RESEARCH ON THE EXPLORATION OF SPRAYED CLAY MATERIAL AND MODELING SYSTEM

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Abstract. As a traditional building material, clay has been used by humans for a long time. From early civilisations, to the modern dependence on new technologies, the craft of clay making is commonly linked with the use of moulds, handmade creations, ceramic extruders, etc. (Schmandt and Besserat, 1977). Clay in the form of bricks is one of the oldest building materials known (Fernandes et al, 2010). This research expands the possibilities offered by standardised bricks by testing types of clay, forms, shapes, porosity, and structural methods. The traditional way of working with clay relies on human craftsmanship and is based on the use of semi-solid clay (Fernandes et al., 2010). However, there is little research on the use of clay slurry. With the rise of 3D printing systems in recent years, research and development has been emerging on using clay as a 3D printing filament (Gürsoy, 2018). Researchers have discovered that in order for 3D-printed clay slurry to solidify quickly to support the weight of the added layers during printing, curing agents such as lime, coal ash, cement, etc. have to be added to the clay slurry. After adding these substances, clay is difficult to be reused and can have a negative effect on the environment (Chen et al., 2021). In this study, a unique method for manufacturing clay elements of intricate geometries is proposed with the help of an internal skeleton that can be continuously reused. The study introduces the process of applying clay on a special structure through spraying and showcases how this method creates various opportunities for customisation of production.

Keywords. Spray clay, Substructure, 3D printing, Modelling system, Reusable.

1. Introduction

The fabrication process that is proposed questions traditional ceramic-making methods (i.e pinching, coil, slab, wheel) and introduces a system of sticks and weaved rope that acts as a substructure to which clay is applied. The inspiration for the components that

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were produced emerged from traditional bricks as a building material and although the specific production method is possible to be used for art pieces and other decorative objects, this research focuses on components intended for architectural purposes. The method that is suggested, in contrast to traditional brickmaking, allows for the customisation of components and the creation of intricate geometries of varying densities, which are typically limited by traditional ceramic forming processes and the material itself. This paper divides the fabrication process in two parts. Firstly, with studies on clay as the primary material and secondly, with the base structure that gives form to the components and creates their unique morphology. Apart from the success of the material and substructure, the chosen method had to abide by certain set parameters. Such parameters were that the components would be durable and strong enough to be stacked one top of the other, as well as be shaped in a way that one could successfully connect to another. Also, the process had to comply with safety regulations for firing and be environmentally aware in terms of the materials that were used.

2. Methodology

This research paper discusses the main challenges of fabricating clay elements with an internal substructure. The clay that would encompass this substructure had to be in liquid form to allow spraying. For this reason, two types of clay were chosen. The first was regular clay mixed with different water ratios and the second slip clay. Conclusions were drawn from the drying results of those mixtures. The option of using natural additives in the mixture was then explored to enhance the material properties. Afterwards, the investigation of the type of internal structure started (plastic, polymorph, wax, and rope) and it was observed how the clay behaved when sprayed onto each structure while taking into consideration whether it produced cracks, the time it took to dry and how easy it would be to fire. From the results of those tests, the best option in terms of clay mixture and structure was selected. The physical fabrication process ran parallel with digital explorations of components that imitated the clay physical models so that faster aesthetic, schematic, and geometrical explorations could be achieved. Therefore, fabrication and digital studies moved in a circular process during which one fed information to the other as the exploration of possibilities for the chosen method moved forward.

3. Material studies

The researchers tested the clay and the structures of sprayed clay.

3.1. CLAY STUDY

The selection of clay mixture depended greatly on the substructure that would be used. The project SUB-C implemented at the Bartlett school of Architecture, experimented with 3D printing PLA lattices which were then dipped into clay. The problem with this method was that the end products couldn't be fired in the kiln because plastic exhausts toxic fumes in high temperatures (He et al., 2019). In the initial explorations, the option of polymorph was investigated as the skeleton for the internal structure, because it was faster than weaving rope. The priority in these initial experiments was to discover what would happen to the clay as it dried, according to its type. Doing tests with polymorph was possible because the pieces were not going to be fired. Thus, terracotta clay was tested with different proportions of water, which as can be seen in the examples in Figure 1 completely cracked.

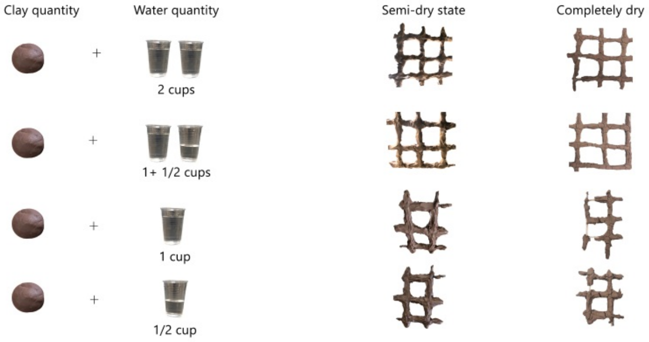

Figure 1. Terracotta and polymorph

After the results of the previous tests, stoneware slip clay was selected which is by nature more liquid and does not require the addition of water. As shown in figure 2 the polymorph pieces were dipped in clay several times but when it dried it also produced cracks - even though fewer than before.

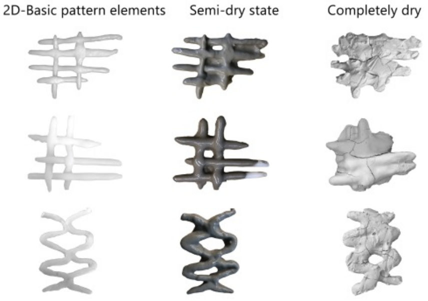

Figure 2. Stoneware slip clay and polymorph

There was optimism that this type of clay held possibilities for further explorations. Therefore, an additive to the mixture was researched that would make it produce fewer cracks. According to Plé and Lé, paper reinforced clay with fibre will reduce cracks in clay and improve its behaviour (2012). So paper pulp was added to the stoneware slip clay to make it more unified. The ratio of clay to paper pulp is 3:1. Figure 3 illustrates the process of experimenting with the specific material and the results were all successful. The natural fibres of paper helped keep everything intact and solidified. Looking at the "completely dry" results it can be seen that the clay while drying produced no cracks. In the physical models displayed further on, this method was used successfully.

The development of pattern studies was fundamental for researching clay behaviour on rope. Clay spreads differently according to the distances between the lines of the pattern When the pattern is denser the result is almost solid as the layers of clay increase. Also, in more dense patterns it is easier for the clay to attach to the geometry even with fewer layers of clay applied as illustrated in Figure 4.

Figure 3. Stoneware slip clay and paper pulp

On the other hand, when the pattern is sparser it is observed that there is usually a need for applying thicker layers of clay both for attachment and also in order to make the piece strong and rigid.

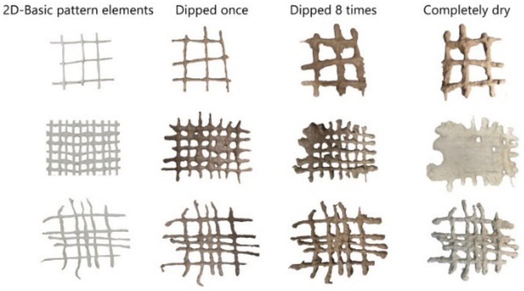

Figure 4. Density and pattern explorations

3.2. BASE STRUCTURE

After experimenting with clay, a controllable base structure was required to form the desired shape. A mould-like tool - but in this case, a thin structure base is used to control the clay. The idea was that this structure would reinforce the clay and give it shape similar to how iron rods act in reinforced concrete. The clay would attach to the structure either by being poured on it, either by spraying, or by dipping it into clay.

An important parameter throughout this process was the firing temperature of clay (approximately 1200°C). This presented an issue firstly in terms of how the internal structure would respond and secondly because clay shrinks in high temperatures (Rahman et al. 2013). Therefore, the substructure would have to definitely be made from a material that ideally shrinks together with the clay or evaporates. That is the main reason why rope seemed like a fitting option and it was decided to look further into it. Overall, factors such as material, thickness, heat durability, and the emissions it might release when fired, had to be considered for rope to be used as a structure. It was concluded to look further into natural materials that would not exhaust any toxic fumes under high temperatures. Thus, the types of rope selected were 100% natural jute, hemp, and sisal which come in a variety of thicknesses and could correspond to the different sizes of objects that would be produced.

In the design studies, experimenting began with lattice systems made of polyhedrons. The idea was that both single polyhedrons and combinations of them could work as components that would be connected to create systems like the ones in the examples shown in figure 5, allowing the development of different types of architectural elements (walls, slabs, columns, staircases etc.)

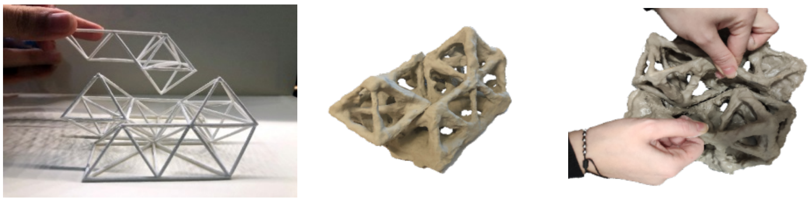

Figure 5. Polyhedron lattice systems

The main structure of the components would be the edges of the polyhedrons which would then be weaved in between with rope and sprayed with clay to become solidified. The basic concept for the implementation-design strategy would be to explore ways to create structures made of rope, afterwards cover them in clay, and in the end-fire them. Except for the importance of finding an efficient way to make rope "self-supported", it also had to be worked with in a way that could predict the clay outcome as much as possible. Therefore, an exploration of the different effects of clay on a variety of densities and patterns, began. This process was crucial for future design studies.

4. Clay on rope applications

Having established the clay mix and the base structure material, the formation studies begin. In this chapter, five physical experimentations will be analysed that helped decide the most successful system to form the clay to the desired design component.

4.1. METHOD 1

The first method for stabilising the rope in a certain form was to create a two-dimensional wooden frame with nails on which rope could be weaved through as shown in Figure 6. After spraying the clay some time was required until it was almost dry to remove it from its frame. The reason for that was to avoid cracks while the clay dried. The difference in coefficient of thermal expansion between the two materials (the drying clay and the rope) causes internal stress to build up, resulting in the clay breaking as it dries. Through this method, clay was applied on different densities of multiple grids and patterns of rope. This process helped with comprehending the properties of clay in terms of density and porosity. The closer the weaved rope is, the denser the clay connects, leading to less porous results.

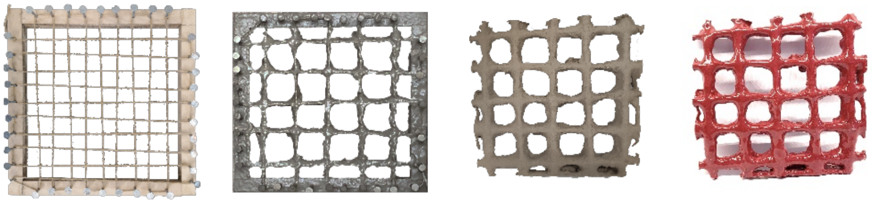

Figure 6. Physical models-2d frame

4.2. METHOD 2

In this second attempt, although the same logic as previously was maintained, it was necessary to test extruding the geometries in the third dimension as well. Therefore, as illustrated in figure 7, taller nails were applied to the frames so that weaving on the z-axis could be enabled. The issue faced with this process was the removal of the clay component before it was dry. The thickness of the geometry made it hard to pull out, so it was inevitable to cut it at the edges, which caused some deformation.

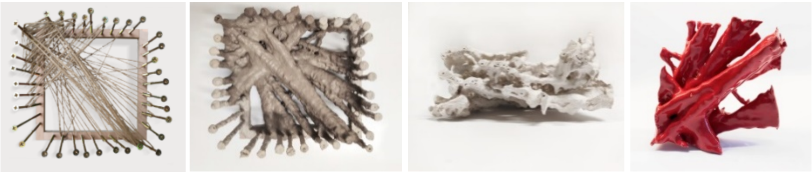

Figure 7. Physical models 3D

Figure 8 displays a first attempt to resolve the problem of having to cut the piece from its frame to remove it. Wrapping rope around the nails prevents clay from drying in contact with the metal. This allowed pulling the piece away altogether from the frame, leaving the nails behind. By studying the previous physical models, the effect the layers of rope created when clay was applied was found very interesting. The pieces displayed depth and porosity at the same time.

Figure 8. Clay element removal from frame

4.3. METHOD 3

The third method displayed in figure 9, included an exterior three-dimensional frame that supported the interior structure made of rope. All the connecting parts between the exterior frame and the interior structure are made of rope, therefore in this method the previous problem of removing the clay when it dried wasn't encountered. The downside to the process was that it was extremely time-consuming. It also presented limited design opportunities due to the cubical frame.

Figure 9. Exterior timber frame

4.4. METHOD 4

Intending to give three-dimensionality to the pieces a centre node was created to which metal sticks were attached. After making the central connection, the rope is tied across the ends of the sticks to create the outline edges of a polyhedron. Finally, rope is weaved around the geometry to develop the final form of the component which is afterwards ready to be sprayed. As mentioned before, for the piece to be able to dry properly a way had to be found to remove the rigid metal sticks before the clay dried completely and shrank. In this method of developing components, the metal sticks meet at the centre node but at the other end, they are exposed. Therefore, this allowed them to be pulled out when the clay was almost dry. Figure 10 illustrates the process that was carried out for this method.

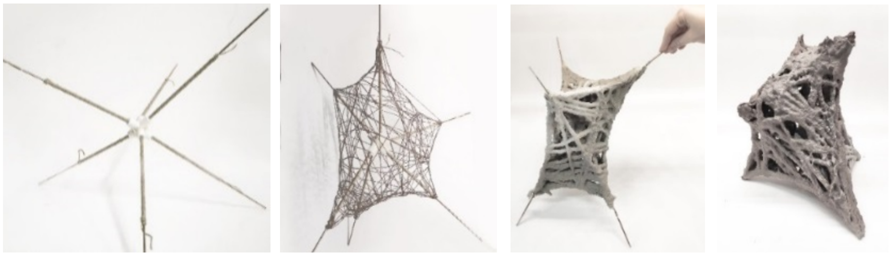

Figure 10. Component with central node

As can be seen from the physical model in Figure 10, when dry, the edges became curved. The reason for that was that they were made out of rope and therefore weren't stiff enough to endure the clay shrinkage. Also, when applying several layers of clay, it adds up to the total weight of the structure and since the edges are thin, they eventually give in to gravity. Even though the component as a piece was successful, this issue still had to be resolved, because having curved edges cannot facilitate a smooth assembly/stacking of components.

4.5. METHOD 5

In order to overcome the problem of the curved edges that the previous process entailed, the goal was to find a way to place the rigid metal sticks on the edges instead of rope. For that reason, Figure 11 presents a new type of node that was placed on the corners of the polyhedrons and held the sticks in place. These nodes are open from both sides, making it possible to pull away the sticks as the clay dries.

Figure 11. Physical model with nodes and sticks on the edges

By comparing the two models as shown in Figure 12, the difference in the edges is obvious. Having components with flat-strait edges is vital for the process of connecting-stacking that is required to produce larger aggregations.

Figure 12. method 4 and method 5 comparison

The inside of this geometry was hollow, which allowed, in addition to the exterior weaved layers, to add layers of rope on the inside as well. After having assembled the component with the nodes and sticks, the weaving process could commence. The components were sprayed about three to four times, and they were then left to dry for five days. During that stage, the nodes and the metal sticks are removed. Each component was fired two times. The bisque firing was first at a temperature of 1200° C, lasting nine hours. The rope was exposed at the edges, turning into powder and falling out after firing. At this stage, the component turns into a ceramic piece. After that, the components are glazed. The type of glaze determines the temperature of the second firing. Three types of glazing were used, which required varying temperatures from 800° to 1200° C for 6-8 hours. In both firing stages, the components were kept in the kiln overnight to cool down to prevent cracks.

5. Digital studies

After the method testing and by observing how clay appears after reaching the final stage which is firing the component, a digital design study was initiated to simulate the clay effect on the rope. The goal was to predict the outcome of a physical component for a specific design. Therefore, a selection of components were digitally created in Figure 13 with catalogues of different patterns and densities. The patterns we experimented with were grid, parallel, fan, and a mix of the above.

Figure 13. Digital pattern catalogues

Each component has a digital translation of the clay implemented to it to enhance the visualisation of the design. This was vital to the process because it saved time and created a preconceived idea about how the component would turn out geometrically and aesthetically before proceeding to the physical manufacturing phase.

The elements that were explored digitally were the tetrahedron and pentahedron because they are able to produce combinations that are possible in all three axes and can be attached by all of their faces. These combinations create bigger components that can grow into architectural elements. As seen in the combinations in Figure 14, the elements that are connected are of varying densities creating larger components that are more porous in some parts and denser in others.

Figure 14. Combination research

This was also applied in the tests that were done for architectural elements. As illustrated in Figure 15, walls and facades were developed digitally in some parts being more solid and in others sparser according to how the light flows within a space. Moreover, the pattern and density studies that were produced both physically and digitally through catalogues were very valuable for this part of the process, because the pattern and density of a single element greatly influenced the larger scale when populated. This system enables the maker to control the design from the small scale of a single component to the larger scale of an architectural element which is normally not feasible with conventional making-designing methods.

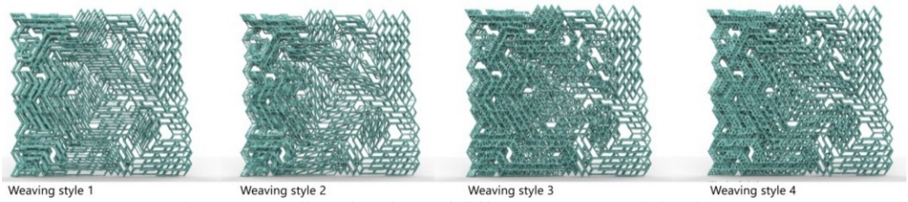
Weaving style 1 Weaving style 2 Weaving style 3 Weaving style 4

Figure 15. Wall explorations of different patterns and densities

6. Conclusion

The fabrication method of clay components that is presented in this paper allows for clay slurry to be used as a main material of physical modeling. This is accomplished with the use of an internal skeleton made of rope to which the clay slurry attaches to. The skeleton is highly customisable providing a level of freedom to the final outcome of the model. The nodes and sticks that are used for the internal framework are removed before the model is dry and therefore can be used numerous times. In addition, paper pulp as a natural additive to the mixture contributes to making this process environmentally aware.

The final outcome of the fabricated elements relies on the internal substructure because apart from giving shape to the components, it also controls the porosity and plasticity of clay through the different densities and patterns of the weaved rope. As digital studies and fabrication tests develop, the understanding of the relationship between clay and rope and how they function as a system, evolves as well. After creating familiarity with the process, this fabrication method holds potential for many explorations of crafting and geometrical articulations of clay that can be applied in any form of art.

The system that is introduced can produce elements that are defined by their complexity and plasticity which is possible due to this unique method of ceramic making. Furthermore, the pieces that are created develop opportunities both independently as well as when used in combinations to create bigger parts. These parts can be constructed physically through stacking and digitally through automative generative processes. The parts can either be comprised by standardised units creating a more traditional repetitive effect but can also be more complex. Such complex geometries hold potential for the development of studies on a larger scale. For this to be achieved, components shouldn't be regarded as units, but as elements that when combined create an overall volumetric outcome, similar to the logic of a puzzle.

If these components are to be used by the building industry, for example, in the development of architectural facades, it is inevitable that a method of mass production be developed. As previously showcased, since the digitisation of the components has already been implemented, the idea of creating a digital platform combined with AR technologies that will contain tools and instructions for fabricating these elements is being explored. Through this platform a system of distributed manufacturing would be enabled for users and ceramist workshops anywhere in the world that are interested in this method of ceramic making. The goal would be to make this platform as accessible and user friendly as possible so that anyone can participate in the production process. This concept is still under consideration but could potentially present interesting opportunities for the future.

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