits with the help of a ceramic 3D printer. Every portrait was reproduced by the same file in large number and exhibited in a row. In this way the viewer was able to see and compare each print and observe that although each work was reproduced by the same file and was machine-created, the 'clones' were not identical. The ironic title of the exhibition sparks the idea of modern technology as mechanical copying machine, but the works show that no two pieces are identical. Mistakes and little accidents make each work different and adds singularity.

The question is whether ceramic 3D printer is a merely tool for fabrication for digitally designed objects creating emotionless items or it can create original expressions creating one of the kind artifacts. The answer lies in the mechanics of the machine and nature of clay. Exploring the process of 3D printing showed that it requires manual assistance during printing that can also affect the result.

The first experimental applications carried out within this academy were aimed at getting to know the relationship between clay and printer. The practical part started by learning to operate with ceramic Delta type 3D printer using stoneware clay and printing simple forms designed on Fusion 360 software program. First trials showed that as important part as designing an object is operating with 3D printer. One of the most important things for successful print is to prepare clay and fill the clay container without air bubbles.

Figure 4. Stoneware clay wasn't prepared good enough. Air bubbles in clay coused clay object to collapse

Figure 5. Ceramic Object collapse coused by unsuitable noozle size and printing speed

Figure 6. Successful print

Choosing right speed, pressure, nozzle size affects not only whenever it will produce a successful print but also can change the design and also can be used as manual tools to create intended imperfections as a part of work. Even during the printing, assistance was needed as air pressure slowly decreases during the printing, therefore has to be carefully increased manually. Getting to know the process, developed ideas using 3D printer in untraditional ways. Beauty of imperfections that break the monotonous rhythm of software produced code and unusual usage of 3D printing are also explored by different ceramic artists and can be served as inspiration.

Figure 7. Elize Hiiop, 3D printed bone china, works from International Bone China Symposium in Kaunas, Lithuania in 2018

Figure 8. Lauri Kilusk 3d printed bone china, these works are part of the larger exhibition project "Systemic Chaos", which took place in October 2017

Figure 9. From personal exhibition of Urmas Puhkan "Nerves"

TESTING EGYPTIAN FAIENCE

Faience first appeared at the end of the fifth millennium B.C. and has occurred in various forms up to the present day. It may have been invented in the ancient Near East following the development of an alkaline glaze on quartz stones. Its technological refinement and major triumphs, however, were surely accomplished in Egypt. (Riccardelli, Carolyn. 2000)

Unlike conventional, clay-based ceramics, the raw material of faience is a mixture of silica, soda, and lime reacted together during firing to make a new medium, quite different in nature to its constituents. The Egyptians referred to the material as tjehenet ("that which is brilliant or scintillating"), because of its reflective qualities, which they associated with the shiny surfaces of semi-precious stones. (Nicholson, Paul, 2009, p.1) Powdered Silica, lime, soda and colorant is mixed with water which results in faience paste. Faience is thixotropic, which means that the paste appears to be a solid, but becomes more fluid and slumps as it is modeled. A paste made of corn starch and water exhibits similar behavior. (Riccardelli, Carolyn. 2000)

Figure 10. Broad Collar of Wah

The faience was used to produce beads, small figures, vessels, amulets and architectural elements. There are three known glazing methods, application, efflorescence and cementation. Glazing methods also can be also combined.

Because of faience pastes thixotropic nature, it requires different approach in forming than when working with clay. It can be moulded in fired clay mould, shaped in smaller section attached together later, carved into. Though there are limitation of shapes and size.

However, limitations can also serve as an inspiration to search for a new unconventional formation methods. There are examples of unusual application of Egyptian paste in contemporary works which shows that this material can be worthwhile not only because of its historical meaning but also in terms of contemporary artistic expression.

Figure 11. Priya Thoresen, Midrange Clay, Egyptian paste

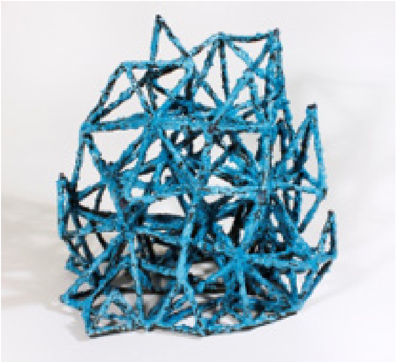

Figure 12. Priya Thoresen, Midrange Clay, Egyptian paste, Luster, 2018

Another kind of formation method that could be used to produce more complicated shapes not possible by using conventional methods, is using Egyptian faience paste is 3D printing.

The intriguing aspect of using Egyptian faience paste in 3D printing lies in the idea of combining historical material which is considered to be a precursor to glazed clay-based ceramics with a modern technology. With help of 3D printing it could be possible to make objects with more complex shapes therefore overcoming limitations of shape and size.

In the same time Egyptian faience just like any type of clay is a material with its own characteristics, visual qualities and therefore exploration of new ways of working with it could expand the range of tools for artistic expressions even beyond the historical meaning. Efflorescence glazing method was chosen as the most suitable. Efflorescence is a self-glazing process when salts in the paste migrates to the surface and develops a glaze when fired.

First step of experimentation started by testing available in different sources Egyptian faience recipes. Two sets of tests from each recipe were made to also test does the drying environment affects the efflorescence process. Zahed Tajeddin in his theses, investigating Egyptian faience technology, mentions that the temperature and air flow can affect the effortlessness process being more successful in higher temperature environment (Tajeddin, 2014, p. 158).

Figure 13. Sodİum salts start to form Figure

Figure 14. Efflorescence process

All samples were fired at 950 degrees. In the result of tests 3 recipes were chosen as the most successful in terms of good glaze development or plasticity.

Figure 15. Recipe A

Figure 16. Recipe B

Figure 17. Recipe C

Recipe A

Silica	35
Soda Feldspar	35
Sodium Carbonate	10
Ball Clay	20
+Copper Carbonate	2%

Recipe A-High ball clay content makes this paste workable, easier to shape and handle. Retains clear texture imprints. After firing develops grained surface structure, not a smooth glaze. Copper dioxide leaves traces on the surface. In further tests the aim was to investigate can the glaze result be improved in the same time maintaining the plasticity of the paste.

Recipe B

Silica	38
Soda Feldspar	38
Sodium Carbonate	6
Sodium Bicarbonate	6
Ball Clay	12
+ Copper Carbonate	2%

Recipe B-Takes a good texture imprint, good workability and glaze.

Recipe C

Quartz	34.5
Potash Feldspar	20
Soda Feldspar	20
Kaolin	11.5
Sodium Carbonate	7
Sodium Bicarbonate	7
+Copper Carbonate	2%

Recipe C - Very low plasticity, poor workability, breaks when bended, and hard to shape. Doesn't take texture imprint very well. From all the test the best glaze result. Recipe was chosen for further tests to investigate is it possible to improve the plasticity so that it could be suitable for 3D printing.

Next step was testing how the recipes could be improved. In his thesis Zahed Tajeddin mentions that adding organic binders such as Gum Arabic, starch, and gum tragacanth could improve the workability of the faience paste.

Test were made with added Gum Arabic to the Egyptian paste recipe C, which had the best glaze result but was the most unworkable. Although it improved the paste plasticity it had to be added in big amounts but still didn't improve the plasticity enough. But it affected the efflorescence process and gave poor glaze results. Zahed Tajeddin in his theses mentions that gum Arabic addition should not exceed 5% which was not enough to improve pastes plasticity enough.

This test showed that Gum Arabic doesn't improve plasticity as necessary for 3D printing and affects the efflorescence process, so no further tests were made in researching specifically Gum Arabic effect.

Ball clay due to its very fine particles is used in ceramic bodies to improve plasticity, workability, adds strength and act as a bonding agent. Two of recipes that already had a high percentage of ball clay had a required plasticity, but the glaze results could be improved.

Following test by changing ball clay ratio in a glaze were made to examine how ball clay is affecting the efflorescence process and glaze.

To understand each pastes suitability for 3D printing, simple test were made by extruding each paste through syringe.

Recipe A

Figure 18. Ball Clay 20%

Figure 19. Ball Clay 10%

Recipe A-By reducing ball clay contend improved the glaze result though the plasticity still being good enough for using in 3D printing.

Recipe B

Figure 20. Ball Clay 12

Figure 21. Ball Clay 9

Figure 22. Ball Clay 6

Recipe B-Samples with 12%, 9% and 6% ball clay show how ball clay affects Egyptian pastes glaze result. Doing extrusion tests with these pastes show that paste that contained 6% ball clay is getting clogged meaning that it wouldn't be possible to print through 3D printer. Therefore, paste that would be possible to extrude should contain more that 6% ball clay.

Recipe C

Figure 23. No Ball Clay

Figure 24. 5% Ball Clay

Recipe C–5% of ball clay adds little bit more plasticity but doesn't improve Egyptian paste enough to be able to extrude it. The glaze is not as thick as in the original recipe.

From these tests it become clear how ball clay affects Egyptian paste. Ball clays makes paste workable, but high percentage makes glaze less glazy and affects the smoothness of the glaze.

Therefore, it is important to find the best ratio between good glaze and plasticity. For 3D printing as the most suitable, recipes A and B with different ball clay, were prepared.

Figure 25. Testing extruding

Figure 26. Efflorescence process

Figure 27. After firing

Next step was preparing Egyptian faience paste for 3d printing. First attempts were not successful. 3D printer's nozzle got clogged and therefore stopped printing. After sieving paste it didn't show any more problems.

Figure 28. First attempt printing Egyptian paste

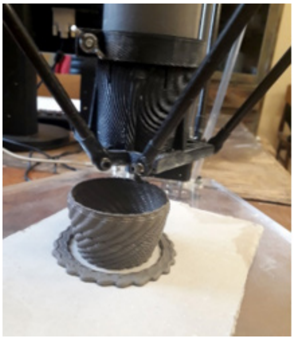

Figure 29. printing Egyptian faience

Figure 30. Printed Egyptian faience drying, efflorescence process

Figure 31. Test using Audrey Blackman Porcelain

Figure 32. Printing porcelain paper clay

Figure 33. Printing porcelain paper clay

Figure 34. Finished porcelain paper clay piece

Porcelain paper clay was made by adding paper pulp to recycled Mont Blanc porcelain. Mont Blanc is one of the whitest and most translucent ceramic bodies on the market but looking from a personal experience it shows some difficulties in work. Recycled Mont Blank porcelain often creates cracks when slip-casted. Adding paper fibre to porcelain body improves the clays strength, gives structure that reduces possibility of appearance of cracks.

Paper clay can have paper pulp clumps that could cause problems in 3D printing. Therefore, it was sieved to remove any clumps and particles that could clog the printers nozzle.

The porcelain paper clay showed good results in printing (better that porcelain clay). Adding paper pulp to recycled clay and using as material for 3D printing could be a way how to utilize recycled clay unsuitable for production.

Figure 35. Preparing porcelain bisque powder

Another material that was planned to try in 3D printing is porcelain bisque powder created by sanding bisque fired porcelain. This is a waste material that is usually thrown away. It can be recycled by adding to the clay body but also creates a hard to work with paste when mixed with water. Although it is very hard to shape, it turns into hard body after firing. Even without adding bonding material it was possible to extrude it smoothly through syringe which means it could also be used in 3d printing to make objects impossible to shape by any other forming technique. The plan was to test this material by itself and by adding binders like gum arabic and small amount of clay.

Similarly, like using recycled clay in 3Dprinting it is a way of making use of material that is being wasted. As we know with the help of 3D printer it is possible to create unusual designs, complex shapes but using more sustainable materials can add a whole new value to the work.

OUTCOMES

The outcome of this personal studio-based research has shown that for the artist and designer, recognising the relationship between clay and the 3D printing process involves a series of complex processes that need to be directly experienced. Thinking with the material forms the circular construct of the process. In a verbal analogy, it can be said that working with 3D printing requires a 3D and flexible way of thinking, designing and realising open-ended potentials. While exploring the ceramic 3D printing process, it has been seen that both working with 3D software programmes to design the object and understanding the structure of the machines is a process that requires different field knowledge and time.

In our research, we searched for how we can experience a personal inquiry and discovery using a 3D printer. Beyond the current practices of studio-based art and design explorations, we tried to capture a perspective that has not been studied, but which is the problems of other fields. We examined the processes that the question "What could be the function of 3D printers beyond being a design tool and shaping machine?" led us to. Beyond the fact that 3D printers can realise complex constructions as an advantage today, we have seen that new challenges are also possible. We have experienced with our personal tests that 3D printers, which provide great convenience for the use of recyclable materials in ceramic production, can also be looked at from this point of view and we have received positive results. This experience, which can be seen as a solution to the unsustainable conditions of ceramic production; post-firing immutability and high energy use, can also be seen as a suggestion and research invitation for ecological and holistic thinking philosophy.

This research, for us, has reinforced the idea that in the future we can look towards unconventional uses of this medium rather than the final product design. In the act of thinking with the 3D printer and the transformed clay material, we experienced why "process" is a big part of ceramic creation. This practical research evolved into new ideas that may develop in a different direction than originally intended and is a suggestion for new research potentials.

The questions and ideas in this research were not only carried out through practical experiments and working with a 3D printer. They were also derived with the support of the know-how environment at the Latvian Academy of Arts with people who have experience of working with 3D printers. This provided the experience that reliable results can be achieved through the collaborative work of many fields of expertise. Research activities on 3D printers require a shared exchange of ideas. It is understood that coordinated, collaborative, challenging methods of research will lead 3D printing research to successful results.

Yazar Katkı Oranları

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Figure 3. Exhibition "Clone" at Riga Porcelain Museum in 2018, https://porcelanamuzejs.riga.lv/en/ gallery/ (under the gallery Exhibition "Clone")

Figure 4., 5.,6. Experimental printing processes, photo credit: Inese Križanovska

Figure 7. Elize Hiiop, 3D printed bone china, works from International Bone China Symposium in Kaunas, Lithuania in 2018, http://www.porcelianosimpoziumas.lt/en/portfolio_page/elize-hiiop-en/

Figure 8. Lauri Kilusk 3d printed bone china, these works are part of the larger exhibition project "Systemic Chaos", which took place in October 2017, https://www.laurikilusk.ee/naitused

Figure 9. From personal exhibition of Urmas Puhkan "Nerves", https://www.icaf-sasama.com/artists-2019-jp/Urmas-PUHKAN-

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Figure 11. Priya Thoresen, Midrange Clay, Egyptian paste, https://www.priyathoresen.com/

Figure 12. Priya Thoresen, Midrange Clay, Egyptian paste, Luster, 2018, https://www.priyathoresen.com/

Figure 13-35. Experimental composition and printing processes, photo credit: Inese Križanovska