NOVA SCHOOL OF SCIENCE & TECHNOLOGY

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LISBOA

JÉSSICA ALEXANDRA PINTO PEREIRA

Bachelor of Fine Arts - Multimedia

ART AS AN ADDI(C)TIVE PROCESS

A MULTIDISCIPLINARY APPROACH OF SCIENCE AND TECHNOLOGY IN ARTISTIC PRACTICE

MASTER IN MASTER IN ART AND SCIENCE OF GLASS AND CERAMICS

NOVA University Lisbon | University of Lisbon

April, 2025

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To you, brave one.

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In the last years of this master's degree, I learned everything, theory and practice, it wasn't always easy. I learned about myself and connections with people. Life is not created alone, be it a piece of art, a research work, there is always a necessary connection, a doubt to clarify, frustrations to share, other experiences to be heard.

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Today it makes perfect sense, thank you Jessica.

“Voa alto.
Se caires, estou cá embaixo"
Pai

ABSTRACT

This thesis explores both the integration of 3D clay printing into contemporary ceramic art, and the current state of art from my perspective, examining both its technical and conceptual aspects. Through experimental research of the material, different stoneware types - PRAI 3D, GRES BG, and GRES BT - were analysed for their suitability in digital fabrication. The study focuses on material properties like shrinkage, porosity, and firing behavior at temperatures of 980°C and 1200°C. Using the WASP 40100 LDM printer, three clay compositions were tested to assess printability, layer adhesion, and surface quality. The research also delves into the balance between traditional manual craftsmanship and the use of digital technologies, questioning the role of intuition and unpredictability in the creative process. By blending science with artistic practice, this work reflects on how new technologies and knowledge about "old" materials are reshaping the relationship between art, craft, and innovation. The findings highlight both the potential and limitations of 3D-printed ceramics in artistic contexts. This thesis contributes to ongoing discussions about materiality, artistic practice, and the evolving role of technology in contemporary ceramics.

Keywords: 3D clay printing, stoneware, ceramics, additive manufacturing, artistic practice.

RESUMO

Esta dissertação explora tanto a integração da impressão 3D de argila na arte cerâmica contemporânea quanto o estado atual da arte através da minha perspetiva, examinando os seus aspetos técnicos e conceituais. Por meio de pesquisa experimental do material, diferentes tipos de grés - PRAI 3D, GRES BG e GRES BT - foram analisados quanto à sua adequação na impressão 3D. O estudo concentra-se nas propriedades do material, como contração, porosidade e comportamento de queima nas temperaturas de 980 °C e 1200 °C. Usando a impressora WASP 40100 LDM, 3 tipos de grés comerciais foram testados para avaliar a capacidade de impressão, a adesão da camada impressa e a qualidade da superfície. A pesquisa também se aprofunda no equilíbrio entre o fazer manualmente e o uso de tecnologias digitais, questionando o papel da intuição e da imprevisibilidade no processo criativo. Ao misturar ciência com prática artística, este trabalho reflete sobre como as novas tecnologias e o conhecimento sobre materiais "antigos" estão a renovar a relação entre arte, artesanato e inovação. As descobertas destacam tanto o potencial, quanto as limitações da cerâmica impressa em 3D, em contextos artísticos. Esta dissertação contribui para discussões em andamento sobre materialidade, prática artística e o papel evolutivo da tecnologia na cerâmica contemporânea.

Palavras-chave: impressão 3D em argila, grés, cerâmica, manufatura aditiva, prática artística.

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ACRONYMS

CENIMAT	Materials Research Center
FDM	Fused Deposition Modeling
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
3D	Three dimensional

1. SOMETHING ABOUT

1.1. Introduction

Artistic creation is an intricate process shaped by uncertainty, intuition, material constraints, and technological possibilities. This dissertation emerges from a curiosity about the relationship between art, materiality, and digital fabrication, specifically in the context of clay 3D printing. It seeks to explore how artistic decision-making is influenced not only by conceptual frameworks but also by the nature of materials.

The motivation for this research stems from a desire to bridge craftsmanship with contemporary technologies. Clay has been used for centuries as a fundamental artistic and functional medium, yet its integration with digital fabrication tools introduces new possibilities and challenges. Unlike other 3D printing materials, like plastic that extrudes a warm filament that is deposited, cools down and retains the desired form, clay behaves a bit unpredictably in the sense that it will be deposited and with the weight of the next layers might deform, might fall, or it might hold on. This tension between precision and organic variability becomes at the same time a limitation, and a possibility.

Beyond the technical aspects, this dissertation also reflects on how artistic value, validation, and authorship are constructed. In a world where digital tools are increasingly mediating creative processes, where does the artist still hold the brush? How does working with a 3D printing machine challenge notions of control and authorship? These questions drive theoretical discussions within this research, exploring themes of judgment, authority, identity, and accessibility in art-making.

By combining practical experimentation with conceptual analysis, this dissertation aims to contribute to both artistic and academic discussions on digital craftsmanship. It is an inquiry into the visceral, embodied, and intuitive aspects of creation, recognizing that making is not merely a technical act but an ongoing negotiation between the artist, the material, and the machine.

1.2. Contributions

The goal here is to explore the intersection between artistic creation, material experimentation, and technological processes, particularly in the context of clay printing. It investigates both conceptual and technical aspects of artistic practice, offering a multi-layered approach that moves between theory and experimentation.

One of the key objectives is to examine the uncertainties and subjective dimensions of artistic creation. Through discussions on words, judgment, authority, image making, emotions, accessibility, identity, and value, this research delves into the complexities of artistic decision-making, validation, and perception. By framing creation as an unpredictable and intuitive process, the dissertation seeks to challenge rigid structures of artistic evaluation.

On a more technical level, this research contributes to the understanding of clay as a medium for 3D printing. It provides a detailed investigation into the material, process, and challenges, covering aspects such as clay shrinkage, absorption, infill variations, and printing limitations. By documenting these experimental results, the dissertation not only expands knowledge on ceramic-based digital fabrication but also highlights the importance of deeply understanding a material's behavior in artistic and design applications.

A significant contribution of this study is its exploration of the body's role in creation—both in the conceptual sense (through discussions on visceral bodies and artistic intuition) and in the material sense (through the physicality of clay and the act of making). It proposes that the process of working with clay, especially in a digital, 3D modelling and printing context, is not just about technology but also about bodily engagement, tactility, and sensory experience.

Ultimately, this dissertation positions artistic creation as an addictive, immersive, and iterative process, where unpredictability and material play a crucial role. By bridging conceptual discourse with material practice, it offers insights that are relevant to artists, designers, and researchers working in the fields of additive manufacture, ceramics, and contemporary art.

1.3. Dissertation Structure

This dissertation is structured into four main sections: **Something About, Art As…,** and **An Addi(c)tive Process**, **All Together** each addressing different aspects of the research from conceptual foundations to material experimentation and conclusions.

The first chapter, **Something About**, introduces the research by outlining its Introduction (1.1), explaining the motivations and context of the study. This is followed by Contributions (1.2), which highlights the main objectives and significance of the research. The chapter concludes with Dissertation Structure (1.3), offering an overview of how the content is organized.

The second chapter explores the conceptual and theoretical dimensions of artistic creation. It begins with THE ABSENCE OF STATE OF ART (2.1), which reflects my position as an artist. The following sections delve into various themes, including WORDS (2.2), which investigates the role of individual experiences, and UNCERTAINTY (2.3), which examines unpredictability in creative practice. The chapter continues with MEMORIES (2.4) and DUALITIES (2.5), which explore the influence of past experiences and the coexistence of opposing forces in artistic expression. AUTHORITY (2.6) address decision-making, critique, and external influences on art. Visual and emotional aspects of creation focus on IMAGE MAKING (2.7) and FEELINGS AND EMOTIONS (2.8), while ACCESSIBILITY (2.9) and IDENTITY (2.10) consider the themes of recognition and self-expression. Further discussions on artistic evaluation emerge in VALUE, VALIDATION, EVALUATION (2.11), followed by an exploration of instinct and spontaneity in UNPREDICTABILITY AND INTUITION (2.12). The final sections - A BODY (2.13), CONNECTIONS (2.14), CREATION (2.15), and VISCERAL BODIES (2.16) - engage with the physical, relational, and sensory experiences of making art.

The third chapter, **An Addi(c)tive Process**, transitions into the experimental and technical aspects of the research. It begins with STATE OF THE ART (3.1), reviewing existing literature and practices related to the study. CHARACTERIZATION AND COMPARISON (3.2) set the groundwork for analyzing different materials and techniques. The MATERIALS (3.3) section provides an in-depth look at the components used in the research, leading to METHODOLOGY (3.4), which details the processes and experiments undertaken. A key focus is on KNOWING THE MATERIAL DEEPLY (3.5), which reflects on the complexities of working with clay and 3D Printing. The chapter concludes with CONCLUSION (3.6), summarizing key findings and discussing their implications.

The fourth chapter, **All Together,** highlights how understanding materials enhances creativity, freedom and confidence in artistic work.

2.

ART AS…

2.1. THE ABSENCE OF STATE OF ART

Over the past three years, my perspective on what it means to be an artist has shifted profoundly. I've stepped away from the notion that I must fully engage with the collective understanding of art at this given moment in time – *NOW* - as if doing so were an obligation for my work to be meaningful. The truth is, I don't need to position myself within contemporary trends and movements if that isn't my nature or desire. My work is meaningful in itself, first and foremost for me, as its creator.

I fully acknowledge the objectives often attributed to art, such as advancing understanding and promoting awareness. However, these are not my primary motivations. What drives me is something more personal: deepening my own awareness, strengthening my connection to my experiences, and understanding how I feel about the world around me. My art is not a means to contribute to a shared intellectual progression, it is a tool for my own exploration. I no longer feel the need to place myself within the ongoing artistic narrative. Whether I like it or not, my work may still be categorized and analysed by the so-called "authorities of art," but that is beyond my control and, more importantly, beyond my concern. I will create, and if my work is placed within a broader context, that will be a consequence, not a guiding principle.

As will become evident in the following chapters, art is for me an individual pursuit, and my creative process begins not with where *art* stands in its historical timeline, but with where *I* stand in my own artistic journey. My rejection of the "State of Art" as a necessary reference point comes from a belief that artistic creation is not dependent on external validation or historical positioning, but rather on an internal necessity. In choosing to focus on my personal perspective rather than the collective "State of Art," I assert a form of artistic independence. Some might call it selfish - but does this independence form its own dialogue, even if unintended? While I recognize that others may interpret my work through the lens of contemporary artistic discourse, that is not my responsibility as a creator. My focus is solely on my personal artistic evolution, and whether or not my work is later situated within a broader conversation is outside my intent or interest. All art, once shared, inevitably exists in relation to its time, shaped by the interpretations of others. However, my creative process is not driven by a need to contribute to that discourse. If my work enters the conversation, it does so on its own terms, not as a conscious pursuit. My approach is deeply personal, and if it happens to engage with the "State of Art," it is merely a byproduct, never the goal.

Perhaps the real question is whether the "State of Art" is something external and fixed, or whether each artist defines their own. For me, it is not a collective construct but an internal matter - a personal evolution rather than a shared framework. I do not reject the idea that my work might be viewed in relation to a wider artistic context, but that is not where my creative process begins.

That being said, my "State of Art" cannot be confined to a single chapter - it *is* my dissertation. It will take shape through my experiences, thoughts, and the works and references that truly resonate with me. Instead of isolating it as an academic analysis, I want it to emerge naturally through everything I explore and create.

2.2. WORDS

Does art concern everyone? In each context, in each story, in each individual, bodily intuition, in each desire to express what is not yet visible? Here I am faced with trying to get to a place without knowing the way there. Each experience is like an arrow that gives ambiguous directions. Hoping that the different materials and different techniques become extensions of my capacity and my motivations hidden from my own self.

Frustration and pleasure must be the words I most associate with the act of creating, trying and being an artist. Perhaps a relationship of love and hate, relaxing and tiring, pride and guilt, transparency and pretence, having to explain the inexplicable. Is Art so full of antonyms? Is this why it is so difficult to justify the word? Or is it because people try to collectivize what belongs to the individual? Why try to summarize the years and years of individuals, such different contexts in the same word? ART. Art, Beauty are words that belong to each individual in such a different and unique way, “Beauty is in the eyes of the beholder” becomes *Beauty is in the being that experiences it.* If art belongs to everyone unequally, how can I judge and criticize another individual's art just because I don't feel it relates to me? Relatable… is it one of the words of art? As an artist, it is valuable when a viewer relates in their own way to my work, sometimes they understand why, but most of the time they don't and there is no problem with that. A sensitive experience, with or without an apparent reason, is still a provocation that the creation of one being provokes in another. This goes beyond concepts and pretences; it focuses on individual sensitivity.

I clarify here that concepts in art and conceptual art sometimes have credible bases with which I can relate and understand what the artist set out to do. However, I have come to believe that we have reached a moment in art when very often concepts are invented on the fly merely to satisfy the demand for justification for art. In the entire course of my path in the arts I have seen colleagues and teachers at pains assigning artworks (that initially didn’t have any known reasons or meanings) the pretense of being in aid of one respectable cause or a noble meaning. Just having an artistic experience without needing to justify it is not acceptable, there has to be a reason behind it, even if the artist hasn't gotten there or realized it yet, the public, the academy, the current world of art demands it. So artistic illusions are created between laughter and moments of concentration to discover the best way to justify something that we don't even fully understand why we did it. The weirdest idea, the better, it makes artists look like they are this new era “Picasso, Dali or any other famous artist for its noticeable style”, the more original, the more outside of the box are the ones that win contests, that are in the galleries, trying so hard to get outside of the box to end up exhibiting in a white cube[1].

[1] White Cube as a particular meaning in the art world, as it’s written in the Tate website a renowned art institution in London: “a certain gallery aesthetic characterized by its square or oblong shape, white walls and a light source usually from the ceiling” https://www.tate.org.uk/art/art-terms/w/white-cube

The problem here is that we are not trying to understand what we did as an individual experience, but we are trying to make it as an experience with the same meaning for everyone.

The rush with which we have to know everything in an instant is not helpful for individual artists trying play with materials to just learn about themselves, nor for the general evolution of our art world, I do feel that's the reason we are so stagnant in the present moment.

People spend their entire lives without knowing themselves, or learning to know themselves, going through phases, ups and downs, but artists are pushed to discover themselves faster, to know who they are as artists, what type/aesthetic of art they practice, all in a rush running for validation and adapting to opportunities. Maybe a potential artist should just refrain from that title. To be an artist isn't to be a person that plays with materials for pleasure, for self discovery, for self-expression. It should mean the same thing, but I think a lot of people haven't realized there is a difference well hidden.

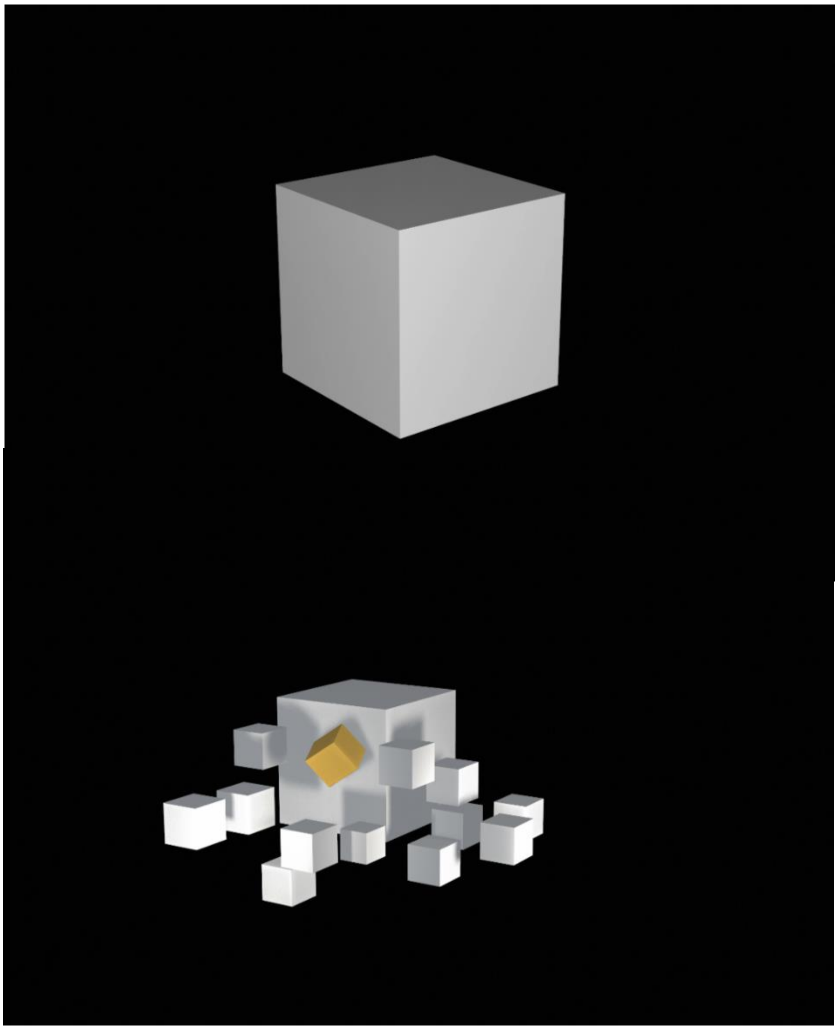


Figure 2.2.1 - Outside of the box, but still close, 2025

2.3. UNCERTAINTY

It is known that most humans do not like to make mistakes, even though we know that we learn much more from each mistake than from successive lucky shots.

Artists deal with these mistakes and learnings every day, it is as frustrating as it is rewarding. Starting a piece, starting to love it and out of nowhere one wrong move and that feeling that everything is lost comes. So, this has been my process, beginnings that I said were failures, but it was learning that remained and movements that will probably never be repeated. It's incredible how much "easier" it is to model something in digital 3D software, where errors are reversible, everything is visual, there's a lack of touch with the material that I certainly miss but a new type of connection with the machine, new learnings and a ton of buttons and short keys to “touch” and form my creation.

Starting something without knowing where we're going is very similar to the cycle of life in a way. We take a material, we wait for our hands to show how to mold and we shape it, through small gestures and choices that can change everything at every moment, but we continue hoping to reach a point where we will know where we are, most of the time without ever knowing. Some of my most appreciated artworks, not only by me as the creator, but by all eyes that have seen it, are curiously the ones that gave me the most pleasure, the ones that I started without a plan. As if they were building themselves, with the help of my hands and experience, I was the artist trying to discover something that was already in there, hidden in plain sight, in the material or in my subconscious, probably both.

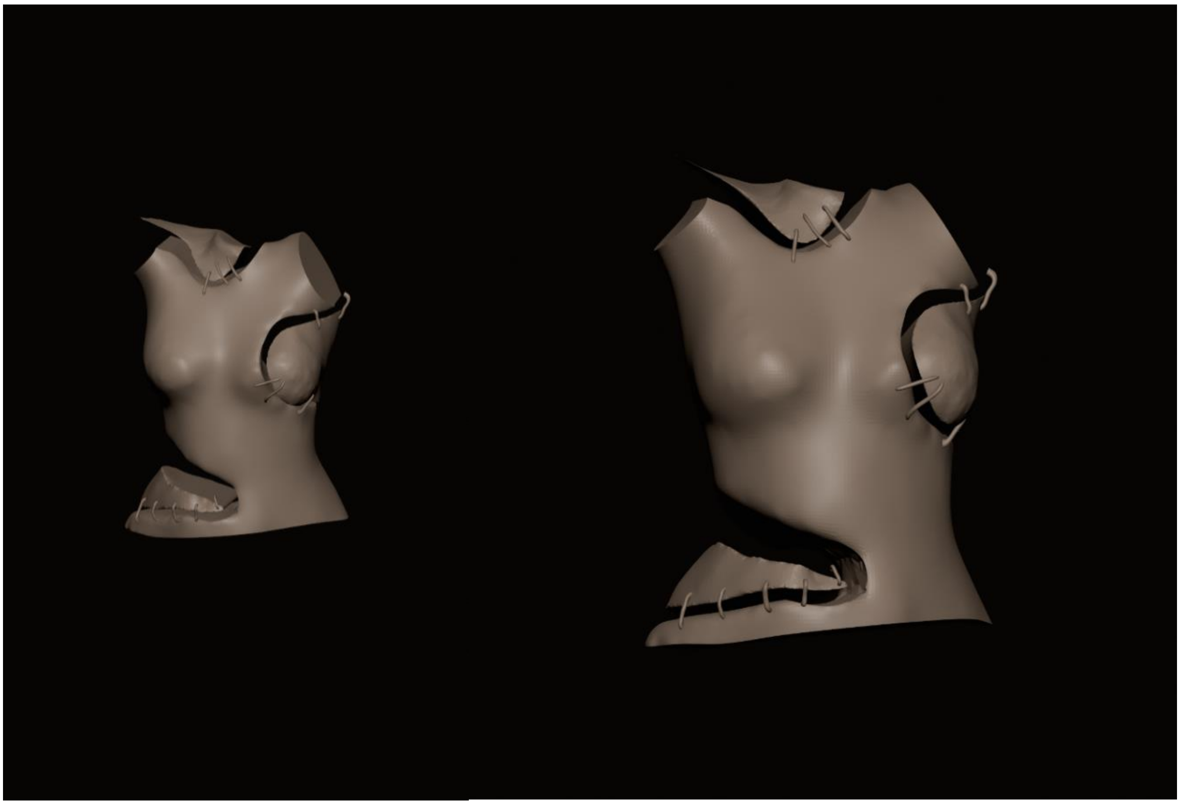


Figure 2.3.1 - Fix it, 2024

Gaining touch, sensitivity, feeling the material where it wants to go and where we want to take it consciously and unconsciously. As the artist gets to know the material, starts to recognize it as an extension of himself, how it should feel in our hands where it needs to be, in the case of clay, knowing when it needs more water, when it needs to knead or let it rest. When we make a mold for glass casting or slumping, we need to make a mixture of plaster with silica and add water to it little by little, stirring and removing lumps, handling very lightly so as not to speed up the process, continuing until it reaches the right consistency and then we know it is ready to pour in the mold. I was asked this question once:

"When do you know it's good?"

"I just feel it"

It was my intuitive response, vague for those who are learning, but understandable for those who know the material. Like a culinary chef, that after cooking for so long, knows how food works, and what needs to be cooked for perfection.

The reality is that the experience of handling the material, whichever this may be, feeling the right consistency, understanding how it works in your hand and with your senses is superior to any recipe or instruction book. I never liked following recipes blindly, it's not that I don't follow them, I just find more pleasure in improvisation and trusting my senses, our bodies can smell, taste and look at something and feel attracted to it or disgusted. It's very natural. This goes deeper than we think, it's part of the human experience to want to experience something with our hands, with the touch of our skin, our senses. It starts in the womb, continues as babies trying to look and touch everything, as if by a touch we would learn all the secrets of life. It is not a lie that tactile perception is a very important element in the development of human beings, it is through the skin that we understand characteristics such as shapes, textures, temperatures and so much more. Our hands, skin, touch, allows us to connect with everything around us.

Touch is connection. Trusting our senses is our nature.

2.4. MEMORIES

There's a purple octopus deep inside one of my childhood memories. I forgot about him for a few years, but he has come to get me and tell me something.

"You can do it, might not be the expected way, but that's your way, there's nothing wrong with it, you can be proud about it"

I don't remember well where or when I met him, but with my purple Maped color pencil I gave him life, I colored him, inside the lines, the same lines all the other kids had, but mine was special, it was created by me, it was different from the others, so with a bright smile that I can still feel today, a warm hand, strong grasp in my pencil and with my chest full of pride, I showed it to my colleagues and my teacher. The smile quickly went away, the knot appeared in my throat and my purple octopus was not special anymore. I was not proud anymore. Poor octopus, it was not his fault.

"Jessica, that's not how it's done, you didn't do it correctly, look at the ones your colleagues did!"

I grabbed my eraser, ready to make him disappear, I started erasing him, but I pushed him so hard against the sheet that he didn't want to leave me.

"Now there's no time for that, do it well next time"

Never saw that octopus again.
I did it well the following times.

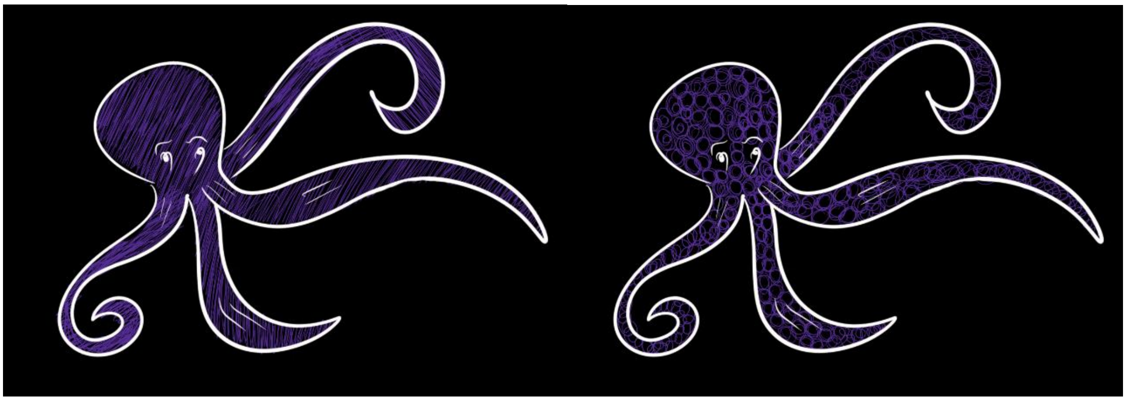


Figure **Erro! Utilize o separador Base para aplicar 0 ao texto que pretende que apareça aqui.**2.4.1 - Expected (left), Special (right)

2.5. DUALITIES

Months of study and logical reasoning, decisions made with all caution and deliberately, should a scientific opinion about something have more value than a glance, a first impression of seconds, an impulsive decision made quickly, an aesthetic judgment? The answer will fully depend on the person who's been asked.

> *"When it comes to the task of understanding ourselves and our world, I think we pay too much attention to those grand themes and too little to the particulars of those fleeting moments. But what would happen if we took our instincts seriously? … making sense of ourselves and our behavior requires that we acknowledge there can be as much value in the blink of an eye as in months of rational analysis" (Gladwell, 2006)*

Perhaps a scientist, who deals with data and analysis on a daily basis, who uses rational and logical thinking for his conclusions, who presents them and has them accepted by an audience who understands them with the same rigor. Or an artist who deals with his intuition, his gaze, who uses a more emotional type of thinking, with a oriented disorientation, uses his aesthetic judgment and his technical knowledge to judge his own result, which may or may not have an audience that is equally governed by their own aesthetic, technical judgment to accept or reject with only a look, a first impression without *fear.*

> *"Art and science are both expressions of what it is to be human. Each one is driven by discovery, curiosity, and a profound longing to know oneself and the surrounding world" (Ruopp, 2020)*

And who am I? An artist who is guided by the moment, goes through her disorientation guided with complete confidence because she knows that any result is a result, there are no right or wrong destinations, there is emotion and that is what controls the ship of my process. The surrounding water, in this case the public opinion, is the most complex part of navigating, we can take the calm and comfortable sea waters that are already accustomed to emotion boats navigating, with passages permitted only with brief glances of intuitive judgment and enthusiasm. Or we can take other seas, ruled by the strong gusts of all data and analyses, scientific and rarely imaginary, which require the understanding of everything they are seeing pass by, all specifications and details are necessary, a fortuitous glance alone is not enough to guarantee passage.

Talking about art and science is the joining of two seas, different and both necessary. Finding the moment, the ideal island to be surrounded by all of this is a challenge.

I have come to realize that it's not "scientists versus artists" but rather "scientists and artists," each enriching the world in their own way.

Figure 2.5.1 – Dualities, 2025

2.6. AUTHORITY

The question of what constitutes art, what makes it good or bad, and who holds the authority to decide is a longstanding debate that engages artists, critics, a big audience.
Art, as a product of human experience, reflects the diversity of those experiences. As noted in a random YouTube comment, "Art is the soul made tangible. A physical representation of the ephemeral atlas of the human mind and emotion. An attempt to communicate something beyond words, to speak subconscious to subconscious with a stranger." Unfortunately, I don't have the author written, nor the complete certainty it wasn't a quote from someone else.

A scene from the film *Mona Lisa Smile* (2003) [2] offers a compelling discussion on the nature of art and its evaluation:

> Students: *"What is that?"*
> Professor: *"You tell me"*
> Students: *"Carcass by Soutine, 1925"*
> Professor: *"Is it any good? Come on, ladies. There's no wrong answer. There's also no textbook telling you what to think. It's not that easy, is it?"*

This dialogue challenges the notion of objective standards in art. The students grapple with the absence of a textbook directive, realizing the complexity of evaluating art without predefined criteria.

The conversation continues:

> Student: *" All right. No. It's not good. In fact, I wouldn't even call it art. It's grotesque."*
> Professor: *"Is there a rule against art being grotesque?"*
> Student: *"I think there's something aggressive about it…and erotic."*

This exchange illustrates the subjective nature of art interpretation, where personal perspectives and emotions significantly influence judgment. The discussion questions the existence of universal standards, acknowledging that elements like technique, composition, and color are traditionally used to assess art but are not definitive.

[2] Mona Lisa Smile is a 2003 American drama film produced by Revolution Studios and Columbia Pictures in association with Red Om Films Productions, directed by Mike Newell, written by Lawrence Konner and Mark Rosenthal, and starring Julia Roberts, Kirsten Dunst, Julia Stiles, and Maggie Gyllenhaal.
In the movie, Katherine Watson teaches art history in 1953 at the respectable all-female Wellesley College. She encourages her conservative students to question and disregard the outdated societal norms for women.

Figure 2.6.1 - Bacon, F. (1924). Carcass of Beef [Oil on canvas]. Buffalo AKG Art Museum.
Image retrieved from https://buffaloakg.org/artworks/rca1939132-carcass-beef
(Accessed March 13, 2025).

The professor's concluding remarks underscore the fluidity and vagueness of art's definition:

> Professor*: "What is art? What makes it good or bad? And who decides?"*
> Student*: "Art isn't art until someone says it is."*
> Professor: *"It's art."*
> Student: *"The right people…"*
> Professor: *" Who are they?"*

This highlights the role of societal and institutional authority in legitimizing art, a process that is inherently subjective and influenced by cultural contexts.

The exploration of art's nature is deeply personal. As an artist, I recognize that I will not arrive at an universal truth. However, through sharing my perspective, research, and practice, I hope to contribute to the ongoing dialogue. Art, unlike objective science, thrives on diversity of thought and interpretation, reflecting the myriad ways in which individuals experience the world.
The question of what constitutes art, its value, and who decides remains open-ended. It invites continual exploration and personal reflection, resisting definitive answers in favor of a more inclusive and subjective understanding.

Bringing Tolstoy to this matter:

> *"In these schools, art is taught! But art is the transmission to others of a special feeling experienced by the artist. How can this be taught in schools? No school can evoke feeling in a man, and still less can it teach him how to manifest it in the one particular manner natural to him alone. But the essence of art lies in these things. The one thing these schools can teach is how to transmit feelings experienced by other artists in the way those other artists transmitted them. And this is just what the professional schools do teach; and such instruction not only does not assist the spread of true art, but, on the contrary, by diffusing counterfeits of art, does more than anything else to deprive people of the capacity to understand true art." (Tolstoy, 2021)*

> *"Art schools are thus doubly destructive of art: first, in that they destroy the capacity to produce real art in those who have the misfortune to enter them and go through a seven- or eight-year course; secondly, in that they generate enormous quantities of that counterfeit art which perverts the taste of the masses and overflows our world (…) These three conditions—the professionalization of artists, art criticism, and art schools—have had this effect: that most people in our times are quite unable even to understand what art is, and accept as art the grossest counterfeits of it". (Tolstoy, 2021)*

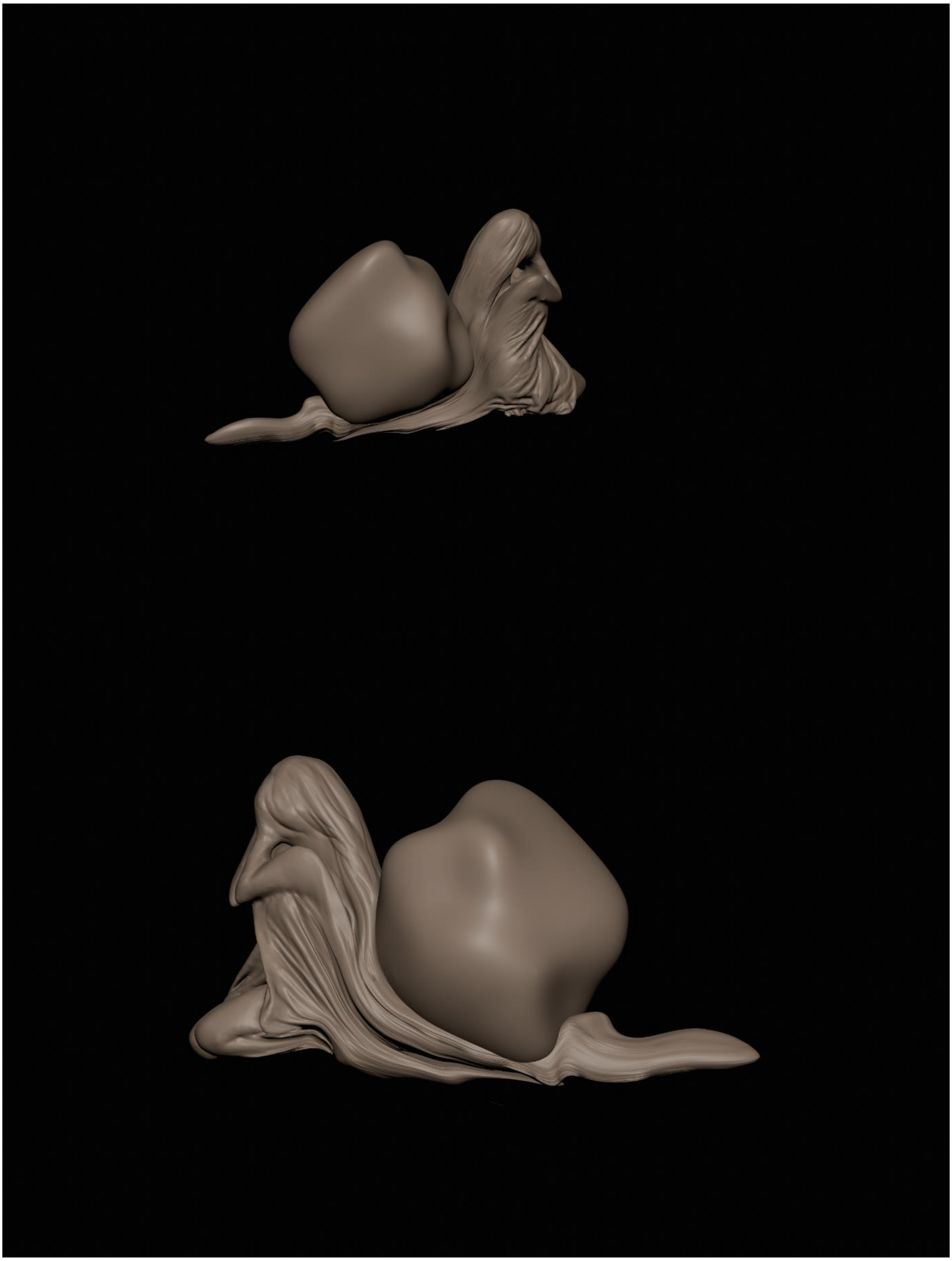


Figure 2.6.2 – Heavy burdens, 2025

2.7. IMAGE MAKING

The journey into the origins of image-making reveals a deep connection between imagination, expression, and the human brain. This exploration ultimately ties into the broader concept of consciousness.

> *Some common, frequently used words are extraordinarily difficult to define. We have noted the problem of defining 'art'. 'Consciousness' is another such word. We all know what it means - until someone asks us to define it." (Lewis-Williams, 2002, p.104)*

In "The Mind in the Cave," the text elucidates how, as human beings evolved, advanced consciousness allowed them to perceive mental images and experience visual aftereffects. These two-dimensional images were not inventions or discoveries; rather, they were intrinsic to human experience, shaped by the brain and nervous system's functions, particularly during altered states of awareness.

The book posits that the creation of images of animals and other entities from mental visions was not an act of invention but a desire to make these visions permanent. This urge was not simply about artistic expression but about a social or communal need to "fix" or preserve these visions. Early humans reached out as if to capture these images on surfaces with their hands, attempting to connect with and materialize what already existed in their minds.

Does this resonate with creative individuals today? When engaging with this idea, I felt a profound similarity to the creative process where we imagine a piece and strive to manifest it in reality, seeking to capture, touch, and bring our visions into the physical world. Although humanity has evolved, this fundamental creative drive remains strikingly unchanged.

> *"…If we could be transported back to the very beginning of the Upper Paleolithic to compliment a painter on the 'realism' of their picture, I believe we would be met with incredulity. 'But,' the painter might have replied, 'that is not a real bison: you can't walk around it; and it is too small. That is a "vision", a "spirit bison". There is nothing "real" about it.' For the creators, the paintings and engravings were visions, not mere representations of visions." (Lewis-Williams, 2002)*

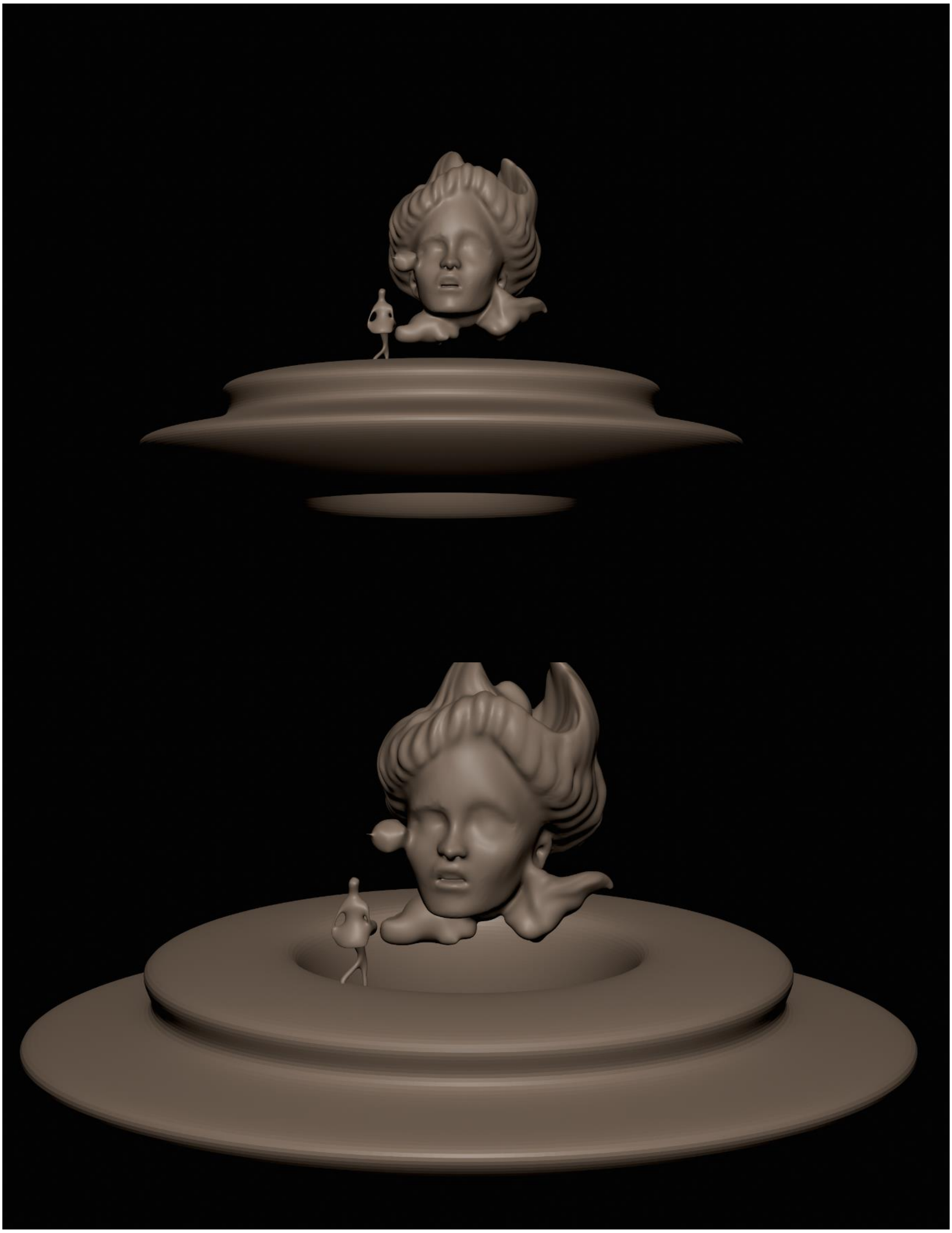


Figure 2.7.1 – Vision, 2025

2.8. FEELINGS AND EMOTIONS

The distinction between feelings and emotions is a nuanced topic, one I began to grasp through conversations with my artistic adviser Richard and my exploration of António Damásio's writings.

In *The Strange Order of Things*, Damásio (2018) clarifies that emotional experiences often share names with the emotions themselves, which contributes to the misconception that emotions and feelings are identical. However, they are fundamentally different. Emotions are automatic and unconscious responses, triggered without our conscious will. Often, we only realize an emotion has occurred after the fact, as the emotional response triggers feelings that, in turn, generate conscious experiences related to the emotion. Once aware of a feeling, we may - or may not - be able to pinpoint its origin or identify precisely why we're feeling a certain way.

Damásio (2018) emphasizes the importance of subjectivity and integrated experience for the development of a cultural mind. Without subjectivity, nothing holds significance; without integrated experience, the reflection and discernment necessary for creativity are impossible. He explains that his ability to express thoughts and claim they are "in my consciousness" is due to the automatic integration of mental images, which he can access and examine. These images, connected to his mind and body, belong to him as part of his living organism. Subjectivity, he argues, is a process, not a fixed entity, relying on two key elements: the creation of a perspective for mental images and the presence of feelings that accompany them.

In *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain*, Damásio (2003) explains that emotions provide an innate mechanism for assessing the environment, both internal and external, allowing for adaptive responses. Often, we consciously evaluate emotion triggers, processing not only the object's presence but also its relationship to past experiences and other stimulus.

Damásio further states:

> *"One of the main aspects of the history of human development pertains to how most objects that surround our brains become capable of triggering some form of emotion or another, weak or strong, good or bad, and can do so consciously or unconsciously. Some of these triggers are set by evolution, but some are not, instead becoming associated by our brains with emotionally competent objects by virtue of our individual experiences. Think of the house where once, as a child, you may have had an experience of intense fear. When you visit that house today you may feel uncomfortable without any cause for the discomfort other than the fact that, long ago, you had a powerful negative emotion in those same surroundings. It may even happen that in a different but somewhat similar house you experience the same discomfort, again for no reason other than you can detect the brain's record of a comparable object and situation. There is nothing in your brain's basic makeup prepared to respond with displeasure to houses of a certain kind. But your life experience has made your brain associate such houses with the displeasure you once had. Never mind that the cause of the displeasure had nothing to do with the house itself. Call it guilt by association." (A. R. Damasio, 2003)*

This explanation resonated deeply with me, as it mirrors how some artworks evoke emotional responses. These responses may stem not from the artwork itself but from deeply rooted personal experiences, as illustrated by the house example.

When Tolstoy (1904) writes that “we cannot fail to observe that art is one of the means of intercourse between man and man” and "whereas by words a man transmits his thoughts to another, by art he transmits his feelings,” he defines art as a human activity where one person consciously transmits feelings to others through external signs, allowing others to experience the emotion that provoked those feelings (*What Is Art?* p. 48).

A human expression of feeling can influence another human’s sense, making him susceptible of facing the emotion the first person felt. May it not be exactly the same but similar, as an artist, I may create a sculpture that evokes a warmth melancholy in me, but for a viewer, it may evoke sadness or the urge to cry, depending on their unique life experiences. While we can all relate to emotions like sadness or joy, the triggers for these emotions vary widely.

In *The Feeling of What Happens: Body and Emotion in the Making of Consciousness*, Damásio (1999) elaborates on the stages of emotion and feeling. He notes that emotions can be triggered and executed non-consciously, feelings can be represented non-consciously, and feelings become conscious when the organism becomes aware of them. This breakdown highlights the complexity of the emotional and feeling processes and their role in human experience.

Damásio (1999) further explains:

> *“There is, however, no evidence that we are conscious of all our feelings, and much to suggest that we are not. For example, we often realize quite suddenly, in a given situation, that we feel anxious or uncomfortable, pleased or relaxed, and it is apparent that the particular state of feeling we know then has not begun at the moment of knowing but rather sometime before. Neither the feeling state nor the emotion that led to it happen in consciousness, and yet they have been unfolding as biological processes. These distinctions may sound artificial at first glance, although my purpose is not to complicate something simple but rather to break down, in approachable parts, something that is quite complicated.” (p. 36)*

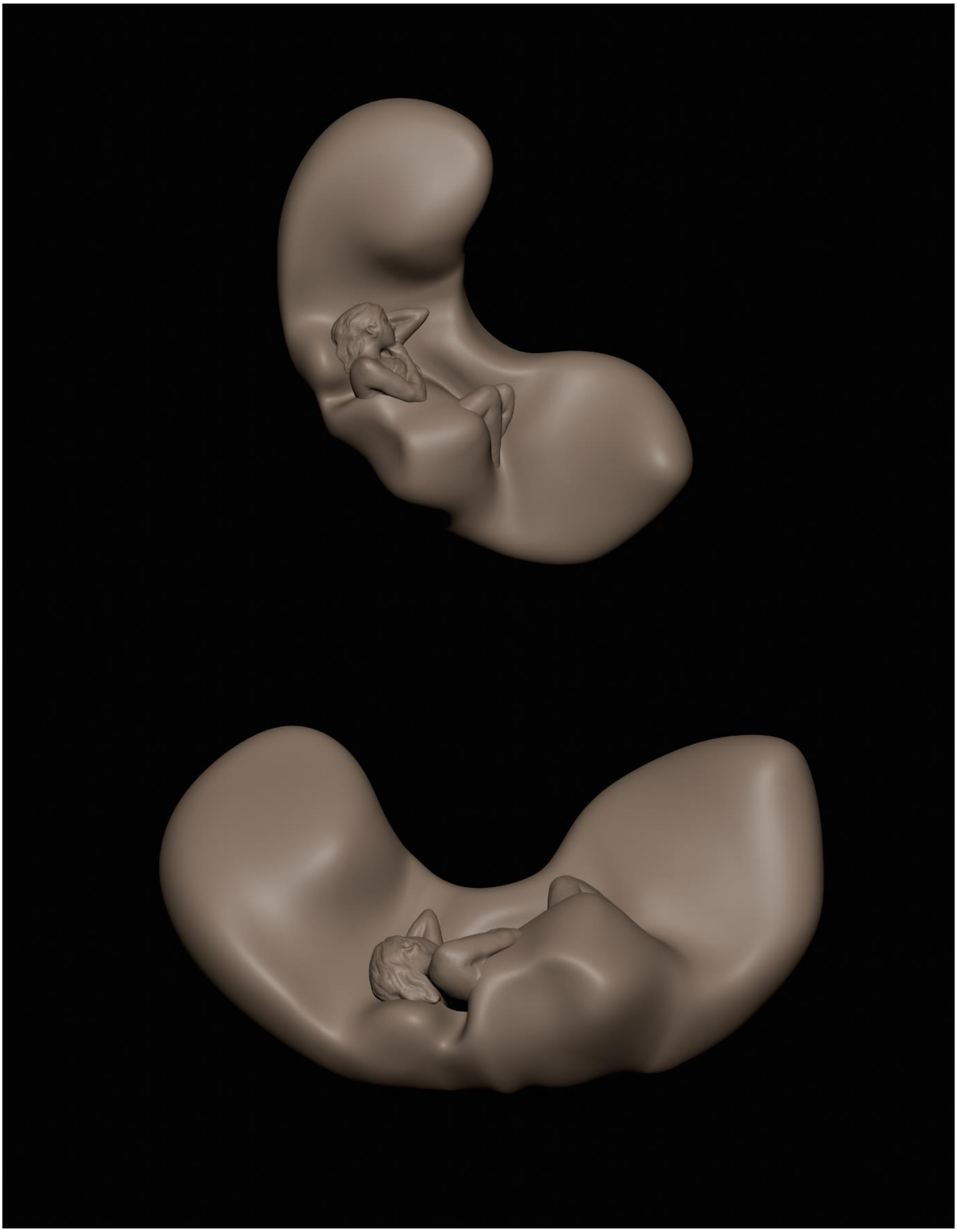


Figure 2.8.1 – Just a human bean, 2025

2.9. ACCESSIBILITY

> *"The assertion that art may be good art, and at the same time incomprehensible to a great number of people, is extremely unjust, and its consequences are ruinous to art itself; but at the same time it is so common and has so eaten into our conceptions, that it is impossible sufficiently to elucidate all the absurdity of it." (Tolstoy, 2021)*

> *"Nothing is more common than to hear it said of reputed works of art, that they are very good but very difficult to understand. We are quite used to such assertions, and yet to say that a work of art is good, but incomprehensible to the majority of men, is the same as saying of some kind of food that it is very good but that most people can't eat it. The majority of men may not like rotten cheese or putrefying grouse—dishes esteemed by people with perverted tastes; but bread and fruit are only good when they please the majority of men. And it is the same with art. Perverted art may not please the majority of men, but good art always pleases everyone. (Tolstoy, 2021)*

> *"Great works of art are only great because they are accessible and comprehensible to everyone.'" (Tolstoy, 2021)*

It amazes me how actual and pertinent this still is, keep in mind that this work of his was first published In English in 1898, 127 years passed, and I can still understand and see it happening.

I agree that art should be accessible and comprehensible. Contemporary art often feels like an intellectual puzzle, requiring detailed explanations, we see things we don't really understand, we read the description, we hear the artist explain and most of the time, we even pretend to get it all, at least I do. And when they bring political and humanitarian causes, I roll my eyes inside, I know, what a shock, an art student, an artist putting things on the table like this. I just stopped trying to figure out, instead I look at it, I might find it interesting or not so much, I think: *this speaks to the artist in some way, relates to him/her, he/she sees himself/ herself in this*, *X it's an good detail, Y is a smart approach, Z is really a choice of material*, and I proceed to the next one. I found this to be my best, sincere approach to contemporary art. I prefer a sincere approach: observing, appreciating details, and moving on without over-intellectualizing. This approach reflects my own artistic practice, where I create sculptures of the human body—recognizable and relatable forms that evoke real immediate emotional connections. I do not want to play mind games, or to intellectualize something. I personally enjoy it when I see people reacting to my work and with a smile can recognize it: *oh! It's a belly…Its a pregnant woman. It's a sad person grabbing onto the knees. It's a baby.* There's beauty in that, people don't like to be unsure, so they grab onto details they can recognize. What can represent us, our humanity, our identity, our emotions and feelings more than what our bodies do?

Figure 2.9.1 - Some body, 2025

2.10. IDENTITY

The moment the music starts to play, and the singer is instantly recognizable even if we never heard that specific song, or when we see a painting and we have an idea of who painted it just by looking at it for the first time. That is something special to me.

A few years ago, I've had colleagues in class doing presentations of their artistic work, without the need to present them because I knew the moment I put my eyes on it, who it belonged to.
I realized later that they were doing things for themselves, if it meant going outside a bit from the proposal the professor established at first, they would do it, "*the work needs to be done like X, but I felt like doing Y so I just did it."* At that time, I felt a bit frustrated because the ones that would do what they felt, deviating from the programmed format, would be prouder of their work, more congratulated and even win more contests (for an art student who would always follow the rules blindly, make and present work that wouldn't feel like mine but at least I followed the program, it felt so unfair, and no doubt indeed it was).
Result was: they were right all that time, doing things for them, they would let their work express themselves, and by doing that each work would be seen and sensed that it was them, because it was.

Now looking back, I wouldn't have followed the program line by line, I would've spent my time following my intuition, caring less about what professors said, I can't even count the times I went home frustrated of being criticized with work that didn't even feel mine.
The perspective started to change when I started to take a look at my professors' work, going to their exhibitions, and realizing I didn't relate to their art, not even in the slightest, made most of the critiques and syllabus rules fall down like water. I appreciate the words, but I don't need to let them affect my way of expressing myself.
I really advise art students to take a look at the professor's works when they feel unfairly criticized, I am not referring to technical learnings or not listening to their experience, we should listen, respect their wisdom, just don't take it to heart if they don't understand what you are doing or find it uninteresting. In the end everyone has something they relate to, and not even a single person can be impartial to their own emotions.

It's not the art students nor the professor's fault, it's the system, the programs schools use, the rules for art they create.

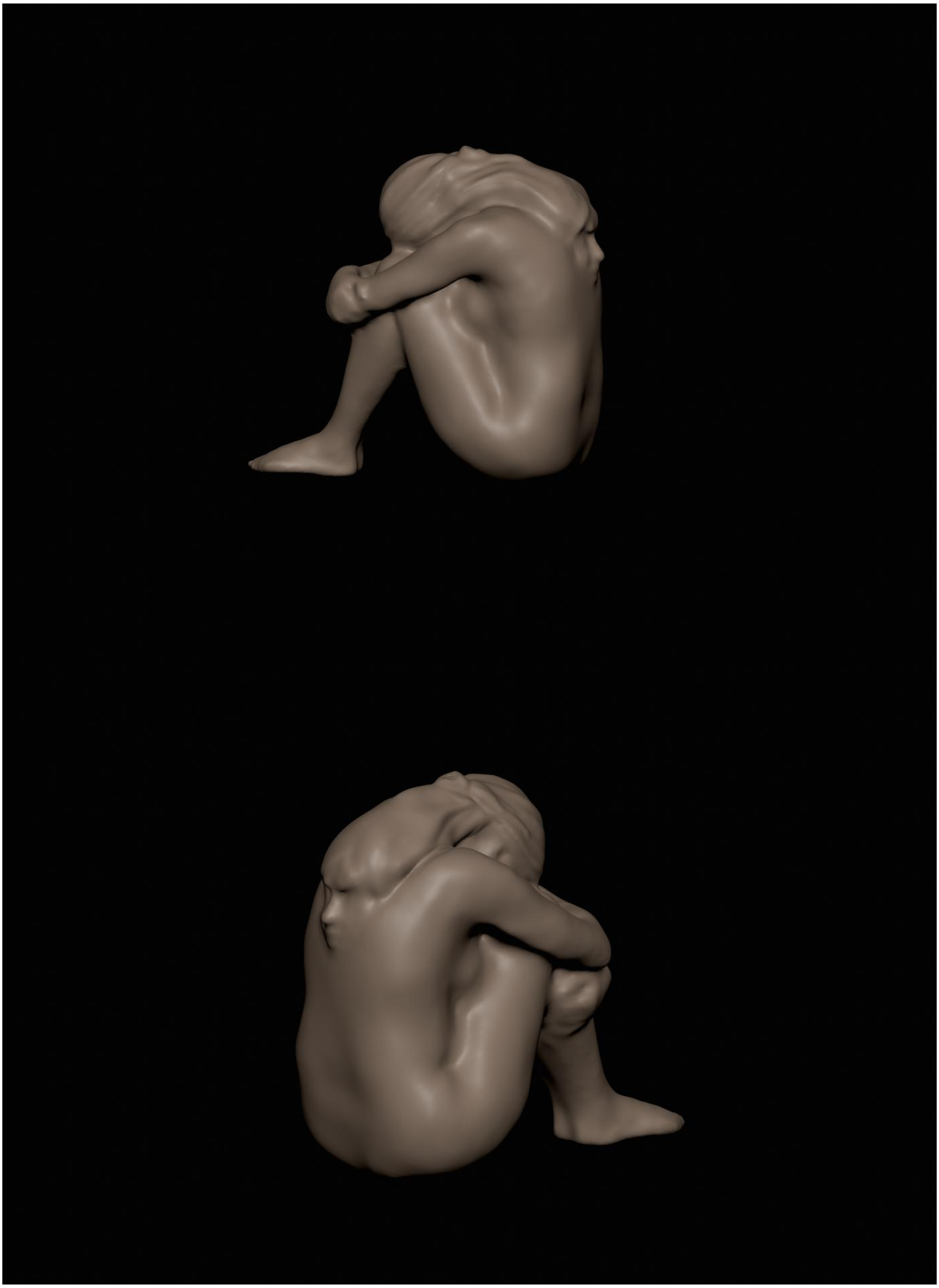


Figure 2.10.1 - Space to doubt, 2025

2.11. VALUE, VALIDATION, EVALUATION

Which has more value?

The dialogue between the artist and his work?

The dialogue between the artist's work and the public?

The primary relationship here is between the artist and their work, the connection between creator and creation. When I think of a dancer, a musician, or a pastry chef, they pursue their craft for themselves. There is a vocation that drives them to learn to dance, play an instrument, or cook, because this ignites a genuine interest within them. They practice until they can express themselves through these actions. Is this to understand themselves or to make themselves known?

They certainly don't need an audience to dance well, hit the right notes, or know if the cake is good. Yet, the search for validation persists.
Does validation help us know ourselves better? I don't think so. For some so-called "artists," validation may be about being told what they are and what their work represents. For me, validation is about appreciating our work - what our bodies and hands are capable of - because it fills a space that we cannot fill ourselves. It's reserved for others and their perspectives. Knowing we can evoke something in another human being reminds us of our capacity to connect through art. I deeply feel that many contemporary artists confuse the need to be told what they are and what their work represents with the appreciation of different perspectives on their work. This confusion isn't a judgment but an observation of something amiss in the Portuguese Art Education system, which I've experienced firsthand.
Having studied art in Portugal for over ten years, I've seen how it's easy to mix criticism with self-doubt and how being told you're not skilled enough or "alternative" enough can be disheartening. Not being "different" enough can mean less acceptance, attention, or expectation of being a good artist.

Art education should foster self-value and discovery for each artist, not for professors, schools, or the art world. Artists need to build a healthy relationship with materials, learning their possibilities without being tied to traditional uses or the pressure of an impressive result. The result shouldn't be everything; the process of experimenting and gaining knowledge should take precedence. Forcing concepts and plans restricts natural discovery and forces us to fabricate motives we'll never truly understand if we keep playing along.

Which takes me to "*false art*"

> *"This is a positive deficiency. To be taken in by false art, or for that matter but pseudo-philosophy or corrupt history, is to have the illusion of understanding where there is none. When this occurs, in a real sense people do not know what they are doing. Thus, the understanding we gain from true art and from all of those activities whose aim is truly aesthetic is certainly no mere luxury. The dangers when false art usurps its place are too great for such a view. Even apart from its sometimes being a goal of action, aesthetic experience in all its form is what gives meaning to our lives." (Cothey, 1990)*

To be taken in by false art, pseudo-philosophy, or corrupt history is to have the illusion of understanding where there is none. This can be dangerous, as aesthetic experience gives meaning to our lives. Many artists create meanings solely for the sake of validation, but in my view, there's no need for false meanings. Art can be created simply because we can, because we want. The meaning can come moments after or even years, the reasons why we do things are not clear as water, there can be reasons where a lifetime is not enough to understand them. Yet, art still seeks validation.

Genuine art deepens our understanding of experience by giving it real meaning. In contrast, false art is not false because it presents the wrong meaning, but because it creates the illusion of meaning without truly providing it.

How do we evaluate something so personal? Judging the result of an artwork, especially with a forced concept behind it, it feels unnatural. Evaluating a process is difficult when one doesn't deeply understand the artwork or the artist. Does studying art (not practicing it) give you the tools to judge another's art? Knowing some artists and styles by book doesn't grant the wisdom to evaluate new artists. This isn't an attack, but a call to rethink how we evaluate art.

Art contests and open calls often impose themes like "changes in the world," "sustainability," or "save the turtles," forcing artists to follow a theme and provide a description. Judges, often from non-artistic backgrounds, evaluate originality, interpretation, technical competence, and presentation. Imagine a science contest judged by artists with no scientific knowledge, it wouldn't be smart. Yet, this is how art is judged.

Art's subjective nature makes objective evaluation criteria challenging. Perhaps a better approach would be evaluating individual artists' growth, but comparisons in a classroom or group setting are inevitable. Professors, managing entire classes, must find a balance between individual evolution and collective comparison.

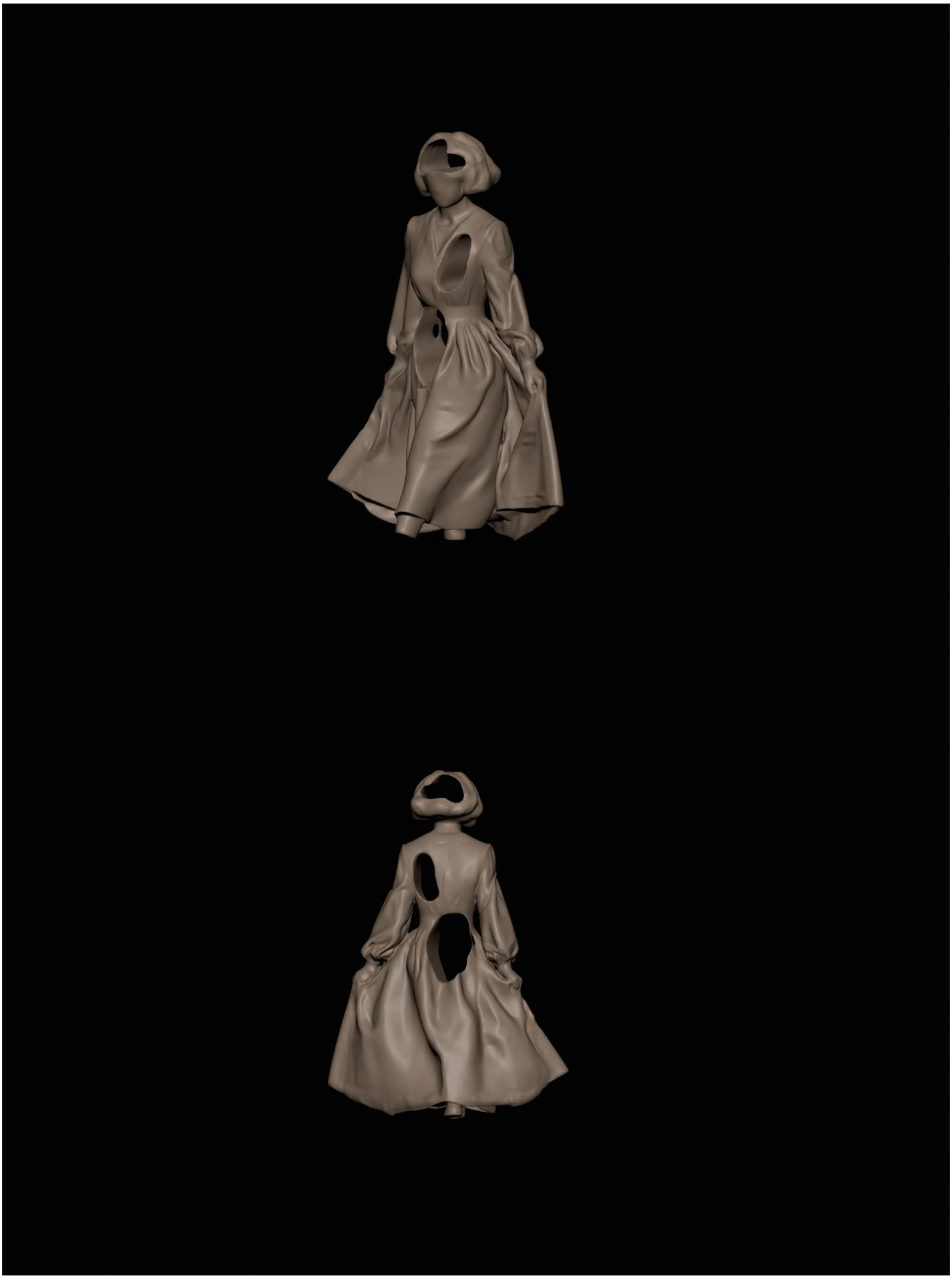


Figure 2.11.1 - A space we cannot fill ourselves, 2025

2.12. UNPREDICTABILITY AND INTUITION

One instance of unpredictability that stands out occurred when I was printing a piece that was clearly not going to turn out as I expected. I found myself thinking, *“Why do I want to see what it will become? Maybe I should just stop the print and start a new one”* Yet, despite the growing uncertainty, I couldn’t help but admire the unpredictability of the moment. I was no longer in control, and that loss of control became the most interesting part of the process.

I have a deep connection to the physical act of making work with my hands, where even in moments of improvisation or unconscious action, my body maintains a sense of control. When working with clay, for example, my hands instinctively respond to the material, considering all the practical experiences and an internal sense of what the piece requires. The process, though spontaneous, is not entirely unpredictable. There is an underlying knowledge in the muscle memory of my hands, a subtle control that allows me to direct the piece’s form.

However, when I am printing, I shift from being the active creator to a spectator. I introduce the data, and the information needed to generate the piece, but once the process begins, I no longer have control over its outcome. I can only observe as the machine takes over, and I watch the piece unfold in ways I cannot fully predict. There is a sense of mystery in this experience, an uncertainty that I do not encounter when I am physically engaged with the material. This loss of control introduces a dynamic that I find both unsettling and exhilarating.

Unpredictability, in this context, is not a flaw or mistake but an essential part of the artistic process. It is what makes the act of creation feel alive, dynamic, and full of possibility. This aligns with the notion that the creative process in art is as much about uncertain as it is about intention and control. The ability to embrace uncertainty and the unknown, to allow the process to evolve without knowing exactly what the outcome will be, is crucial to my experience as an artist.

For me, unpredictability is deeply tied to intuition. When working with materials, when working with my hands, I am always responding to a deeper, intuitive knowledge that I may not be fully conscious of at the time. In moments of unpredictability, this intuitive knowledge is allowed to surface, revealing new possibilities that would not have been apparent through mere control. The final piece may not align with my initial expectations, but it is, in its own way, a more authentic expression of what emerged in that moment.

Bringing up an Italian critic, idealist philosopher, and politician, with his theory of art that centers on the unity of intuition and expression, Benedetto Croce argues that intuitive knowledge that arises from direct perception and imagination, is self-sufficient and autonomous, making it fundamentally different from logical knowledge, which requires intellectual synthesis. In this sense, Croce sees intuition as inherently expressive, not as raw material awaiting refinement by the intellect.

The process of creating becomes a process of self-expression that is not limited by preconceived ideas or rigid plans. When I allow myself to embrace the uncertainty of my work, I let the piece express itself through the process, rather than trying to control it or force it into a predetermined outcome. This surrender to uncertainty fosters a deeper connection between intuition and expression, allowing work to evolve in ways that transcend my original intentions.

While art often involves an interplay between control and spontaneity, unpredictability highlights a paradox in the creative process: the more I attempt to control or predict an outcome, the more I risk losing the very essence of creativity. In my experience, the most exciting moments occur when I release control and allow for uncertainty to play a role in the creation of the piece. It is in these moments of unpredictability that the work takes on a life of its own, and the artist is no longer merely a technician, but a witness to the unfolding of something greater than their own intentions.

This reflects Croce's view that artistic creation is not a skillful translation of ideas but a dynamic expression of intuition. By letting go of certainty, the artist taps into a more profound, organic form of expression, one that emerges through uncertainty rather than through rigid planning. The unpredictability of the process, much like the intuition that guides it, becomes an integral part of the artwork itself.

In the book *Nature of art,* we get at a certain point:

> *"What kind of knowledge allows an artist to create their works?" Croce argues that by identifying intuition with expression, he arrives at a clear and straightforward answer. For Croce, the knowledge conveyed by a work of art cannot be abstracted from the work itself; therefore, the artist cannot be seen as merely using techniques to communicate something they already know. Instead, Croce claims it is fundamentally mistaken to assume that the artist needs such means. The knowledge a work conveys is intuitive knowledge of the work itself. Since, in Croce's view, intuition and expression are one and the same, the artist's intuition of their work is indistinguishable from the process of expressing it." (Cothey, 1990)*

For Croce, the artist's creative process is not about skilfully transferring preconceived ideas onto a medium but rather about allowing the artwork to emerge as an organic, unified expression of intuition. He challenges the view that artistic ability relies on technical skill alone, emphasizing instead that the artist's intuition is fully realized in their expression.

> *"Every individual possesses this intuitive potential, some become great artists or poets, while others remain less remarkable in their expression"(Cothey, 1990).*

Croce frames art not as an intellectual exercise but as the purest form of knowledge, where intuition and expression are indivisible.

Figure 2.12.1 - Asemic Writing, 2021

2.13. A BODY

As I work, my body becomes a medium for both expression and intuition. I do not consciously dictate each movement, but instead, my hands act instinctively, responding to the needs of the material and the moment. In this way, the body becomes an extension of my intuition. This connection between body and intuition is echoed in Paracelsus's belief in the power of the spirit over the material body.

> *"As Guido Giglioni explains in The Paracelsian Image of the Body and Its Legacy, Paracelsus asserts that "The imagination is not the flesh and the blood, but in the spirit of the star, which is in each single man. The spirit is replete with knowledge about the future, the present, and the past, and with all sorts of skills" (Paracelsus, 1929-1933, p. xiv, 317). Here, Paracelsus posits that the spirit—the intangible, imaginative aspect of human consciousness—guides and informs the body. This notion suggests that knowledge is not confined to intellectual or physical domains but is embedded in the human spirit, which transcends the material world."*
> (Biblioteca Nacional (Portugal), 2010)

In the context of artmaking, this view aligns with my own experience of the body's role in creation. The spirit, as described by Paracelsus, is not separate from the body but resides within it, guiding the artist's actions, intuition, and imagination. While the body may appear to be simply a vessel for action, it is the channel through which the artist's deeper knowledge and creative impulses are expressed. The intuitive knowledge that guides my hands and body is not learned through intellectual effort but is instead innate emerging from the very spirit that Paracelsus describes as "replete with knowledge." This embodied knowledge is deeply intertwined with my artistic practice, suggesting that the act of creation is not merely a mechanical or technical exercise, but an expression of a deeper, spiritual intelligence.

This understanding of the body as a vessel for spirit and intuition extends to the unpredictability I experience in my creative process. When working with my hands, I often let go of preconceived expectations, allowing the piece to evolve through spontaneous gestures and movements. While there is an element of control in guiding the material, the unpredictability of the body's responses to the medium is something I embrace. The unpredictability I experience when working with my hands is different from that encountered when using a 3D printer, where I am distanced from the outcome. In the tactile engagement with material, the body becomes a site of negotiation between control and spontaneity.

The spirit, in Paracelsus's view, is not only a source of knowledge but also a dynamic force that can influence the body's actions in ways that transcend conscious thought. In my experience, the unpredictability of the body's movements while creating is not an absence of control but a release of control that allows for something greater to emerge. The spirit, or the intuitive knowledge embedded in the body, often takes over, guiding me toward an outcome that I could not have predicted consciously.
The idea that the body acts as an instrument of expression resonates deeply with Benedetto Croce's theory of intuition and expression. As I talked before, Croce asserts that intuition and expression are inseparable, suggesting that the artist's creative process is not merely a skillful transfer of preconceived ideas onto a medium, but rather an unfolding of the artist's inner vision through embodied action. This view complements Paracelsus's assertion that the body and spirit are intertwined, with the spirit guiding the body's movements and actions.
In my work, I often find that my body's responses to the material are driven by a form of intuitive knowledge—an embodied intelligence that goes beyond the intellectual understanding of the piece. The spirit, as Paracelsus might argue, is not only responsible for imagination and skill but also for the way in which the body interacts with the medium, shaping the form in unpredictable yet meaningful ways. In this sense, the unpredictability I experience in the process is an essential part of the creative act, allowing the spirit to manifest through the body's actions.

The human body, in its intuitive and unpredictable responses, plays a pivotal role in my artistic process. Whether working with clay or engaging with technology, be it 3D modelling, my body serves as the conduit through which intuition and imagination flow. Paracelsus's view of the spirit as a source of knowledge and skill reinforces the understanding that the body is not merely a physical tool but an integral part of the creative process. The body, guided by the spirit, allows for a form of expression that is deeply connected to intuition, unpredictability, and imagination. By embracing this connection between body and spirit, I can tap into a deeper, more authentic form of artistic expression that transcends intellectual control and allows for the unexpected to emerge.

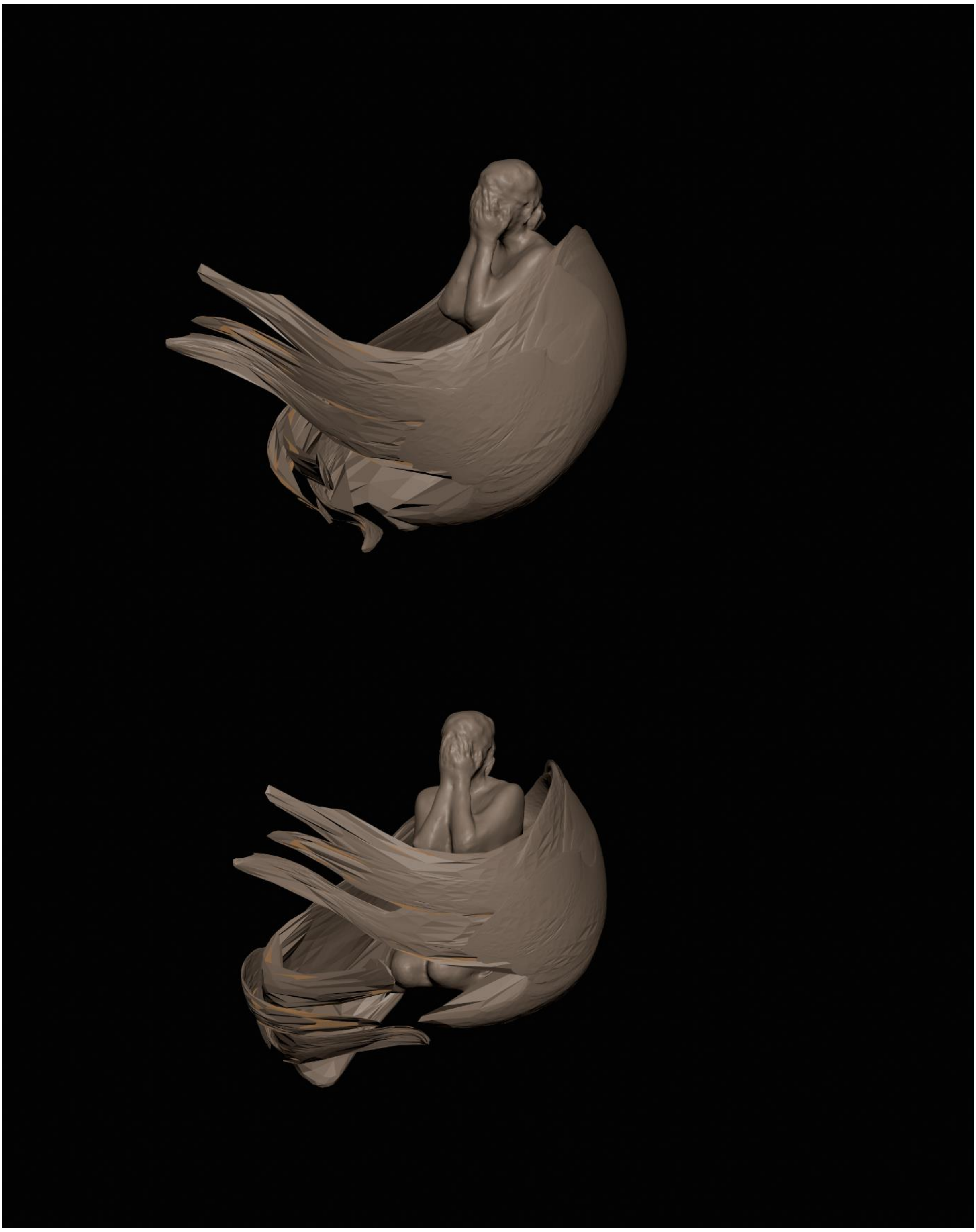


Figure 2.13.1 - More than flesh and blood, 2025

2.14. CONNECTIONS

Lately, I've been deeply immersed in anatomical art books, particularly ***Human Anatomy: Depicting the Body from the Renaissance to Today***, ***Atlas of Human Anatomy and Surgery***, and ***Anatomica: The Exquisite and Unsettling Art of Human Anatomy***. As I continue exploring this subject, I have several books on my list for future acquisitions, including ***Ernst Haeckel: 40th Anniversary Edition***, ***Art Forms in Nature: The Prints of Ernst Haeckel***, ***The Sick Rose: Disease and the Art of Medical Illustration***, ***Anatomicum, Crucial Interventions, The Anatomical Venus***.
As I went through the pages, absorbing the drawings I couldn't pinpoint precisely why it was so attractive to me, but there's a intrinsic beauty in the way bodies are depicted, some of the illustrations don't show just a simple skeleton or the muscles with the names attached.

It showed me something more.

> "*There was more than scientific accuracy at play in Vesalius's illustrations. Unlike the skeletons in medieval representations of the Dance of Death, those in Book I of* De fabrica *are not external agents of destruction, but all-too-sentient victims of a difficult posthumous world. These figures openly mourn their own deaths and grief the passing of others. (…) In book II of De fabrica, the cadavers are discombobulated, stripped of their last leaving layers beyond the help of medicine. Their mortality seems all too real, too accurately drawn, to be other than human. Far beyond the needs of medical illustration their palpable sufferings touches deeply.," (Rifkin, Ackerman, & Folkenberg, 2006, p. 16)*

Realness or a feeling for life, as if the bodies dissected were still alive, with being drawn they surely kept their life in a certain way. In 2025, here I am looking at a drawing of a body someone studied, scientifically accurate or not, it's someone's body, we don't know their name, their identity, their story, but we relate to them. We all have something in common, a body, a soul.
My goal is not to romanticize the dead, or the dissection of bodies, as we know all of this posed a lot of health safety concerns and ethical issues, created tensions between the people, medical and artist groups. My truth is that I do see beauty in the drawings, in the studies.

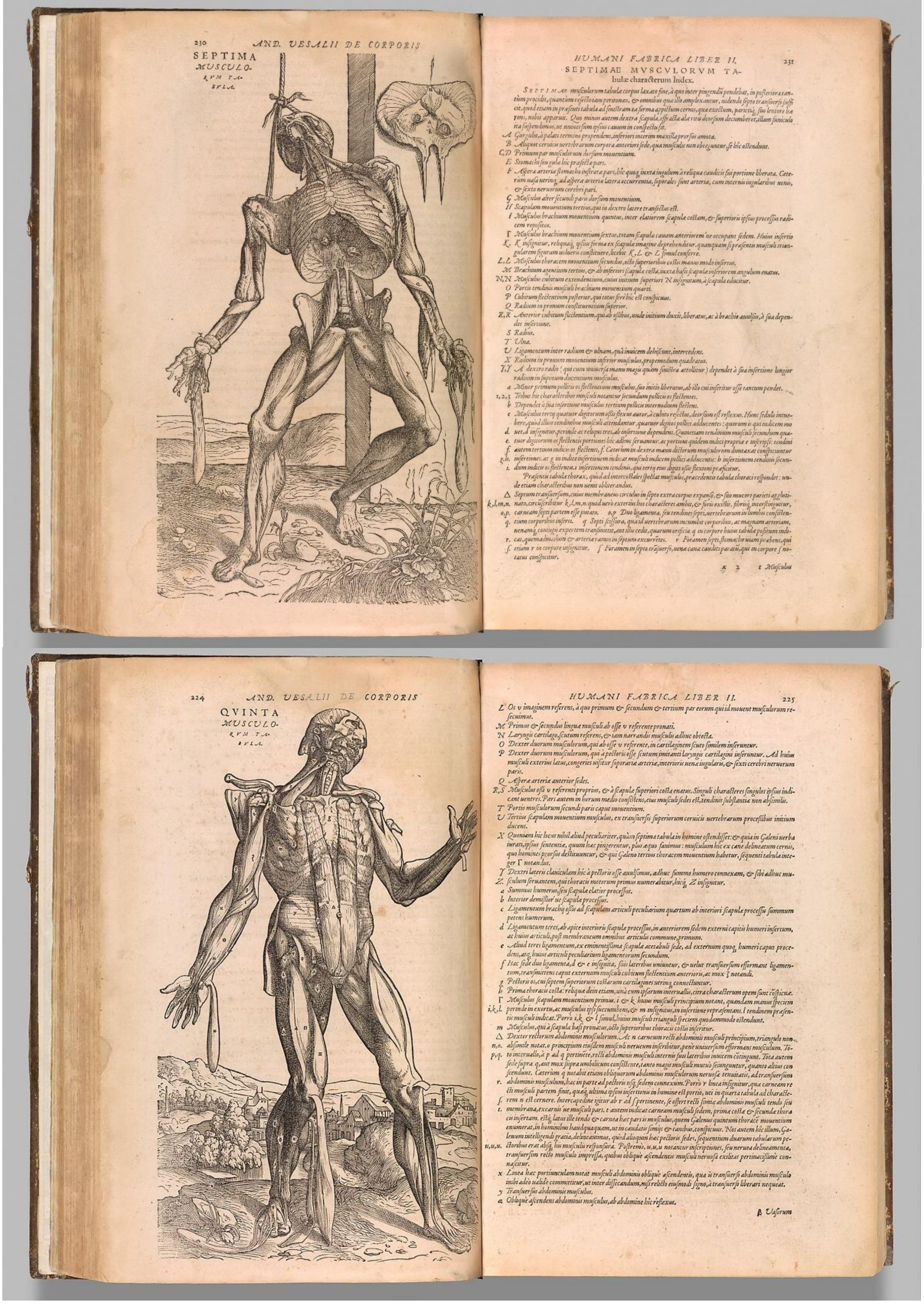


Figure 2.14.1 - Anatomical Illustrations from De humani corporis fabrica (1555) by Andreas Vesalius, with engravings attributed to John of Calcar. Image courtesy of The Metropolitan Museum of Art.

Anatomical illustration has long played a crucial role in both the scientific study of the human body and artistic expression. These drawings were done for educational purposes, aiding in the understanding of the body's structure and function. However, many artists throughout history have transcended the purely technical nature of anatomical illustrations by infusing them with narrative, composition, and emotion. By blending scientific accuracy with artistic flair, these works have transformed the study of the human body into a medium of storytelling and reflection.

In early anatomical studies, artists didn't just aim to depict bones, muscles, and organs, they sought to capture the living essence of the human form. Even as the goal was to accurately represent the body's structure, there was often a sense of movement, emotion, and energy within these works. Whether through dramatic poses or carefully considered compositions, anatomical illustrations began to tell stories, conveying not just the mechanics of the body but their dynamic function in life. Instead of presenting the human form as static, these artists showed muscles in motion, the fluidity of movement, and the intricate connection between the body's parts. Their compositions gave the viewer more than just anatomical knowledge; they conveyed a sense of life, action, and even drama within the body's internal processes. In doing so, they created a deeper connection between the scientific and the emotional, illustrating how the body was not just a machine but a vessel for human experience.

Anatomical illustrations were sometimes presented as if they were scenes from a play, with the figures of the body posed to reflect the function of muscles, joints, or organs. These works highlighted the complexity and beauty of human form.

This blending of science and narrative continued into later periods, with artists using the body to explore broader philosophical or symbolic themes. Some artists depicted anatomy in a symbolic manner, suggesting deeper ideas of life, death, and suffering through the human form. These works went beyond the purely technical, using anatomical references to tell stories about human existence and our connection to the world around us.

Even as the focus of anatomical illustration shifted over time, the human body continued to serve as both a subject of scientific inquiry and a canvas for artistic exploration. In each case, whether consciously or not, the works of artists transcended the boundaries of pure anatomical study to tell a story about the human condition making anatomical art not only a tool for understanding the body but also a medium for reflecting on life itself.

> *"The divorce of art and science was clear by 1858, when Henry Gray and his illustrator H. V. Carter produced* his *Anatomy Descriptive and Surgical. Precise in description, its neutral, gray-toned vignette illustrations, engraved in woodblock and later printed from steel-faced plates, share Leonardo's aversion to stylistic distortion. Already in its twentieth edition by 1918, Gray is still sometimes used in medical schools, but never in an art class, where its didactic isolation of viscera offers little help in modeling a figure" (Rifkin, Ackerman, & Folkenberg, 2006, p. 67)*

These books and illustrations have provided me with a profound appreciation for the ways in which art and science intersect, we also have animal anatomy and botanic but there's something particular in the depiction of human form that calls for me.

From Anatomical Drawings to Wax Figures

As anatomical drawing evolved during the Renaissance, with artists and scientists like Leonardo da Vinci and Andreas Vesalius pushing the boundaries of human understanding, another form of representation emerged that would take these studies into new, lifelike dimensions: wax figures. These intricate models became essential tools for both medical education and artistic expression. While drawings could capture the precise details of muscles, bones, and organs, wax figures brought these depictions to life, offering a three-dimensional, tactile representation of the human body. They allowed students, physicians, and artists to study the form from multiple angles, providing an even deeper understanding of the body's structure and function.

Wax models were particularly significant for their ability to mimic the textures and nuances of human skin, muscle, and fat, and were often painted to resemble real-life skin tones. These figures were displayed in anatomical museums, where they served as a more permanent, accessible alternative to live dissections. By the 17th and 18th centuries, medical schools and anatomical museums across Europe were filled with highly detailed wax models of the human body, used to demonstrate everything from healthy anatomy to diseased states. These wax representations acted as visual tools for teaching both anatomy and pathology, providing a bridge between the scientific study of the human body and the artistic skill of representation.

One of the most notable aspects of these wax figures was their ability to evoke a strong emotional response. The lifelike quality of the models often inspired awe and discomfort in viewers, blurring the line between art, science, and macabre. This tension between beauty and the unsettling nature of the human body would continue to inform the development of medical art, leading to an ever-increasing interest in exploring the human form, not just in its idealized state, but in its most vulnerable and diseased forms as well.

Museu de Dermatologia Portuguesa Dr. Sá Penella

The Museu de Dermatologia Portuguesa Dr. Sá Penella is located in Portugal. Founded in 1955, the museum houses a collection of 266 wax figures depicting a wide range of dermatological conditions. These figures illustrate the consequences of accidents, diseases such as cancer, and the effects of venereal diseases. The pieces were originally part of the dermatology services at the Hospital dos Capuchos, and the Hospital do Desterro. These wax representations serve as a haunting, yet educational tool, presenting both the visible and emotional dimensions of skin conditions. These models offer an educational perspective on dermatological health and evoke powerful emotions by confronting the viewer with the imperfections and vulnerabilities of the human body.

The journey from Renaissance, 15th century and early 16th century, and Mannerism, 16th century 17th century anatomical drawings to the wax figures of the 17th and 18th centuries, and then to modern museums like the Museu de Dermatologia, reflects a long-standing tradition of using art to explore and educate about the human body. Throughout history, artists and scientists have sought to understand the form and function of the body in all its complexity. From idealized representations to the depiction of disease and imperfection, anatomical art has evolved alongside our understanding of health, illness, and human experience. (Ebenstein, 2020)

In the case of the Museu de Dermatologia, the art of anatomical representation continues to serve a dual purpose: to educate and to evoke an emotional response. The use of wax figures not only allows for a deeper understanding of the skin and its conditions but also serves as a reminder of the ongoing dialogue between art, science, and our perceptions of the body.

Whether in the form of Renaissance and Mannerism anatomical drawings, 18th century wax models, or contemporary exhibits like the one in this museum, the representation of the human body remains a powerful tool for exploration, education, and reflection on what it means to be human.

Figure 2.14.2 - Museu da Dermatologia Portuguesa Dr. Luís de Sá Penella, July of 2024

Figure 2.14.3 - Wax figure - Museu da Dermatologia Portuguesa Dr. Luís de Sá Penella, July 2024

2.15. CREATION

Clay, one of the oldest materials manipulated by humanity, has long been a medium that reflects both our creative potential and our relationship with the earth. Its foundational role in the history of art and craftsmanship is emphasized not only in modern times but also in ancient myths, which imbue the material with symbolic meaning. The mythological creation of Pandora, the first woman, as told in Hesiod's *Works and Days*, encapsulates the transformative power of earth and clay in human creation, blending divine craftsmanship with human vulnerability.

In Greek mythology, clay is elevated to a divine material through the work of Hephaestus, the god of craftsmanship and creation. Hesiod’s account of Pandora’s creation demonstrates the integral role of clay as both a medium and a symbol.
As Zeus commands Hephaestus to "mix earth with water" to fashion Pandora, we witness the fusion of natural elements that becomes an expression of divine craftsmanship. Hephaestus is tasked with giving the form of a human being to Pandora, a figure who embodies both beauty and danger, as various gods bestow upon her distinct gifts that influence humanity’s fate.

> *“So said the father of men and gods and laughed aloud. And he bade famous Hephaestus make haste and mix earth with water and to put it in the voice and strength of humankind…” (Hesiod, Works and Days, trans. Hugh G. Evelyn-White, pp. 60-63).*

In this passage, the earth and water, the key components of clay, are imbued with a powerful potential to create life and meaning. The gods’ collaboration in shaping Pandora reflects the blending of raw natural material with divine influence.
Pandora’s creation is deeply tied to the idea of material transformation; Hephaestus’s molding of clay serves as a metaphor for human creation itself, blending the earth with artistic intent to create something of both aesthetic beauty and inherent danger. While Pandora is constructed from the earth itself, it is the divine imposition of form, power, and consequence that gives her life. Thus, clay becomes more than just a passive medium, it represents both the foundation of human existence and the divine intervention that shapes it.

As we transition from mythological narrative to the scientific understanding of clay, we see that its physical properties further illuminate the reasons behind its enduring use as a creative medium. Clay, in its most basic scientific form, is a natural, fine-grained material that combines elements of silica, alumina, iron, alkalis, and water. When mixed with water, it becomes plastic and moldable, retaining its shape when dried, and hardening permanently when fired in a kiln. The chemistry of clay reflects its malleability and capacity to transform under certain conditions, akin to the mythological process of creation, where material is shaped and imbued with meaning.

Clay's inherent capacity for transformation mirrors the mythological narrative of Pandora’s birth. Both in the realm of science and mythology, clay holds the potential for change and creation, allowing the artist or craftsman to mold it into various forms, while at the same time imbuing it with meaning and intent. The transformation of raw clay into a sculpted form is an act of human intervention that mirrors the divine creation in Hesiod’s myth.

The myth of Pandora, where the gods use clay to shape a being imbued with both beauty and consequence, highlights the profound role of material in the creation of life and art. As I reflect on my own artistic process, the connection between myth and material becomes evident. The plasticity of the clay, much like Pandora’s nature, allows for both control and spontaneity in the creative act. Just as the gods infused Pandora with qualities that transcended her material form, the artist, too, breathes life into clay, shaping it, transforming it, and giving it meaning.

In my own practice, I often view clay as a collaborator, a medium that allows for a fluid dialogue between my intent and the unpredictable outcomes that emerge as I work with it. While the process may seem scientific at times - measuring, mixing, and molding - the result always holds an element of surprise, all the possibilities that the material allows us to mold, all the different works we can create with this plastic material are endless.

Through this lens, the transition from mythology to scientific is not a mere shift from the imaginative to the factual, but rather an exploration of how material, intent, and transformation intertwine to give birth to both tangible forms and deeper meanings. Clay, as a material, embodies this union of myth and science, where raw earth is shaped by both human hands and divine inspiration, and where unpredictability and creativity coexist in the making of something profound.

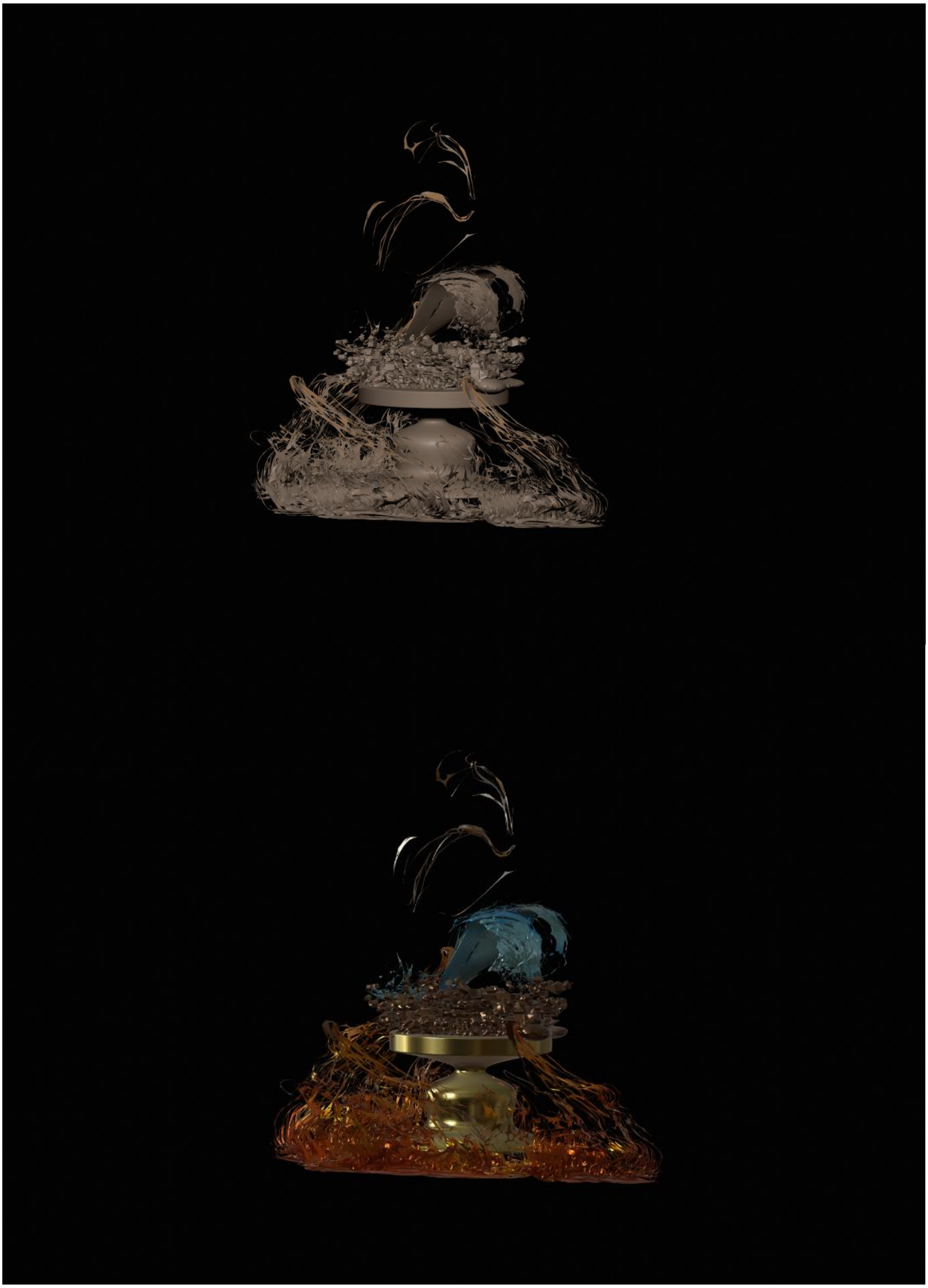


Figure 2.15.1 - Elementos, 2025

2.16. BODILY EXPERIENCE

I understand it might sound confusing to talk about the physical sensation of shaping clay by hand and then suddenly bring in 3D printing. But for me, these two approaches are deeply connected.

During my first year, I worked a lot with traditional ceramic techniques, especially the coil technique. When I made pieces by hand, my hands and gestures naturally led me to create thicker, chunkier forms, it was very difficult to make thin layers or delicate details.

But then, when I started experimenting with 3D printing, I realized something fascinating: the printer essentially "coils" thin layers of clay, one on top of the other, much like my handmade coil method, but with a precision I couldn't achieve by hand.

This technology allowed me to explore thin, detailed forms that my hands wouldn't easily make. And yet, my bodily experience wasn't absent from the process, there were moments while printing when I had to intervene physically, using a brush or stick to shape or push the clay, to prevent the nozzle from pulling the material away.

After printing, I did try to shape the piece by hand but often found this weakened the structure or caused cracks. Instead, I learned to accept the texture and finish that the printer creates, focusing my bodily interaction more on the design and preparation phase, scanning myself, adjusting the 3D model, slicing, and deciding how it prints.

In the end, 3D printing for me is not a replacement for handmade ceramics but a complementary practice, it expands my material vocabulary while still relying on my bodily intuition and experience, just at different stages of the creative process.

Working with the printer at Vicarte was an interesting and necessary point in my path as an artist, but of course it's not the final step, im just starting. Experimenting this new possibility allowed my ideas into reality. In a way that I can see them in my hands and feel them, my body got to know them beyond imagination.

2.17. VISCERAL BODIES

All these reflections and aspirations have led me to develop a profound trust in my artistic process. "Visceral Bodies" is the title of my solo exhibition, taking place at Cisterna, Faculdade de Belas Artes de Lisboa, from April 7^{th} to April 17^{th}.

The term "visceral" pertains to deep, instinctive emotions rather than intellectual reasoning, an immediate, raw, and affective response. This exhibition explores the corporeal through a diverse range of materials, including 3D-printed stoneware, porcelain, beeswax, glass, and rope. These materials give form to bodies that exist in a liminal space between materiality and emotion, revealing the layered complexity of embodied experience.

I have deliberately chosen not to include photographs or detailed explanations of each piece, allowing space for improvisation and intuitive decision-making. Rather than being confined by predetermined descriptions, I want to remain open to the evolving dialogue between my works and the exhibition space, letting the final selection emerge organically.

More than a visual display, this exhibition is intended as a multisensory encounter, one that invites the viewer to engage beyond sight, fostering a felt and immersive experience.

Choosing such an expansive venue for a solo exhibition presents both an opportunity and a challenge. The vastness of Cisterna raises questions about how to situate the sculptures and engage with a space that, despite its scale, can never truly be filled. Yet, each time I step into Cisterna, I am reminded of its richness, of the possibilities it offers, alongside the inevitable uncertainties it brings. In embracing these unknowns, I find the essence of "Visceral Bodies": a continuous negotiation between form, space, and emotion.

Figure 2.17.1 - The space

3.

AN ADDI(C)TIVE PROCESS

3.1. STATE OF THE ART

3D printing with clay is at the intersection of art and science, revolutionizing both fields by merging traditional craftsmanship with cutting-edge digital fabrication. This chapter explores the state of the art in clay 3D printing, examining its technological advancements, applications in artistic expression, and its role in scientific and industrial innovation.

The evolution of additive manufacturing has enabled unprecedented precision and complexity in working with ceramic materials. In art, clay 3D printing has opened new possibilities for contemporary ceramists, allowing them to create intricate forms, push the limits of material behavior, and blend digital design with traditional techniques. This being said, artists now use 3D digital modeling and 3D printing to produce works that redefine the boundaries of ceramic art

Beyond artistic exploration, clay 3D printing is proving to be an essential tool in scientific and architectural research.

Technological Advancements and Applications

Clay 3D printing has seen rapid advancements in both hardware and software. Extrusion-based techniques, such as Liquid Deposition Modeling (LDM), allow precise layering of clay, enabling detailed and structurally sound prints. Innovations in parametric design and generative algorithms have expanded the creative and functional applications of clay printing. Hybrid approaches that combine hand-finishing and glazing with digital fabrication techniques are gaining popularity, reinforcing the synergy between traditional and modern methodologies.

In artistic contexts, the ability to create intricate lattice structures and organic forms has revolutionized ceramics. Many artists are leveraging computational design to explore new aesthetics and redefine the role of craftsmanship in the digital age. Additionally, the customization possibilities in ceramics, from functional homeware to sculptural installations, have broadened the reach of clay 3D printing in the creative practice.

In science and engineering, clay 3D printing plays a significant role in sustainable architecture and material research. Projects focusing on additive manufacturing with raw earth materials are demonstrating how these technologies can lead to low-carbon, locally sourced building solutions. The TECLA project[3], a 3D-printed sustainable housing initiative using raw clay, is an example of how such advancements can address global housing challenges.

[3] "TECLA (which takes its name from Technology and Clay) was made in Massa Lombarda (Ravenna – Italy) with Crane WASP – WASP's brand-new 3D printer in the construction sector – it represented a real challenge for 3D printing, maximizing the performance of a material among the oldest and at the same time among the most stimulating for the future of the green economy: the raw earth."
https://www.3dwasp.com/en/3d-printed-house-tecla/ (Accessed March 13, 2025).

Challenges and Future Directions

Despite the progress in 3D printing, a lot of challenges and limitations remain. In the case of clay, the material consistency, shrinkage and cracking during drying and firing (which are inherent aspects of the material and not only on the printing process), turn the process more complex in comparison with printing with other materials. Additionally, maintaining a precise consistency in the extrusion process and optimizing print parameters for complex geometries require further research. Addressing these technical issues will be crucial for the widespread adoption of clay 3D printing artistic domains.

Future research aims to refine material formulations, improve printer reliability, and possibly integrate artificial intelligence to optimize design and fabrication. Moreover, interdisciplinary collaborations between artists, engineers, and material scientists will further push the boundaries of what is possible with clay 3D printing.

3D printing with clay represents a fusion of tradition and innovation, bridging the gap between artistic creativity and scientific advancement. As technological capabilities expand, so do the opportunities for experimentation and functional application in architecture, design, and space exploration with Project Olympus[4]. While challenges persist, continued research and development will unlock new possibilities, ensuring 3D printing remains a transformative force in multiple disciplines. By leveraging the unique properties of clay and the precision of digital fabrication, this field is set to open new doors for the future of ceramics.

[4]The approach taken by Project Olympus also differs significantly from previous ideas. While others had previously suggested the use of inflatable tent components or elaborate metal structures, Project Olympus will introduce entirely new technologies in order to meet the challenge. The project team, which has already started work on the endeavour, is convinced that robust constructions on the moon's surface can be created using 3D printing technology.
There is a trick to this: none of the material needed for this enormous "house printing" venture would have to be transported to the moon. Rather, the goal is to source building materials from substances already existent on the moon itself. The overall costs would be reduced considerably by this approach. The team is also confident that any potential pollution of the moon's surface can largely be prevented this way.
https://www.ubm-development.com/magazin/en/project-olympus-on-the-moon/ (Accessed March 5, 2025).

3.2. CHARACTERIZATION AND COMPARISON

The materials we choose to use in our artistic practice tell us something more than what most people think. I did use all kinds of materials for my pieces throughout my master's degree but for the sake of this dissertation I will proceed to analyse only the clays I used for 3D Printing.

> *Quite simply, clay may be defined as a natural, earthy, fine-grained substance that develops plasticity when combined with water, retains its shape when dried, and is no longer susceptible to the effects of water when baked. It is composed essentially of silica, alumina, and water, as well as appreciable quantities of iron, alkalis, and alkaline earths. The precise components of these elements in clay are commonly described in terms of crystalline minerals, known as clay minerals, that occur naturally in sedimentary rocks and in continental and marine sediments."* (*Sketches in Clay for Projects by Gian Lorenzo Bernini*, pg31)

Thinking of clay and baked clay (ceramic), in my sensible view, is thinking about the four main elements, earth, water, air, fire. The preciousness and necessity of all of them and what they can create together with human hands and now even with technology.
Saying this, the aim of this part of the study is to evaluate the suitability of three types of stoneware for 3D printing applications, focusing on their composition, color and resulting properties.
It all started with easy questions:

> *"Why do they sell already prepared 3D Printing clay for such a price? If we can use cheaper options…" ("Because they can", I know now)*
>
> *"Can I really use any clay I want? Will I be able to print well without a new recipe, or additives in the original composition?"*

The intention here was never to complicate the process, my thought was always on:
How can I simplify this process so that anyone could print with a cheaper option, without having to take a science course, having to buy more materials and create full recipes.

<u>Accessible, cheap, uncomplicated was the motto.</u>

3.3. MATERIALS

Printer and Set up

Although clay is the main character here, the printer is important for this study.
The Ceramic 3D printer used was the one available at the research unit VICARTE with the name WASP 40100 LDM, it's designed to print any fluid-dense material, including Clays, Stoneware, Porcelain and Earthenware.
In the product sheet of the printer, we can read the following description:

> *"The device described in this manual is a printer intended for 3D printing using fluid-dense material. The printer consists of an extruder with a screw mounted on a delta robot type structure and a work bed. The material is put under pressure and pushed towards the extruder where it is dosed in a controlled manner by a screw and poured through a nozzle that deposits very small quantities of material on the work bed. The material is deposited by the head layer upon layer according to instructions on the file made with the use of slicing software. It is therefore possible to make any shape and any type of object within the limits of this technology."*

Technical data:
Technology – LDM
Cylindric build area - Ø 400 x 1000 mm
WASP LDM Extruder 3.0
Nozzle Kit (from 1.26mm to 3mm)
Layer resolution - 0,5 mm
Axis precision - 0,2 mm
Maximum speed - 200 mm/s
Tank volume - 5 l

Interface and software
Operative systems Windows, Mac, Linux
Slicing software Cura, SLic3r, Simplify3D
Software interface Repetier Host, Pronter Face
File formats. stl, obj, gcode
Interface SD card, LCD display

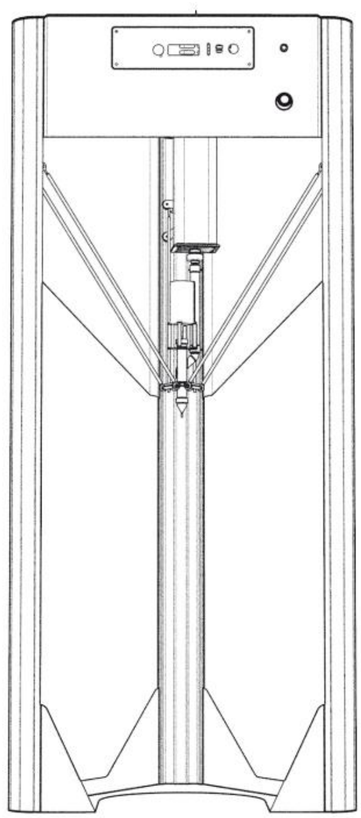


Figure 3.3.1 - WASP 40100 LDM

Clays

I could choose any clay I wanted to, but low budget limited me, so I had to restrict my options. Laying all these options at an imaginary table, faience, red clay, stoneware, porcelain, should go with chamotte or without.
Red clay – too sticky, Porcelain – expensive, Earthenware – more fragile than stoneware and porcelain. The final decision was Stoneware.
At the art store Ponto das Artes in Lisbon, I got a package of prepared 3D Printing Clay (PRAI 3D), the next stop was to get cheap stoneware, one with chamote (GRES BG 0-0,2) and one without (GRES BT), got them from Cristalcer in Caldas da Rainha.

Table 1- The information presented here is exactly as it appears in the official Catalog records.

	PRAI 3D	**BG 0-0,2**	**BT**
Firing temperature	1240-1300ºC	1260-1280ºC	1250-1280ºC
Biscuit temperature	1000ºC	1025ºC	1025ºC
Percentage| Chamotte Size	40% |0-0.2 mm	30%|0-0,2 mm	18%|75 M (0.075 mm)
Humidity (water percentage)	22	20	20
Drying Shrinkage	8%	6,70%	7,50%
Firing Shrinkage	7,00%	5,50%	5,50%
Porosity (water absorption)	0%	7%	2,50%
Package	5Kg	12,5Kg	10Kg
Price per package*	13,4€	13,3€	9,9€
Price per Kg*	2.9€	1.1€	0.99€

* The prices shown exclude travel costs and shipping costs.

Sample Preparation

a) Manually

To start the manual process, it was necessary to have 2 different types of samples.
The first one being small flat balls set aside to dry, fire and grind to later test the powder for the XRD and XRF tests. The second type also to dry and fire but in this case the goal was to be able to see and measure the line of contraction and the absorption between the different firing temperatures, and clays.

<u>First type:</u>

A small flat ball of each clay is about 1.5cm in diameter.
Left to air dry.

<u>Second type:</u>

12cm x 2cm sample bars – with 10cms marking.
Seven sample bars of each clay were made.
After air drying for two weeks the samples were fired.

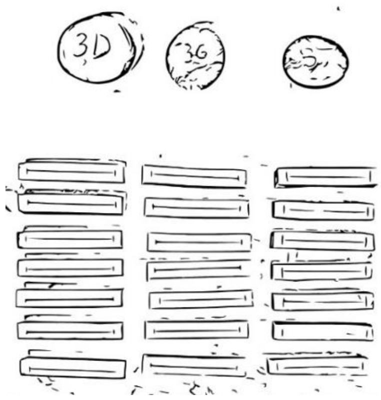


Figure 3.3.2 – Drawings of the first and second type samples

Table 2 – Three samples of each clay were fired at 1200ºC

Program of samples (3D, BG, BT) 1,2,3

Temperature	Stage	Duration
1200º C	↑ Heating	11.30h
1200º C	↔ Soaking	20min
	↓ Cooling	Natural cooling

Table 3 - Three samples of each clay were fired at 980ºC

Program of samples (3D, BG, BT) 4,5,6

Temperature	Stage	Duration
980º C	↑ Heating	9.30h
980º C	↔ Soaking	5min
	↓ Cooling	Natural cooling

Two weeks later both the dried flat balls and the fired bar samples were ready to be grinded on the Retsch™ RM 200 Mortar.

Between each clay grinding, all the parts of the mortar were properly cleaned to not compromise the results.
Turning 3 small flat balls to 3 small containers with a fine powder of each dried (not fired) clay (PRAI 3D, BG, BT)
Some fired bar samples were broken and smashed until they were small enough to go to the mortar. Each sample was grinded two times. Ending with 6 small containers of fired samples, each clay for each temperature. In other words, a sample of clay:
PRAI 3D fired at 980ºC and another at 1200ºC.
BG fired at 980ºC and another at 1200ºC.
BT fired at 980ºC and another at 1200ºC.

Figure 3.3.3 - Drawing of Retsch™ RM 200 Mortar, in Vicarte

All the grinded samples were analysed[5] with 2 machines, available at CENIMAT-I3N.

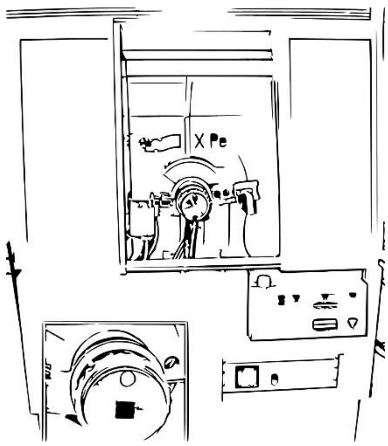


Figure 3.3.4 - Drawing of PANalytical Xpert PRO MRD diffractometer

X-ray diffraction (XRD) analysis for the identification of mineralogical phases of the samples was performed using a PANalytical Xpert PRO MRD diffractometer, with an X'Celerator 1D detector and Cu Kα radiation at 45 kV and 40 mA settings, in the 2θ range of 10–65, with steps of 0.02 and an acquisition time of 33 s per step, in continuous scan
mode.
The identification of crystalline phases was carried out using the X'Pert High Score Plus software.

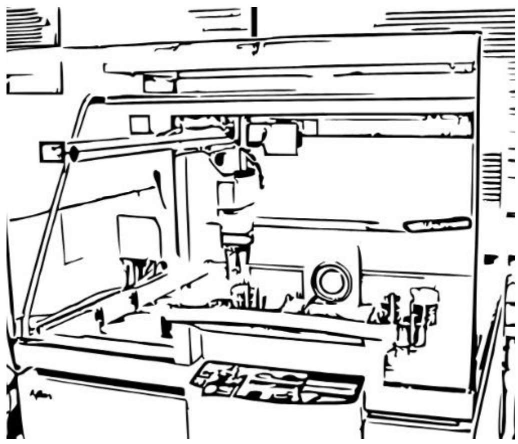


Figure 3.3.5 - Drawing of WDXRF; PANalytical Axios 4.0

The X-ray fluorescence for chemical analysis was performed using an X-ray fluorescence spectrometer with a wavelength-d system (WDXRF; PANalytical Axios 4.0), with a rhodium X-ray tube, under conditions optimized for element quantification. The crystals LiF220, LiF200, Ge, PE, and PX1 were used for the separation of fluorescent X-ray peaks covering the whole measurable range.
Analysis was performed under He flow, and spectral deconvolution was carried out using the iterative least-squares method and standardless semiquantitative analysis based on the fundamental parameter approach with the SuperQ IQ Plus software package (PANalytical BV, Almelo, Netherlands).

[5] The analysis was performed with the help of my adviser Fernanda Carvalho.

b) Printed

To create an organized and fair comparison I printed in the 3 different clays the same sample file. A rectangular prism was created with the same measurements of the manually made samples (second type), 12cm x 2cm sample bars.

The parameters exported from the slicing software Cura were:

layer height – 1.0mm;
initial layer height – 0.3mm;
line width – 2.0mm;
infill line width – 2.0mm;
wall line count – 2;
top/Bottom thickness – 4.0mm;
top layers – 4;
bottom layers – 4;
infill line distance – 5.0mm;
infill pattern – zigzag;

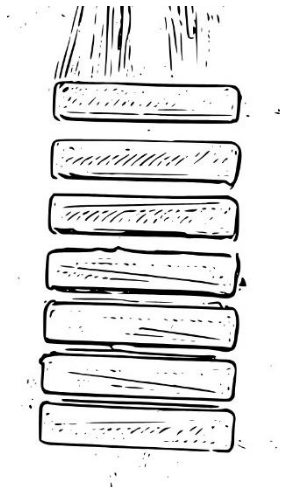


Figure 3.3.6 - Drawing of Printed samples

Seven sample bars of each clay were made. After air drying for two weeks the samples were fired.

Table 4 -Three bar samples of each clay were fired at 1200ºC

Program of samples (3D, BG, BT) 1,2,3

Temperature	Stage	Duration
1200º C	↑ Heating	11h
1200º C	↔ Soaking	10min
	↓ Cooling	Natural cooling

Table 5 -Three bar samples of each clay were fired at 980ºC

Program of samples (3D, BG, BT) 4,5,6

Temperature	Stage	Duration
980º C	↑ Heating	9.30h
980º C	↔ Soaking	5min
	↓ Cooling	Natural cooling

I did not grind these samples, nor evaluated them on the X-ray diffractometer, X-ray fluorescence spectrometer since the clay used to print the bar samples was the same, the goal here was to measure the shrinkage, weight loss and deformation, compared to the handmade ones.

3.4. METHODOLOGY

Clay Printing - How it worked

Clay Preparation

Preparing the clay to 3D Printing is not a complicated task, but it needs some practice to be more and more intuitive, I will be sharing some measures I used and some tips, but this is only a guide to getting close to the best consistency to print, ultimately the feeling and intuition will have to speak louder as it did for me. This way of preparing clay, was following some recommendations of Jonathan Keep, Enôre and other examples I had the opportunity to study.
To determine the water needed for the both clays I took notes of the quantity of water I used until it the clay consistency "felt right", the water-to-clay ratios were calculated based on the volume of water used per kilogram of clay.

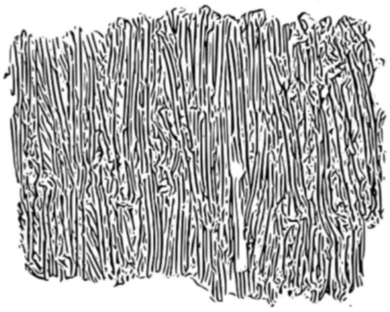
Clay BT (5 kg batch): 40.0 ml/kg (200 ml for 5 kg) / (3 kg batch): 53.3 ml/kg (160 ml for 3 kg)
Clay BG (3 kg batch): 70.0 ml/kg (210 ml for 3 kg)
Clay 3D didn't need preparation as it is commercially sold already prepared for printing.

While the calculated water-to-clay ratios provide a useful guideline, several factors can influence the actual water absorption and workability of the clay. Variables such as ambient temperature, relative humidity, air circulation, and drying conditions can significantly impact the clay's moisture retention.
A study on Direct Ink-Write Printing of Ceramic Clay took an innovative approach by embedding a wireless temperature and humidity sensor within the printed structure. This smart integration allowed real-time monitoring of environmental changes, demonstrating that humidity and temperature fluctuations directly affect the drying and workability of the clay (Marquez et al., 2023). Additionally, differences in clay composition, particle size distribution, and mixing methods further alter the required water content.

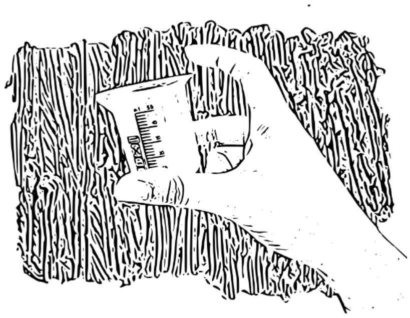
This is evident in my results, where stoneware clay, rather than porcelain like in the study, exhibited varying water demands based on batch size and type. The 3 kg batch of Clay BT required 33% more water per kilogram (53.3 ml/kg) than the 5 kg batch (40 ml/kg), likely due to differences in water absorption caused by batch size, mixing efficiency, or particle distribution. Furthermore, Clay BG had the highest water demand at 70 ml/kg, 31% more than Clay BT (3 kg batch), emphasizing how different clay compositions influence absorption, plasticity, and drying behavior. These variations reinforce the need for adjustments to the water ratio based on the specific working environment and processing conditions, as external factors and material properties directly impact the clay's behavior in 3D printing.

The following preparation guide was only done to BT and BG paste, since the 3D clay only needs to be deposited in the tank for printing, no preparation required.

1) Slabs are cut out of the bag, thickness should be between 1-2cm



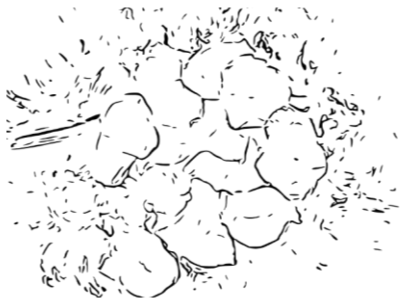
2) With a fork, pass it through all the clay



3) Add water, 50ml at a time

4) Make the water enter the clay with hands

5) Join all the clay back together



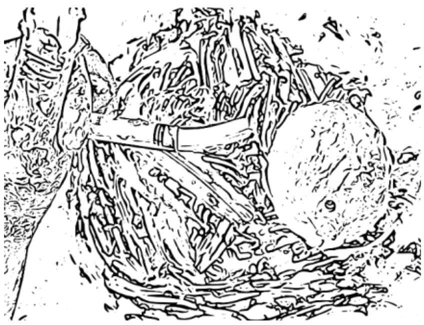
6) Spread the clay evenly again

7) Fork it through again, add more water, mush It once more

8) Form a pile of clay

9) Drag through the clay pile from the bottom to the top, with the tip of fingers, and slap It down to another pile

10) Repeat the last step 3/4 times, until no bubbles or lumps are felt.



11) Extrude some clay with a syringe and observe how it behaves, it should be soft enough to bend a bit, but dry enough to hold it position

12) Place the pile of clay onto a bag or a bucket with a lid, before closing splash a bit of water to retain some moist

Figure 3.4.1 - Drawings of clay preparation

Clay Shrinkage

To study the shrinkage of clay is important as it directly influences the quantity of clay, and the size of piece that I will be need. If I need a cube of 15cm x 15cm but I know the clay will shrink in drying and firing, I won't make or print the cube with 15cm x 15cm, I'll do it bigger with the correct measures from my studies. It is important for handmade pieces, as for printed ones.
Shrinkage is observed at two stages:

Drying Shrinkage (Raw → Dry): When there's a reduction in size after air drying.
Firing Shrinkage (Dry → Fired at 980°C or 1200°C): When it shrinks even more due to firing.

Drying Shrinkage (Raw to Dry)
All samples started at 10 cm in the raw state.
After drying:
3D samples: 9.2–9.4 cm (~6–8,5% shrinkage).
BG samples: 9.5–9.7 cm (~3,5–5% shrinkage).
BT samples: 9.3–9.7 cm (~3–7% shrinkage).
Observation: The 3D clays shrink the most during drying, while BG clays shrink the least.

Firing Shrinkage (Fired at 980°C or 1200°C)
At 980°C:
3D clays shrink significantly, with handmade samples shrinking to 9.2–9.7 cm (~2–5% shrinkage).
BG clays remain relatively stable, with shrinkage around 2–3%.
BT clays show moderate shrinkage, decreasing to 9.3–9.6 cm (~3–4% shrinkage).

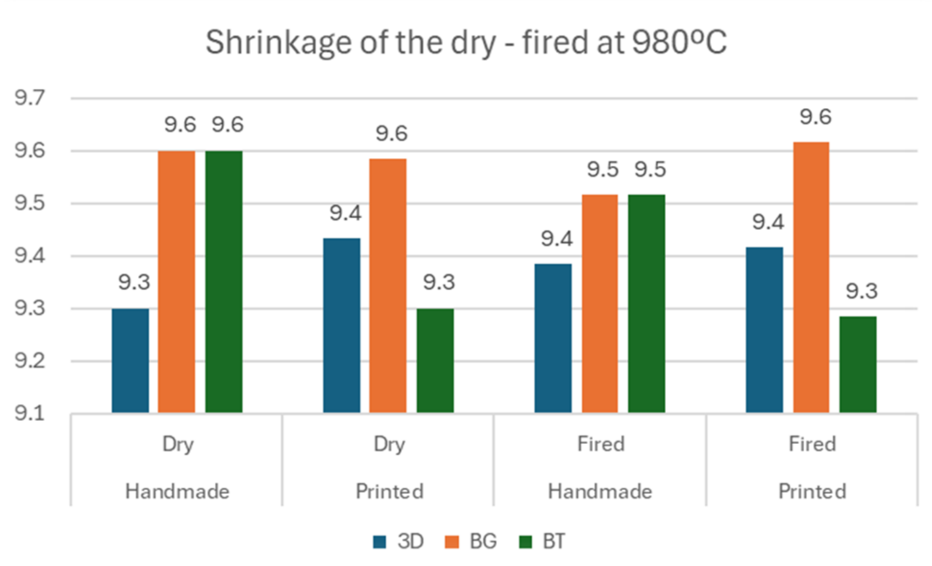


Figure 3.4.2 - Shrinkage of the clay samples, handmade vs printed, air dried vs fired at 980ºC

At 1200°C:

3D clays exhibit the highest shrinkage, with sizes dropping to 8.7–9.0 cm, meaning total shrinkage from raw clay reaches 9–14%.

BG clays remain relatively stable, ranging from 9.2–9.7 cm, with total shrinkage around 7–9%.

BT clays shrink noticeably, reaching 8.9–9.4 cm, showing 8–11% total shrinkage.

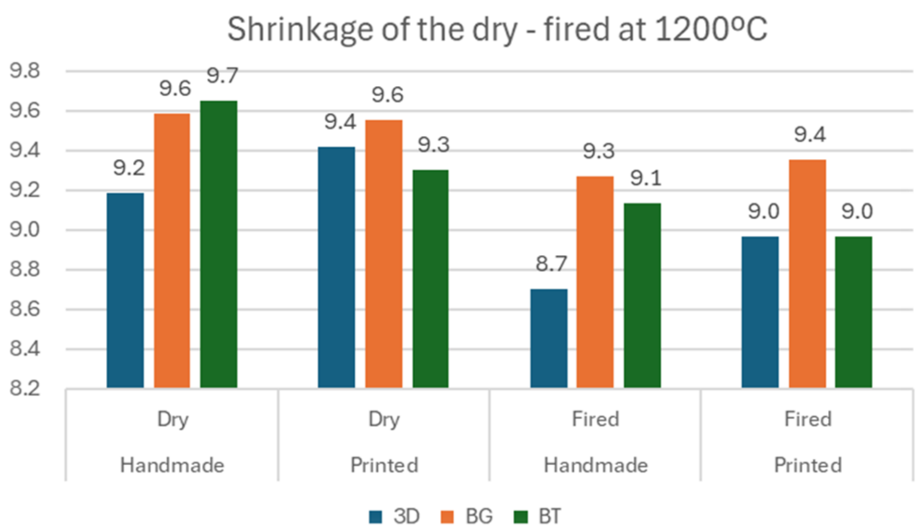


Figure 3.4.3 - Shrinkage of the clay samples, handmade vs printed, air dried vs fired at 1200ºC

Higher firing temperatures increase shrinkage, with the biggest contractions occurring at 1200°C.

3D clays shrink the most overall (~9–14% total shrinkage), indicating higher plasticity, finer particles, or greater water content.

BG clays are the most stable, showing the least shrinkage (~7–9%), likely due to coarser particles or lower water absorption, we know that grog/chamotte in a clay body lower its shrinkage and helps in drying.

BT clays have intermediate shrinkage (~8–11%), behaving closer to BG at 980°C but becoming more like 3D at 1200°C.

All the samples started with a 10cm marked line.

Table 6 - Clay Shrinkage in centimeters.

Sample	Handmade		Printed	
	Dry	Fired	Dry	Fired
3D1	9.2	8.7	9.4	9.0
3D2	9.2	8.8	9.5	9.0
3D3	9.2	8.7	9.4	8.9
3D4	9.3	9.2	9.5	9.4
3D5	9.2	9.6	9.4	9.4
3D6	9.4	9.4	9.5	9.5
BG1	9.6	9.2	9.5	9.4
BG2	9.6	9.4	9.7	9.4
BG3	9.6	9.2	9.5	9.4
BG4	9.6	9.5	9.5	9.5
BG5	9.6	9.6	9.6	9.7
BG6	9.6	9.5	9.7	9.7
BT1	9.7	9.1	9.3	9.0
BT2	9.7	9.1	9.3	9.0
BT3	9.6	9.2	9.3	8.9
BT4	9.6	9.5	9.3	9.3
BT5	9.6	9.5	9.3	9.3
BT6	9.6	9.6	9.3	9.4

It is important to notice that the samples were not bisque fired before firing it to high temperature since glazing was not on the plans since the beginning, the intention was to see the temperature differences on the clays. The samples were not too thick, and they were well dried before putting them in the kiln, to prevent them from cracking and exploding. If I was doing a thicker piece or wanting to glaze It after, I would most likely do a bisque firing first.

Clay Absorption

A porous body consists of two types of porosity: open porosity (Pa) and closed porosity (Pf). In this context, we are focusing on determining the open porosity (Pa), which can be calculated by evaluating the volume of open pores (vpa) and the total volume (v).

$$\boldsymbol{V} = \frac{\boldsymbol{mSat} - \boldsymbol{mSusp}}{\boldsymbol{\rho l}}$$

$$\boldsymbol{VPA} = \frac{\boldsymbol{mSat} - \boldsymbol{mDry}}{\boldsymbol{\rho l}}$$

This being **mSat** as the mass of the sample saturated with liquid, **mSusp** as the mass of the sample suspended in liquid, **mDry** as the mass of the sample when dry, **ρl** as the density of the liquid (water) - 1.00 g/cm^3

The open porosity (Pa) is then calculated as the ratio of the volume of open pores (VPA) to the total volume (V) of the sample, expressed as a percentage:

$$\boldsymbol{Pa}\,(\%) = \frac{\boldsymbol{VPA}}{\boldsymbol{V}} \boldsymbol{X\ 100}$$

The samples were weighted using a balance, a 1-liter goblet of water, a nylon thread, and a metal support.

The samples were weighed; dry weight was noted down.

Figure 3.4.4 - Dry Weight measure

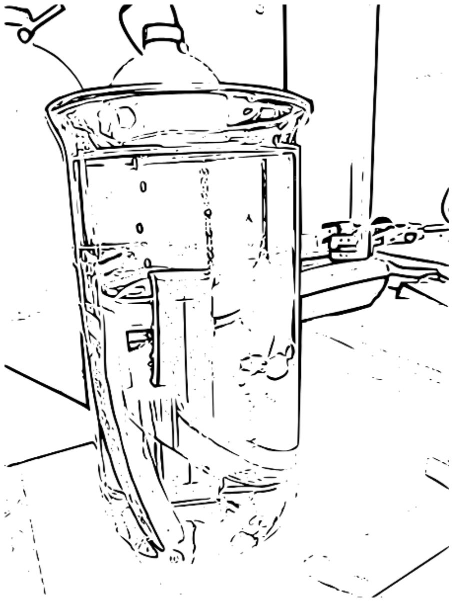
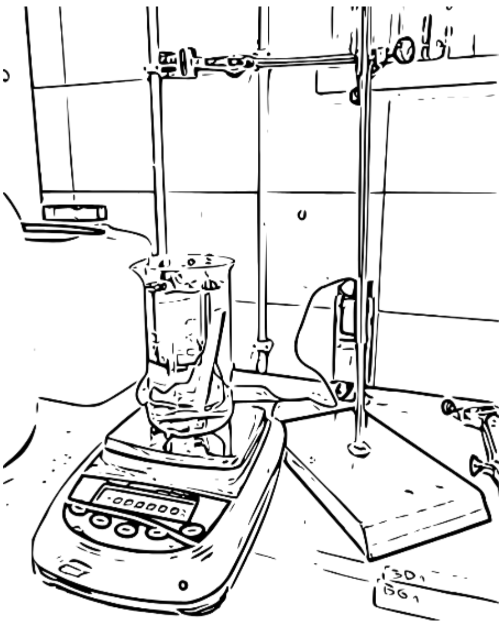


Figure 3.4.5 - Samples submerged in water

To get the saturated mass, we submerge the sample in the goblet filled with water, ensuring it is fully immersed. Allowing sufficient time so that all air trapped in the open pores is expelled.

We remove the sample from the water, gently blot it with paper to prevent water from dripping and place it on the petri dish. Record the mass of the sample (mSat).



For the mass of each sample suspended in water (mSusp). A goblet is filled with water and placed on a balance. The sample gets submerged again in water not touching the sides or bottom of the goblet, suspended by the nylon thread attached to a metal support.

Figure 3.4.6 - Suspended sample submerged

Table 7 - Porosity and Water Absorption Data for Handmade and Printed Samples

		Samples	Dry (g)	Sat (g)	Susp (g)	VPA (g)	V (g)	Open Porosity (%)
Handmade	1200ºC	3D1	45.1	47.9	20.8	2.7	27.1	10.0
		BG1	45.3	48.5	21.7	3.2	26.8	11.9
		BT1	45.9	46.4	20.7	0.5	25.7	2.1
	980ºC	3D4	41.6	47.9	22.5	6.3	25.5	24.8
		BG4	46.6	52.7	24.2	6.1	28.6	21.4
		BT4	49.6	55.6	25.6	6.0	29.9	20.0
Printed	1200ºC	3D1	35.3	38.2	17.0	2.9	21.2	13.5
		BG1	41.6	45.1	21.3	3.5	23.8	14.8
		BT1	42.1	43.6	19.4	1.5	24.2	6.2
	980ºC	3D4	38.9	45.1	22.3	6.2	22.8	27.3
		BG4	53.1	60.6	28.8	7.5	31.8	23.6
		BT4	43.1	48.7	23.1	5.6	25.6	21.8

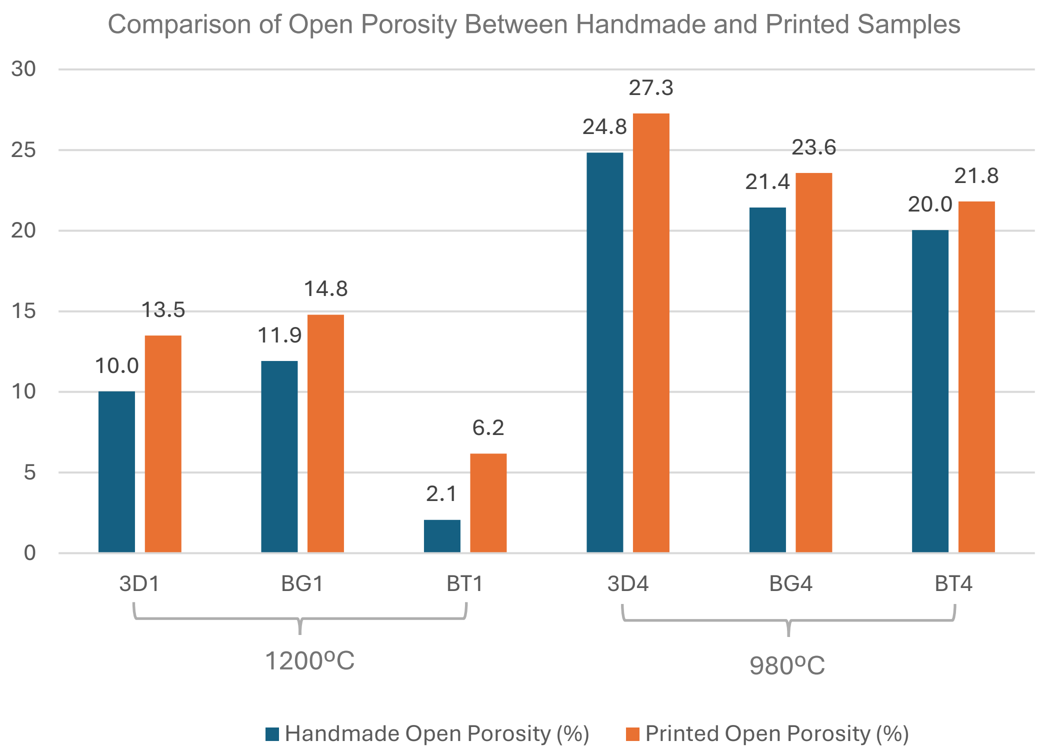


Figure 3.4.7 - Comparison of Open Porosity Between Handmade and Printed Samples

The study of shrinkage and open porosity in different clay samples got me to understand a bit more about the material. Handmade samples were generally more compact, exhibiting lower porosity and water absorption compared to their 3D-printed counterparts. This suggests that the manual process leads to a denser structure with fewer micro-voids. Additionally, material composition played a significant role, with BG and 3D samples showing higher porosity than BT clay in both handmade and printed forms.

This could be attributed to differences in particle distribution, the presence of chamotte, or variations in water content during preparation. Notably, BT samples emerged as the densest and least porous, indicating their suitability for applications requiring low permeability, such as waterproof materials. In contrast, the higher porosity observed in BG and 3D samples suggests their potential for applications where water absorption or lightweight properties are beneficial, such as filtration systems or thermally insulating structures. It all depends on what we are looking for.

The choice between handmade and printed methods directly impacts porosity, density, and shrinkage, making it a crucial factor in material selection. Additionally, the variations between BT, BG, and 3D compositions suggest that clay formulation should be carefully considered depending on the intended application. If low porosity and higher density are required, BT clay proves to be the best option. Conversely, for applications where higher porosity is advantageous, such as filtration or lightweight construction, BG and 3D clays offer superior performance when fired at 980ºC. This understanding is essential for optimizing clay-based additive manufacturing processes to achieve specific functional properties with the research being less time-consuming and less costly.

Printability/Extrudability

Support/No support

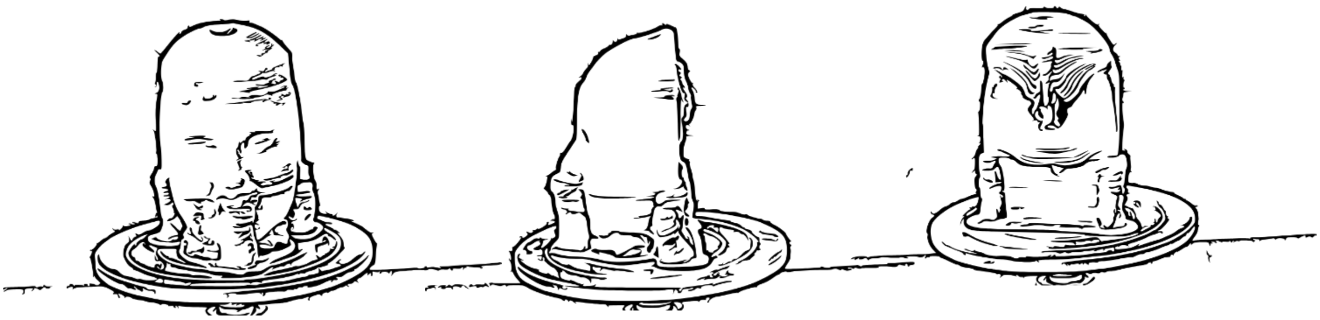


Figure 3.4.8 - Drawings of a printed model in BT clay with support

Figure 3.4.9 - Drawings of a printed model in BT clay without support

Support vs. No Support Observation

The comparison between printed models with and without support shows the crucial role of support structures in maintaining print accuracy and stability. The models printed with support exhibit a more defined shape, albeit with some surface imperfections due to support removal. In contrast, the models printed without support show significant deformation, loss of detail, and structural collapse, particularly in overhanging areas. This suggests that for complex geometries, the use of support is essential to prevent print failures and ensure dimensional accuracy.

Infill/ No infill

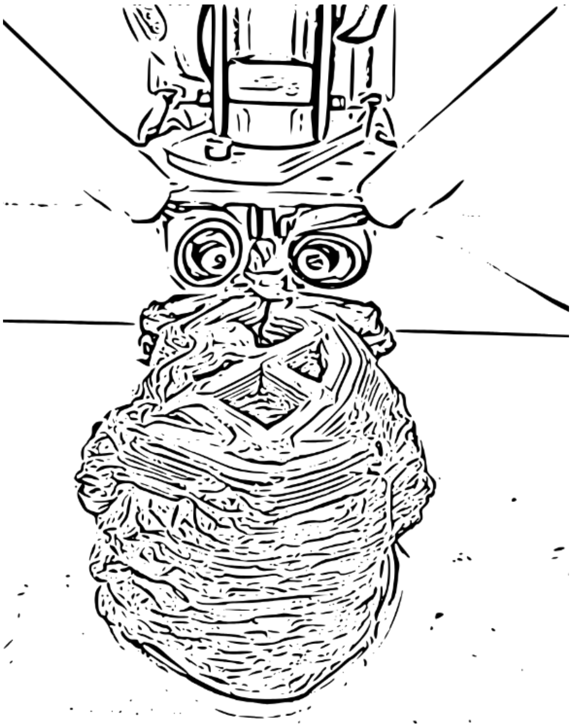


Figure 3.4.10 - Drawing of a printed model with infill

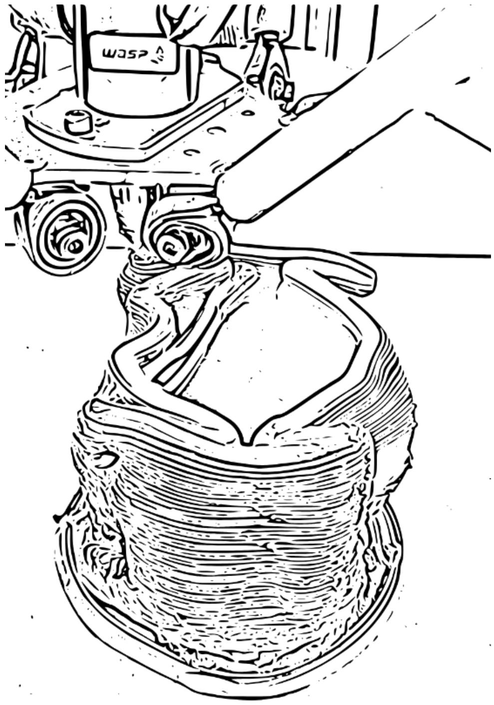


Figure 3.4.11 - Drawing of a printed model without infill

Infill vs. No Infill Observation

The comparison of models printed with and without infill demonstrates the impact of internal structure on print integrity, weight, and material usage. The model with infill maintains a more stable and consistent shape, showing reduced deformation and better layer adhesion. However, it is noticeably heavier, takes longer to print, and consumes more clay, increasing both material costs and print time. In contrast, the model without infill is significantly lighter and prints faster with less material usage, but at the cost of reduced structural integrity, leading to some collapse or warping during printing. This highlights the trade-off between strength and efficiency in 3D printing, where the choice of infill percentage must balance durability, weight, and resource consumption.

Clay Printing Limitations

3D printing with clay, while promising and versatile, comes with several limitations due to the properties of clay as a material and the constraints of current technology. One of the most significant challenges is its fragility. Unfired clay prints are extremely delicate and prone to breaking, and even once fired, they can still be more fragile than traditionally crafted ceramics. Additionally, clay undergoes shrinkage as it dries and is fired, which can lead to deformation or cracks. A print might appear perfect initially, but once it has dried and been fired, hidden flaws often become apparent.

The technology itself presents various challenges, particularly with 3D printers designed for clay. One major limitation is the restricted layer height dictated by available nozzles. For instance, when using a Delta WASP printer, the available nozzle sizes ranged from 1.26mm to 3.0mm. This affects the resolution and surface detail of the prints, as finer details require smaller nozzles and a longer printing time. Another issue is equipment wear; clay, especially when it contains grog or chamotte, can be abrasive, leading to faster wear on printer components such as nozzles and extruders. Moreover, the particulate nature of clay makes clogging a frequent issue, necessitating regular cleaning and maintenance. Changing from one type of clay to another also demands thorough cleaning of the entire machine, which is time-consuming and labour-intensive. While the cleaning process itself is not particularly complex, it involves multiple steps, and without the right tools or knowledge, there is a risk of improperly maintaining or damaging the printer.

Structural and design constraints also play a significant role in the limitations of clay 3D printing. Unlike standard FDM printing, where the material hardens almost instantly, clay remains wet, making it difficult to print overhangs or complex geometries without support structures. There is also a risk of prints collapsing under their own weight if the layers are too thick or if drying occurs unevenly. Shapes such as spheres or rounded tops present additional difficulties, often causing the structure to collapse inwards.

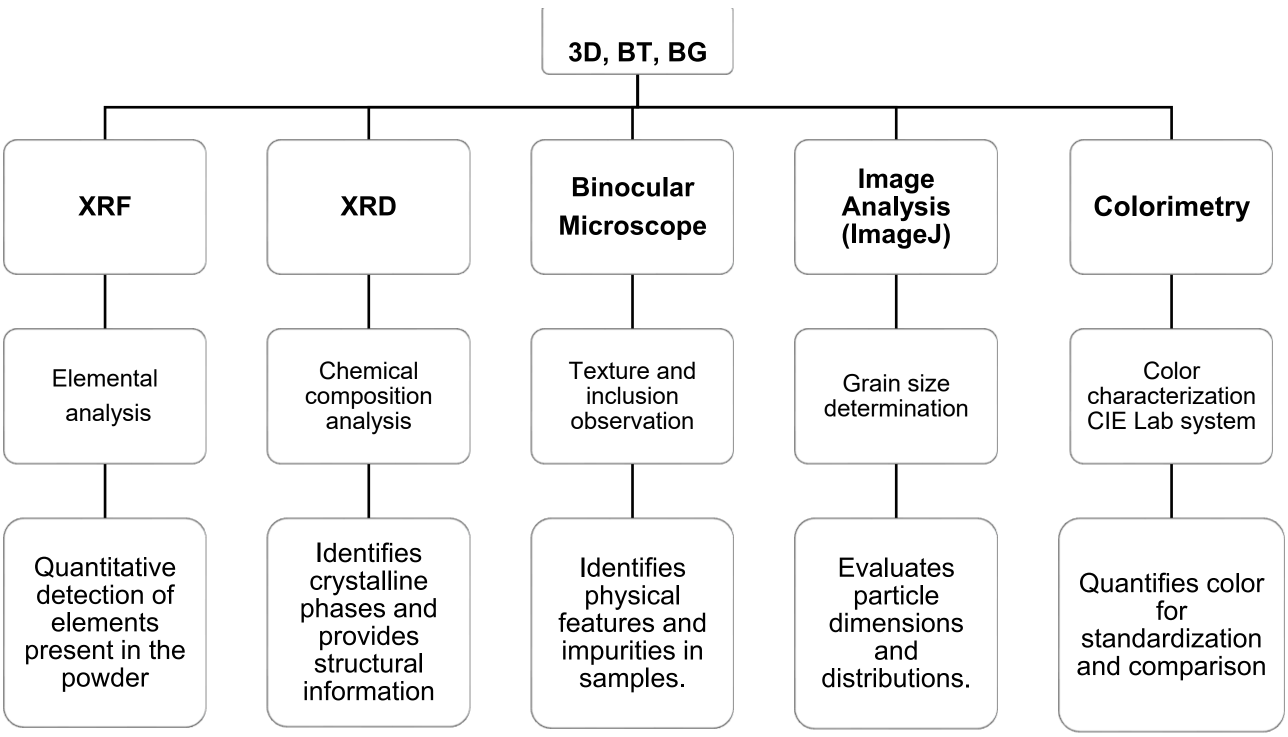
Material properties and workflow considerations further complicate the process. Achieving the right clay consistency is crucial; it must be soft enough to extrude smoothly while still firm enough to maintain its shape. Drying times are another major factor, prints must be dried carefully to prevent cracking, which can significantly slow down production. While the printer itself offers precision, clay as a material for 3D printing does not always behave predictably, as it has its own movement and inconsistencies that cannot always be controlled. Unlike plastic or resins, clay is soft, malleable and sensitive to its context environment like moisture, temperature, and drying speed. The tendency to slump, sag, or shift due to gravity and its own weight, especially in taller or overhanging structures. The printed layers may not hold their shape as precisely as intended and deform the print. Variations in moisture can affect how smoothly the clay is extruded, leading to irregular layer deposition, looking too squished or looking dry and uncomplete. Printed layers may compress or spread, impacting structural integrity as clay remains soft until it dries or is fired.

Finally, cost and accessibility present barriers to widespread adoption. Clay 3D printers are far less common and more expensive than standard FDM or resin printers, making them less accessible to hobbyists and small-scale creators. I do feel that the more open access a new technology is, the quicker it's evolution. Furthermore, mastering the process requires expertise not only in 3D printing technology but also in ceramics, adding another layer of complexity for those looking to adopt this technique.
Despite these challenges, clay 3D printing remains an exciting and evolving field. As technology improves and solutions are developed for these limitations, it has the potential to become a more viable and accessible tool for artists, designers, and manufacturers.

3.5. KNOWING THE MATERIAL DEEPLY

During this last year I got to learn the importance of knowing the material with my adviser Fernanda Carvalho. Knowing our material can help us save time, having less costs and adapt.
As an artist, material is always important, nonetheless sometimes we underestimate the value of knowing the material, doing tests, seeing how the material behaves and understanding why, is more useful than I expected.
The analyses made of 3D, BG, BT clay in order to characterize each one of them and compare them, were the following:

Table 8 - Analyses made of 3D, BG, BT clay



XRF

From the XRF (X-ray Fluorescence), we can see a quantitative detection of elements present in the powder.

Table 9 - Data obtained from XRF

Samples		SiO_2	Al_2O_3	K_2O	TiO_2	Fe_2O_3	MgO	CaO	Na_2O	Others
Raw	3D	61.2	32.6	1.9	1.8	1.5	0.3	0.1	0.0	0.5
	BT	67.8	26.2	2.1	0.9	1.1	0.3	0.5	0.8	0.3
	BG	62.8	31.3	1.6	1.9	1.6	0.3	0.1	0.0	0.3
980ºC	3D	61.5	31.2	1.7	1.7	1.4	0.5	0.2	1.5	0.3
	BT	67.9	26.1	2.0	0.9	1.0	0.3	0.5	0.9	0.2
	BG	62.8	31.7	1.5	1.8	1.4	0.3	0.2	0.0	0.3
1200ºC	3D	61.8	31.9	1.9	1.9	1.5	0.4	0.4	0.0	0.2
	BT	69.3	24.8	2.1	0.9	0.9	0.3	0.6	0.9	0.2
	BG	63.7	30.8	1.4	1.8	1.4	0.4	0.3	0.0	0.1

This analysis examines the chemical composition of three clay samples (3D, BT, and BG) in their raw state and after firing at 980ºC and 1200ºC. The variations in elemental content highlight important transformations, including changes in silica (SiO_2) and alumina (Al_2O_3) ratios, volatilization of certain oxides, and phase evolution.

Silicon (SiO_2) and Aluminum (Al_2O_3) Content

SiO_2 is the dominant component in all samples, showing a slight increase after firing at 1200ºC, likely due to densification as other oxides volatilize or react to form new phases (Iqbal & Doss, 2015). For example, BT increases from 67.8% (raw) to 69.3% (1200ºC), with similar trends in BG and 3D. Conversely, Al_2O_3 decreases slightly, particularly in BT (26.2% to 24.8%), due to interactions with fluxing agents such as alkali metals, which lower its melting point and contribute to glassy phase formation (Reed, 1995).

Alkali and Alkaline Earth Elements (K_2O, Na_2O, CaO, MgO)

K_2O remains relatively stable, while Na_2O, a highly volatile oxide, diminishes at 1200°C in the 3D and BG samples. These alkali oxides act as fluxing agents, reducing the melting point of silica and promoting densification (Kingery et al., 1976) CaO and MgO show minor variations, aiding in new mineral phase formation and ceramic body densification.

Iron (Fe_2O_3) and Titanium (TiO_2)

Fe_2O_3, crucial for coloration and structural integrity, decreases slightly upon firing but remains largely stable. TiO_2 shows only minor fluctuations, indicating limited volatilization or phase interaction.

Effect of Firing on Open Porosity and Densification

The presence of K_2O and Na_2O significantly influences porosity (Chin et al., 2017). Samples with higher alkali content exhibit greater densification at 1200ºC, as these elements facilitate liquid phase formation during sintering. For example, BT1 (2.03% K_2O, 0.91% Na_2O) shows a drop in open porosity from 20.04% (980ºC) to 2.07% (1200ºC). In contrast, BG1 (1.42% K_2O, 0% Na_2O) maintains a higher porosity of 11.92% at 1200ºC, indicating a weaker fluxing effect. This trend is also observed in 3D-printed samples, where increased K_2O content leads to reduced porosity.

The observed compositional shifts during firing highlight key processes such as volatilization, phase transformation, and vitrification. The increase in SiO_2 and reduction in Al_2O_3 suggest progressive densification, while alkali oxides play a crucial role in controlling porosity and mechanical properties. Understanding these transformations is essential for optimizing firing conditions in ceramic production, particularly in 3D-printed clay objects (Chin et al., 2017).

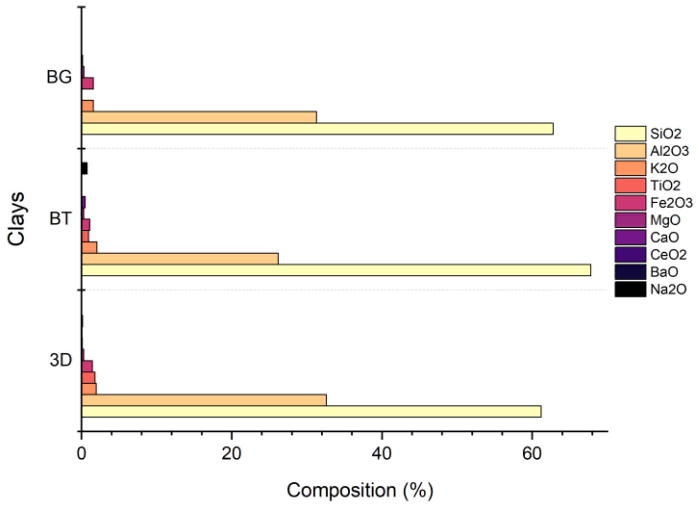


Figure 3.5.1 - Chemical composition of non-fired samples (BG, BT, 3D)

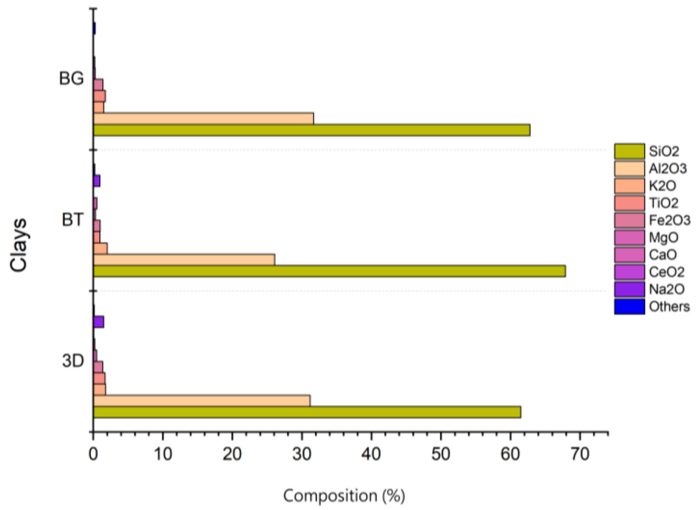


Figure 3.5.2 - Chemical composition of 980ºC fired samples (BG, BT, 3D)

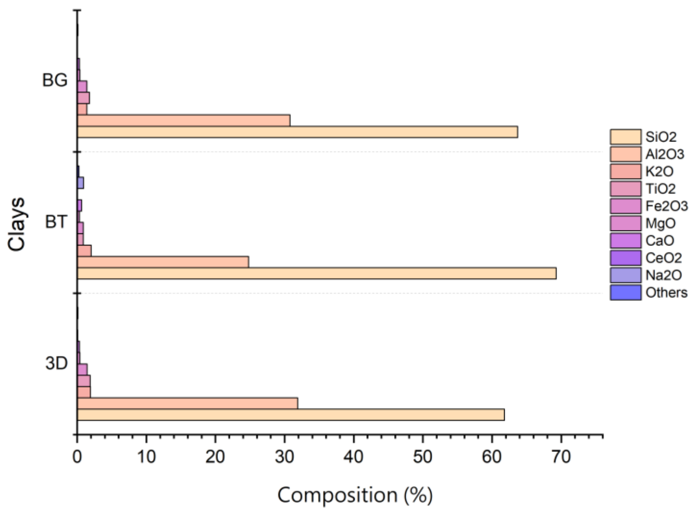


Figure 3.5.3 - Chemical composition of 1200ºC fired samples (BG, BT, 3D)

The figures 3.5.1, 3.5.2 and 3.5.3 illustrate the elemental composition of materials across the three sample categories: 3D, BT, and BG, before firing at 980ºC and 1200ºC. Firing at higher temperatures induces further compositional shifts, reflecting thermal effects on the material's structure and phase evolution.

SiO_2 remains the dominant component across all firing temperatures, with slight variations maintaining the material's silicate framework. Al_2O_3 shows a minor decrease, particularly in BT, suggesting structural adjustments. K_2O and Na_2O exhibit slight increases in some samples, reinforcing their role as fluxing agents in sintering. TiO_2 and Fe_2O_3 undergo minor reductions, indicating phase transformations, while MgO and CaO show modest variations, with CaO increasing in BT at higher temperatures. The "Others" category remains minimal but fluctuates slightly, likely representing minor phases formed during thermal reactions.

Overall, firing at 980°C and 1200°C induces subtle yet significant chemical changes, with elements such as K_2O, Na_2O, TiO_2, and CaO displaying increased mobility and reactivity. These transformations influence the final composition, and can affect the structural integrity, and phase evolution of the material.

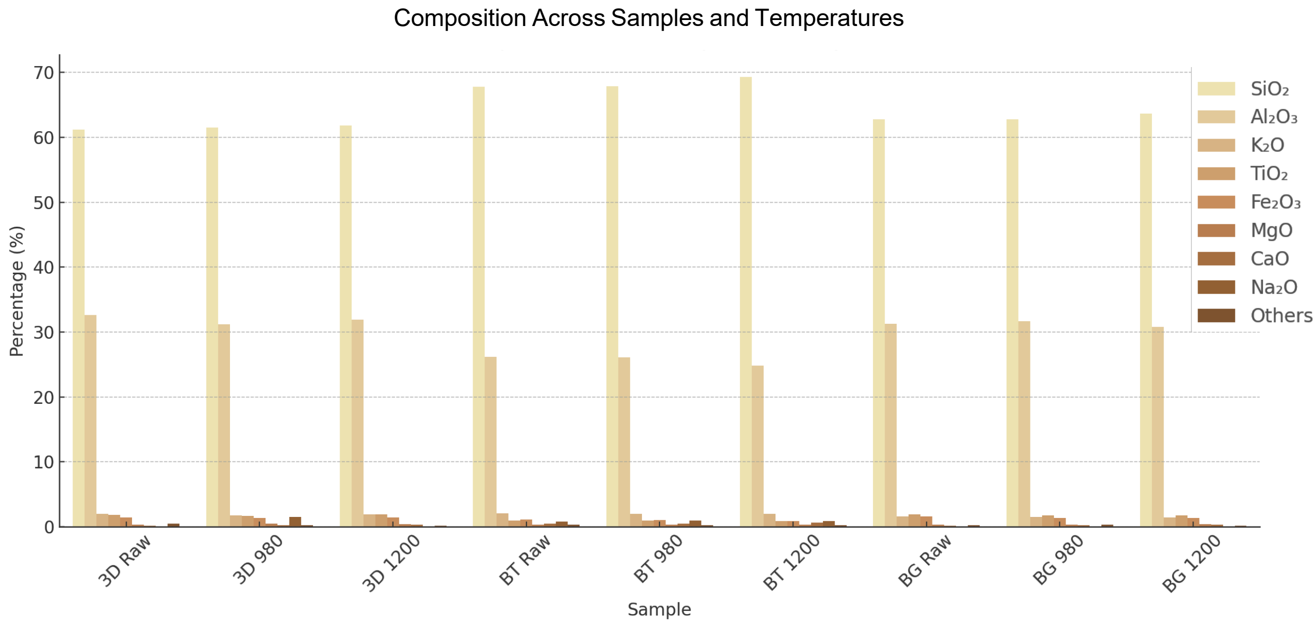


Figure 3.5.4 - Composition results with XRF

XRD - Phase analysis

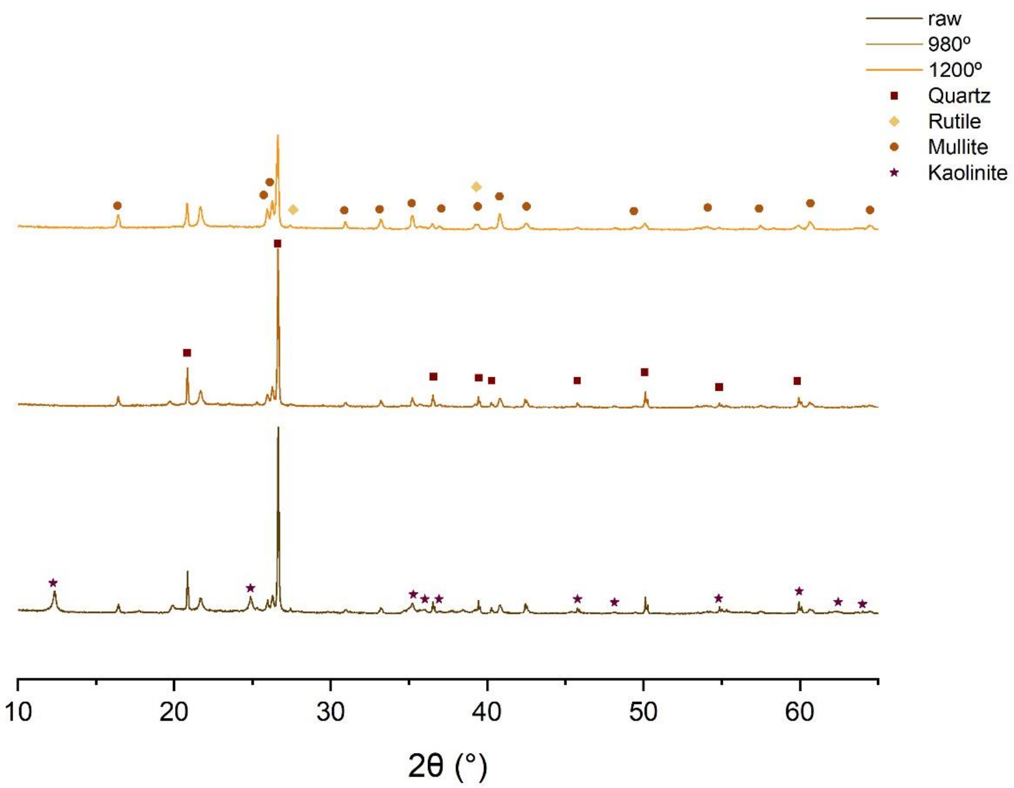


Figure 3.5.5 – Phase identification of 3D Clay

X-ray diffraction (XRD) analysis revealed significant phase transformations in clay materials with increasing firing temperature. In the raw state, quartz is the dominant crystalline phase, it was identified with the more intense peaks, but Kaolinite also had identified peaks, it is a key component in stoneware, kaolinite was one of the first minerals used for pottery due to its plasticity and heat resistance. (Mindat, n.d.)

At 980°C, kaolinite peaks disappeared, confirming decomposition, while quartz remained stable. By 1200°C, the XRD pattern showed pronounced changes, with the emergence of mullite, a high-temperature phase associated with structural strengthening. Additionally, rutile was detected, suggesting the presence of titanium-containing impurities specific to this sample.

The increasing intensity and sharpness of diffraction peaks indicate enhanced crystallinity and structural ordering with higher temperatures (Giacovazzo, 2002). These findings highlight the role of thermal treatment in promoting phase transformations and stabilizing the material's mineralogical structure.

For phase identification, XRD peak positions were compared with reference databases, including the International Centre for Diffraction Data (ICDD) PDF-4 and the Crystallography Open Database (COD), ensuring accurate mineralogical characterization and an improved understanding of thermal behavior.

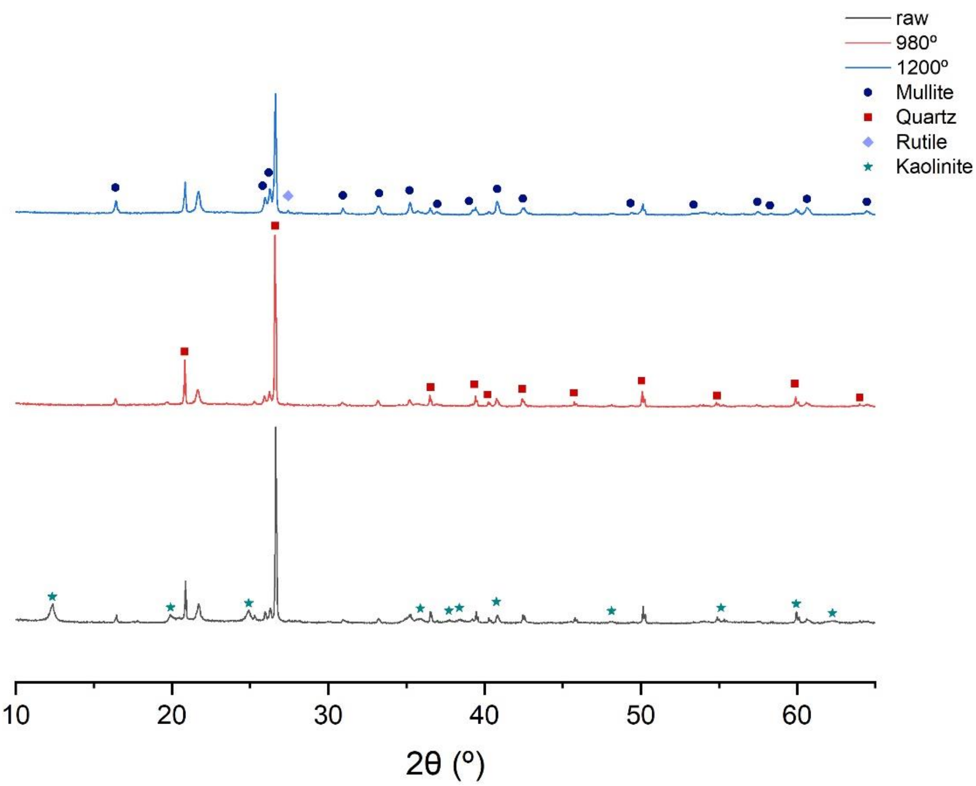


Figure 3.5.6 - Phase identification of BG Clay

The phase transformation behavior of the BG sample followed a similar pattern to that of the 3D sample. In its raw state, the primary crystalline phases present were kaolinite, quartz, and albite, with their characteristic diffraction peaks confirming their presence.

Upon heating to 980°C, kaolinite underwent thermal decomposition, as evidenced by the disappearance of its peaks. Quartz remained stable, retaining its diffraction pattern, while albite, like in the 3D sample, was no longer observed after heating. This suggests that albite underwent a phase change or decomposition during the thermal treatment.

At 1200°C, mullite emerged as the dominant new phase, with distinct diffraction peaks confirming its successful formation. Notably, no rutile was detected in the BG sample, consistent with the results from the 3D sample. This absence of rutile further supports the hypothesis that the BG and 3D samples share similar raw material compositions, as they exhibit comparable phase transformations under similar thermal conditions.

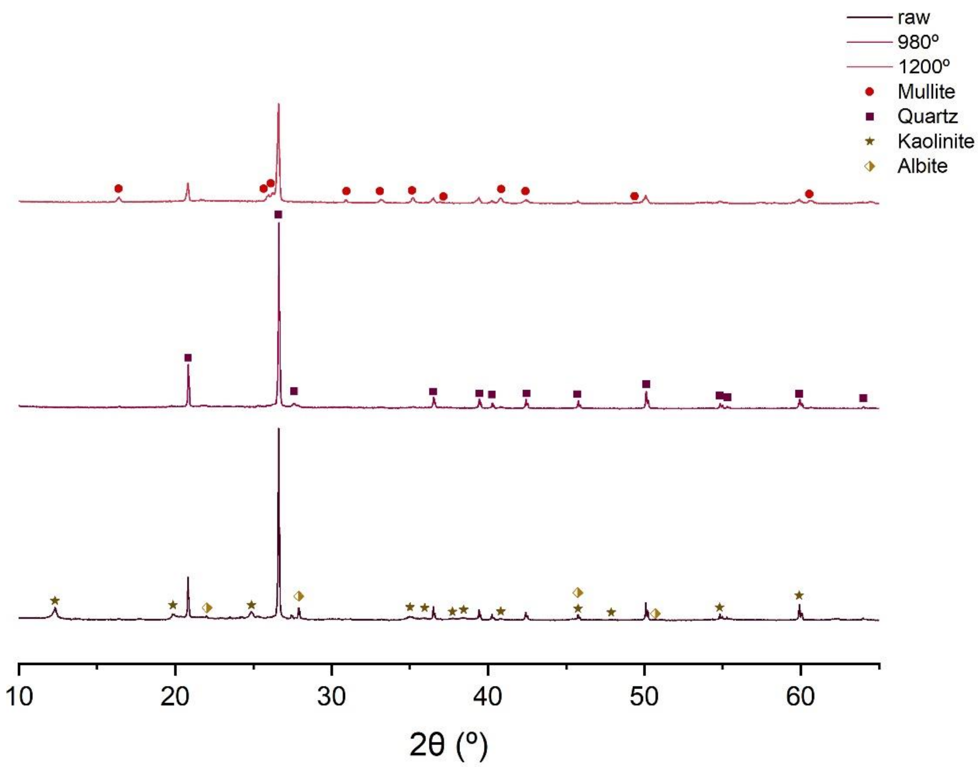


Figure 3.5.7 - Phase identification of BT Clay

The XRD analysis of the BT sample revealed phase evolution similar to that of the 3D sample, with a few key differences. In the raw state, kaolinite was the primary phase, accompanied by quartz and albite. The presence of albite in the raw material distinguished the BT sample from the 3D sample.

Upon heating to 980°C, kaolinite underwent decomposition, as evidenced by the disappearance of its diffraction peaks. Quartz remained stable, showing no significant structural changes. Albite, which was initially present, was no longer detected at this stage, indicating its breakdown or transformation under heat.

At 1200°C, the formation of mullite was observed, confirming the expected phase transition at high temperatures. However, unlike the 3D sample, rutile was absent, suggesting that the BT sample lacked titanium-based impurities. This absence of rutile further supports the notion that the raw materials for the BT and 3D samples differ chemically, leading to distinct phase evolution under similar thermal conditions.

The XRD analysis of the 3D, BG, and BT clay samples demonstrated significant differences in phase evolution and crystallinity, which can be attributed to the unique compositions and mineralogical properties of each clay type.

In all three samples, kaolinite decomposed by 980°C, and If we observe the results, the intensity of the main quartz peak decreases at 1200°C compared to the raw and 980°C results. I believe that some of the mineral phases formed at this temperature may result from reactions with quartz. Therefore, it can be concluded that quartz does not remain stable throughout the entire thermal treatment. This suggests that at higher temperatures, quartz undergoes transformations, potentially reacting with other components in the material, leading to the formation of new phases and a reduction in the intensity of the quartz diffraction peak.

The interaction of Al_2O_3 with fluxing oxides could contribute to mullite ($Al_6Si_2O_{13}$) formation, which improves the mechanical strength of ceramics at high temperatures, mullite formation was consistently observed at 1200°C, aligning with the expected high-temperature phase transitions for clay materials. However, the phase composition varied across the samples. The absence of rutile in the BT and BG samples further emphasizes the compositional differences, as these clays likely lack the titanium-based impurities present in the 3D sample. Moreover, the disappearance of albite upon heating in both BT and BG clays supports the presence of feldspar components that are not found in the 3D sample.

The differences in phase compositions observed across the samples can be attributed to variations in raw material chemistry, impurities, and structural order. These findings highlight the importance of understanding the mineralogical makeup of raw clays to predict their thermal behavior and potential applications.

Binocular Microscopy

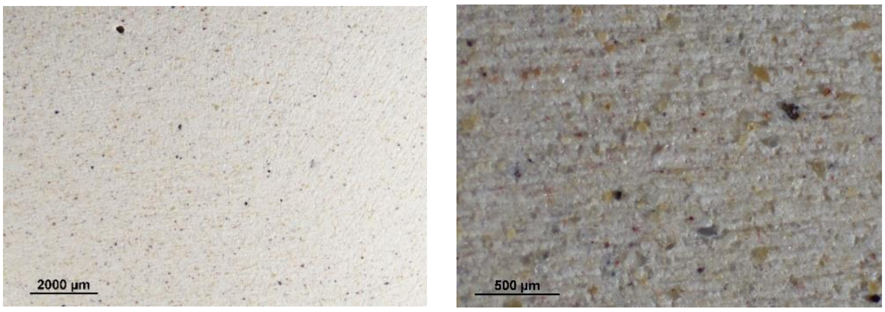


Figure 3.5.8 - 3D_980ºC_1x, 5x

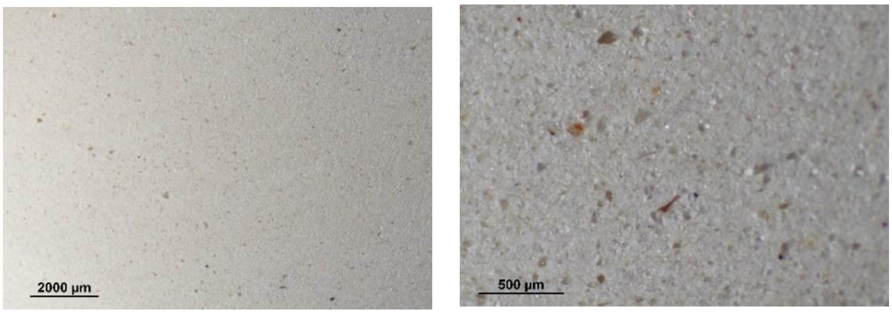


Figure 3.5.9 - BT_980ºC _1x, 5x

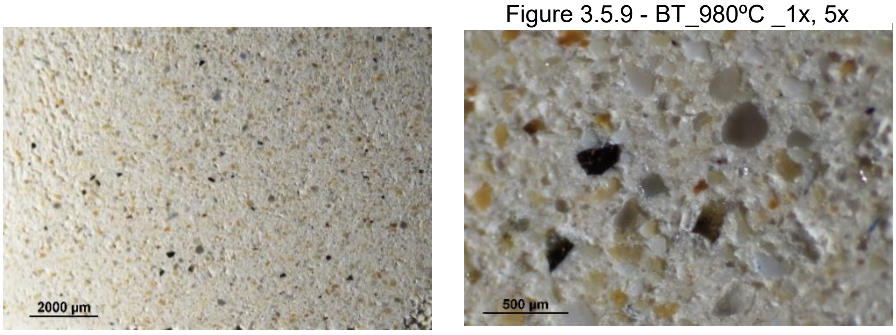


Figure 3.5.10 - BG_980ºC _1x, 5x

The images show three different material samples (3D, BT, and BG) that were fired at 980°C. Each sample is photographed at two magnifications: 1x and 5x, giving us a closer look at how their textures and structures look after the firing.

Figures 25 (BT sample at 980°C, 1x and 5x magnification): The 1x magnification shows a smooth, even texture with fine granules. When it zoomed in to 5x, small irregular particles started to appear, but the overall texture still looks uniform. Figures 26 (3D sample at 980°C, 1x and 5x magnification): At 1x magnification, the 3D sample also looks smooth, but you can spot some scattered dark specks. At 5x, more details come through, showing a slightly wider range of particle sizes than the BT sample. Some areas have larger particles or inclusions. Figures 27 (BG sample at 980°C, 1x and 5x magnification): The BG sample at 1x (Figure 5) shows a smooth surface with a few small dark spots. At 5x magnification (Figure 6), the texture becomes more granular, with a mix of fine and coarse particles. You can also see some larger inclusions, suggesting variations in the material's composition, which makes complete sense since this clay has chamotte 0-0.2 mm.

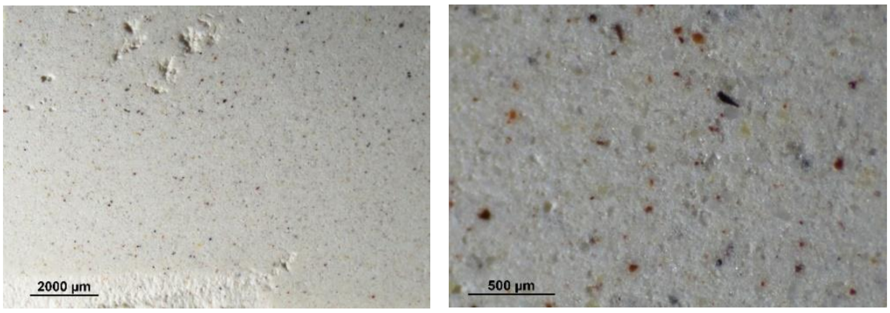


Figure 3.5.11 - 3D_1200ºC _1x, 5x

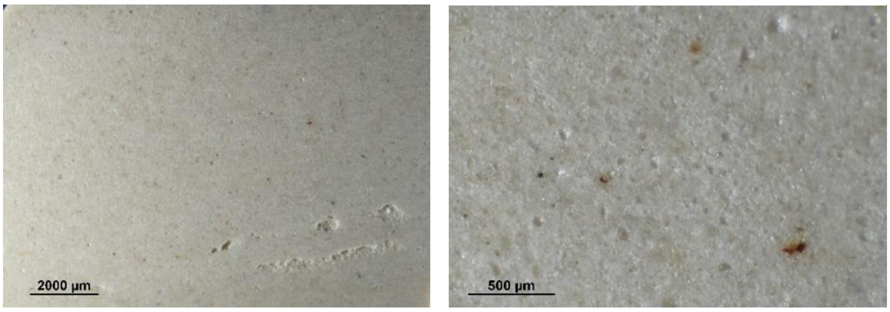


Figure 3.5.12 - BT_1200ºC _1x, 5x

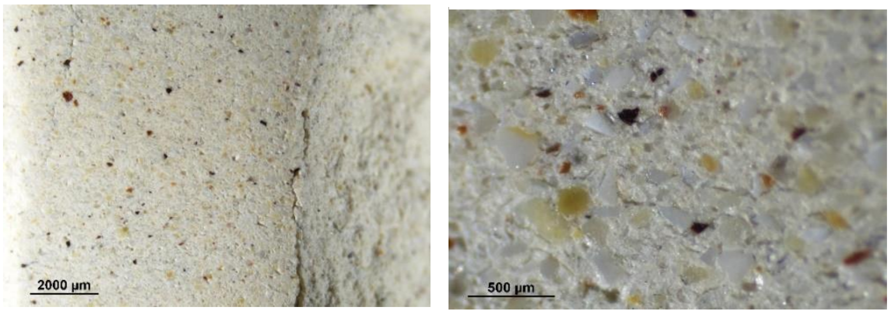


Figure 3.5.13 - BG_1200ºC _1x, 5x

The second set of photographs show once more three samples (3D, BT, and BG) but this time fired at 1200°C, observed again at 1x and 5x.

Figures 28 (3D sample at 1200°C, 1x and 5x magnification): At 1x magnification, the 3D sample exhibits a generally smooth and uniform surface with minor imperfections, such as small cracks or irregularities. At higher magnification, the microstructure reveals dispersed particles, some of which are darker in color, suggesting inclusions or impurities. The texture remains relatively consistent, with fine particles distributed across the surface. Figures 29 (BT sample at 1200°C, 1x and 5x magnification): The BT sample at 1x magnification also shows a smooth surface with minimal visible features, like the 3D sample. However, subtle irregularities, such as small cracks or depressions due to the grinding process, are present. Zooming in to 5x magnification reveals a finer and more compact microstructure, with fewer visible inclusions compared to the 3D sample. The surface appears dense and well-formed, suggesting good thermal stability. Figures 30 (BG sample at 1200°C, 1x and 5x magnification): The BG sample at 1x magnification shows a surface with a slightly rougher appearance compared to the other samples, including visible cracks and uneven areas. At higher magnification, the microstructure becomes more granular, with larger and more varied particles visible. The surface contains noticeable inclusions, with dark and coloured particles dispersed throughout, indicating a more heterogeneous composition compared to the 3D and BT samples.

Granulometry Analysis Using ImageJ

The granulometry analysis was conducted on the clay samples using ImageJ to measure the apparent grain size. It is important to note that these measurements reflect the visible size of the grains in the image, which may not correspond exactly to their true physical size, as factors like image resolution and the angle of observation can influence the results.

The grain size distribution for each sample was determined, and the following data represent the range of grain sizes observed as well as the calculated mean grain size for each sample:

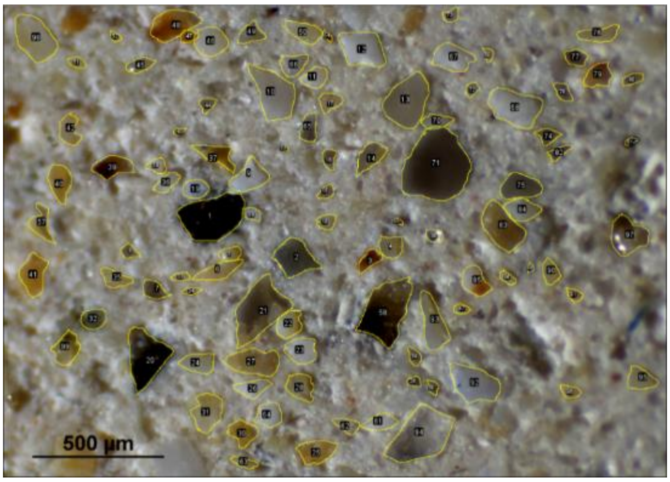


Figure 3.5.14 - BG_980º - Apparent Grain Size Distribution Measured Using ImageJ

Table 10 - Grain Size Range and Medium Size of Samples at 980ºC and 1200ºC

Sample	Grain size (µm)	Medium size (µm)
BT_980ºC	6.39 – 138.95	43.80
BG_980ºC	32.35 – 311.92	131.83
3D_980ºC	13.04 – 155.07	59.83
BT_1200ºC	5.58 – 148.47	33.23
BG_1200ºC	22.42 – 315.51	132.84
3D_1200ºC	11.80 – 146.38	48.30

The grain size range represents the minimum and maximum values measured for each sample, while the medium size is the average grain size calculated for each. This data provides insights into the particle distribution of the clay and helps predict its behavior during drying and firing. Microscopic analysis also reveals the presence of chamotte, a pre-fired, non-plastic material that reduces the clay's plasticity. By limiting the water retention capacity, chamotte makes the material less pliable, enhancing its stability during shaping and handling. While this property strengthens and stabilizes the clay, excessive chamotte can make it more brittle and less workable.

In terms of drying shrinkage, chamotte acts as an inert filler, helping control excessive contraction. Since it does not absorb water like raw clay particles, chamotte helps maintain the material's structure as it dries, reducing the risk of warping or cracking. It also minimizes firing shrinkage by providing a stable framework within the clay body, preventing excessive contraction at high temperatures. This is especially beneficial for applications requiring dimensional stability, such as 3D-printed ceramics or large sculptural pieces.

In conclusion, the interplay between grain size distribution and chamotte content plays a critical role in determining the final properties of a ceramic material. By modifying water absorption, drying shrinkage, and firing shrinkage, chamotte improves the stability, workability, and durability of clay bodies. However, attention must be given to particle size, particularly in 3D printing, as overly coarse particles can clog the printer nozzle and negatively affect print quality. Proper control of particle size is essential to ensure smooth extrusion and optimal print performance in additive manufacturing processes.

Colorimetry

A Lovibond TR500 Series spectrophotometer with a 2mm mask was used to measure the color of the historical mortar samples, mounted in resin, in cross-section. The data were recorded in SCI mode with a D/8 geometric optical illuminator and processed by the OnShade software in the CIELab color space. The analyses were performed in three distinct areas of each sample, when possible, with averages being calculated.

Table 11 - Average L, a*, b* Values Across Three Distinct Areas for Each Sample

Color	Sample	L*	a*	b*	Calculated average of L*, a*, b*		
	BT_Raw	70.60	2.36	8.03			
	BT_Raw	70.47	2.43	7.83	71.70	2.13	7.37
	BT_Raw	74.03	1.61	6.26			
	BG_Raw	78.26	1.10	7.28			
	BG_Raw	78.66	0.92	7.09	78.13	1.00	7.09
	BG_Raw	77.48	0.99	6.89			
	3D_Raw	75.98	0.66	6.93			
	3D_Raw	76.59	0.77	7.45	76.44	0.60	6.92
	3D_Raw	76.75	0.36	6.38			
	BT_980	88.98	3.08	8.67			
	BT_980	89.52	3.37	8.79	88.92	3.20	8.73
	BT_980	88.26	3.14	8.73			
	BG_980	84.10	1.92	6.40			
	BG_980	87.60	2.07	6.60	85.55	2.07	6.78
	BG_980	84.95	2.22	7.33			
	3D_980	85.41	2.51	6.80			
	3D_980	82.20	2.64	7.42	84.36	2.82	7.64
	3D_980	85.48	3.32	8.71			
	BT_1200	85.28	2.10	14.30			
	BT_1200	86.63	2.12	14.00	85.85	2.18	14.46
	BT_1200	85.65	2.32	15.08			
	BG_1200	84.50	2.33	17.38			
	BG_1200	84.45	2.48	16.92	84.48	2.50	17.44
	BG_1200	84.48	2.70	18.03			
	3D_1200	85.06	2.75	14.45			
	3D_1200	84.04	2.71	14.46	84.00	2.72	14.46
	3D_1200	82.89	2.71	14.46			

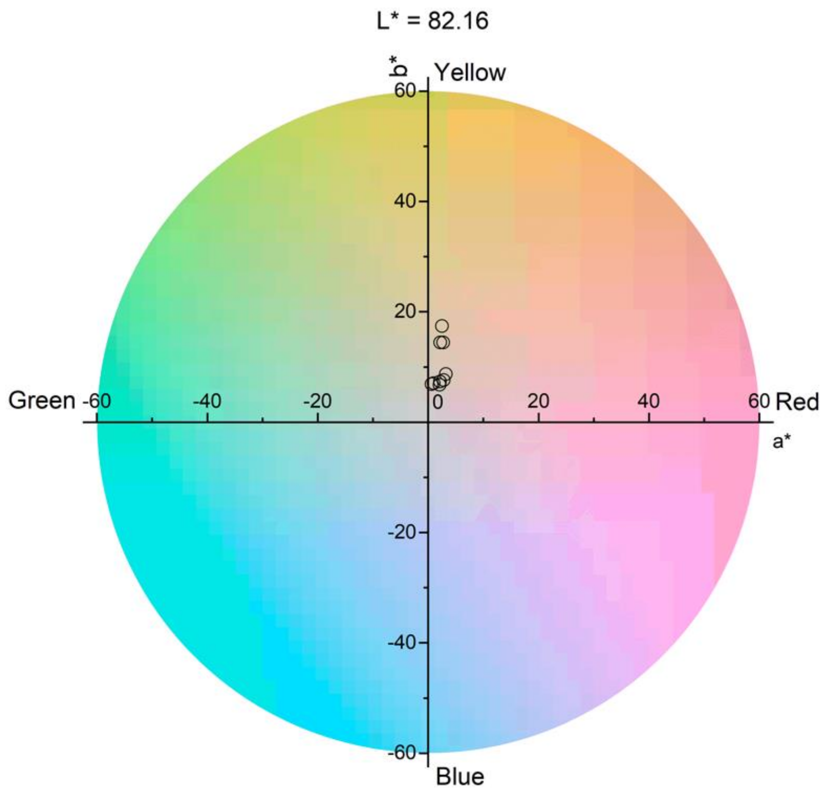


Figure 3.5.15 - Visualization of Color Shifts in Clay Samples

The data shows that lightness (L*) values decrease slightly as firing temperature increases, with materials fired at 1200°C appearing darker than those fired at 980°C. This darkening effect is more noticeable in certain clay types, such as BG_1200 and 3D_1200, which have lower L* values compared to their 980°C counterparts.

As for the red-green (a*) and yellow-blue (b*) axes, the a* values remain relatively stable across all samples, indicating minimal changes in the red-green spectrum. However, the b* values, representing the yellow-blue axis, tend to increase with higher firing temperatures, particularly in clay types like BG_1200 and BT_1200. This suggests that these clays become more yellowish as the temperature rises.

From the CIELAB chart, it's evident that the data points cluster in the yellowish region of the color space, with only minor shifts in red and green. This indicates consistency in color trends across the samples, although subtle variations point to the fact that different clay compositions respond differently to firing temperature.

Overall, higher firing temperatures seem to cause darkening and intensify yellow tones in the clay, likely due to oxidation and mineral transformations. The response to temperature varies across different clay types, with some showing more pronounced shifts in color than others.

3.6. CONCLUSION

This study presents a detailed analysis of the mineralogical, structural, and chemical transformations occurring in the 3D, BT, and BG clay samples during thermal treatment. Through X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses, key phase transitions were identified with increasing temperature, offering a deeper understanding of the material behavior at elevated temperatures.

At 980°C, kaolinite undergoes complete thermal decomposition, marking the beginning of phase restructuring. The disappearance of kaolinite peaks confirms its transformation, while quartz remains stable, retaining its characteristic diffraction peaks, though with decreased intensity compared to the raw samples. Microscopy at this stage reveals an increase in grain size, minor textural changes, and small inclusions, indicating early-stage mineral rearrangement. Granulometry analysis using ImageJ further highlights significant variations in particle size distribution, which can impact porosity, shrinkage, and mechanical properties. By 1200°C, the clay bodies undergo substantial phase transformations. Mullite emerges as the new crystalline phase, signifying high-temperature stabilization. Notably, the 3D sample exhibits rutile, a titanium-bearing phase, attributed to a higher TiO_2 content, while BT and BG samples, which initially contained albite, show its complete disappearance upon firing. Sharper diffraction peaks at this temperature indicate increased crystallinity and a more consolidated, mechanically stable structure. (Giacovazzo, 2002). It can be observed that the BG and BT samples, which exhibited high levels of SiO_2 and Al_2O_3, also showed the greatest variation in particle size distribution. This aligns with the role of quartz, as well as chamotte, in reducing the tendency for deformation by promoting a more stable structure. The higher levels of SiO_2 and Al_2O_3 may contribute to enhanced crystallinity and structural ordering, as indicated by the reduced open porosity and grain size variation at higher firing temperatures. BT samples have also shown a relatively low open porosity even at the higher firing temperatures, which suggests that BT has a more compact structure and may be less prone to having large pores after firing. This was further confirmed by the bar deformation test, where both BG and BT samples showed the lowest percentage of contraction, indicating their superior resistance to deformation.

The increase in MgO and CaO at higher temperatures may indicate enhanced mechanical strength and reduced porosity due to improved sintering. The loss of Na_2O and BaO in certain cases suggests their contribution to early-stage melting, which could influence glass phase development in the ceramic body. Colorimetric analysis highlights the effects of thermal processing as well. A reduction in brightness (L*) and an increase in yellow tones (b*) with rising temperatures point to oxidation processes and compositional changes in the fired clay. These shifts are particularly pronounced in the BG and BT samples, which contain higher proportions of alkali and alkaline earth oxides influencing color development during firing.

The role of chamotte in modifying the physical properties of the clay bodies was also significant. As a non-plastic material, chamotte effectively controls shrinkage, enhances structural integrity, and minimizes warping by reducing excessive contraction, a critical factor in achieving uniformity and dimensional accuracy in 3D-printed ceramics.

Among the three clay samples, the densification observed in BT clay, along with minimal shrinkage and a smooth microstructure, positions it as the most suitable candidate for high-temperature applications requiring durability and strength.

Beyond these scientific findings, this research also explores the broader implications of 3D printing in ceramic fabrication. Digital fabrication introduces a new set of possibilities that complement traditional ceramic techniques rather than replacing them. The integration of 3D printing with conventional methods expands both the creative and functional potential of ceramics. This study demonstrates that 3D printing in clay is not a substitute for the rich tradition of handmade ceramics but an innovative tool that enhances material understanding and process optimization, leading to more efficient material selection, reduced costs, and targeted experimentation.

The integration of XRD, XRF, microscopy, granulometry, and colorimetric analysis has provided a multidimensional perspective on how different clay compositions respond to thermal treatment. The findings suggest that controlled thermal processing enhances phase stability and mechanical integrity, rendering these materials suitable for both artistic and industrial applications. Future research should focus on refining firing conditions, optimizing material formulations to mitigate cracking during drying, and exploring advanced sintering techniques to enhance the performance of 3D-printed ceramics. Additionally, technical aspects such as nozzle size, layer height, infill patterns, print speed, air pressure, and flow dynamics warrant further investigation, as they significantly impact printing precision and structural integrity. Overhangs remain a particular challenge, requiring innovative solutions to improve the overall feasibility of clay printing. Another crucial factor is printing time, for instance, a 40 cm × 12.5 cm × 40 cm piece takes a minimum of four hours to print with a 2 mm nozzle, with increased speed compromising detail. These challenges underscore the need for continued research, and while this dissertation marks the completion of this phase, I am eager to further explore these topics and contribute to future advancements in the field.

My goal is not to change ceramics, but to introduce and explore another possibility, to deepen my understanding, and to share this knowledge with others. I can proudly say I have contributed to making 3D clay printing more known and accessible, and I intend to continue doing so.

Through this research, I have filled a gap in my knowledge of 3D printing in clay. While I do not claim to know everything, I have taken meaningful steps forward. There is still much to learn, not only about clay and its behavior but also about the technical aspects of 3D modelling and printing. Looking ahead, I have many experiments and ideas I want to explore.

There are different approaches to working with this technology. Some prefer to follow strict guidelines, ensuring that every step aligns perfectly with technical specifications. While I respect the machine and its constraints, I do not limit myself to rigid rules. If an idea seems feasible, I will test it. I value a creative approach that is informed by scientific and technical knowledge. Understanding clay types, analysing technical data, and running practical tests allow me to predict which materials will succeed and which will likely fail, saving both time and cost.

Ultimately, this balance between technical precision and creative exploration is what drives me. With each experiment, I refine my process and expand my understanding, ensuring that 3D clay printing continues to grow as a viable and exciting medium.

There are different types of people, the ones who like to do everything as if they were following a guidebook, all the corners, all the specifications of printing, everything made “right”.

I respect the machine, I respect the specifications, but I don’t stop myself from improvising and make it work how I want. If I think about a possibility and sounds feasible, well I’m trying it out.

A creative approach while gathering the necessary tools from the scientific and technical is all I wanted. To understand what type of clay I should go for, looking at the technical sheets and after some tests, to know what type of clay will most likely fail and what won’t. This is extremely relevant in order to save time and having less costs.

4. ALL TOGETHER

So, bringing everything together, I paused for a moment to reflect on how the scientific data I studied, and the artistic process relate. Why was it so important for me to deeply understand the material, to grasp its behavior, its limitations, and its possibilities?

Because knowing the material could save me time and resources, with less waste and more certainty. Certainty about which temperature I should fire at to obtain a specific color I envision in my exhibition space. From the beginning, I knew I did not want to glaze my pieces, it was a deliberate choice, so I needed precision in the color tones and texture details I wanted to achieve. Not glazing also means one less layer of impermeability. If I choose to integrate water or plants into my final pieces, I need to ensure their porosity and impermeability align with my intentions.

I have come to realize that studying all of these aspects in the beginning allows me more possibilities and confidence in my improvisations. This approach not only provides technical control but also enhances my artistic freedom. Understanding the material at a deeper level allows me to make informed choices without feeling constrained by material or technical unpredictability. Rather than imposing rigid guidelines, my research has granted me the ability to adapt, to experiment with confidence, and to allow the material itself to participate in the creative process. It has become a dialogue between knowledge and intuition, between structure and spontaneity.

Regarding the technical aspects of 3D printing with clay, there is still much research to be done and documented. The field is constantly evolving, and new possibilities are emerging. In this dissertation, I focused on what best suited my needs and desires, acknowledging that this is only the beginning of a much larger exploration. Perhaps I will continue to delve deeper into these matters, expanding my knowledge and refining my practice. But for now, time and pages have reached their limits, and we all know those constraints well. Yet, within these boundaries, I have found new ways to push forward, to challenge, and to create.

Thank you for accompanying me in this moment of reflection and discovery.

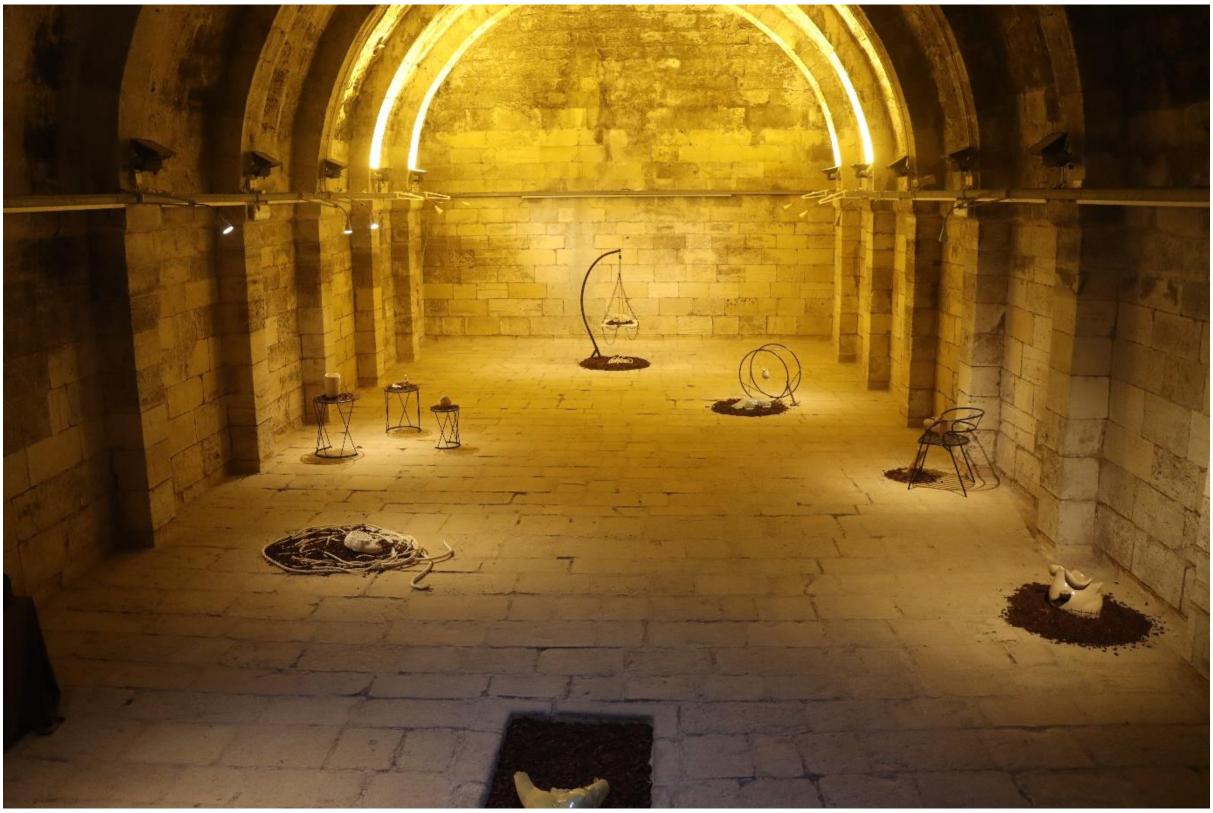


Figure 4.1 and 4.2 - Visceral Bodies Exhibition, 2025

Figure 4.3 and 4.4 - Visceral Bodies Exhibition, 2025

Figure 4.5, 4.6 and 4.7 - Visceral Bodies Exhibition, 2025

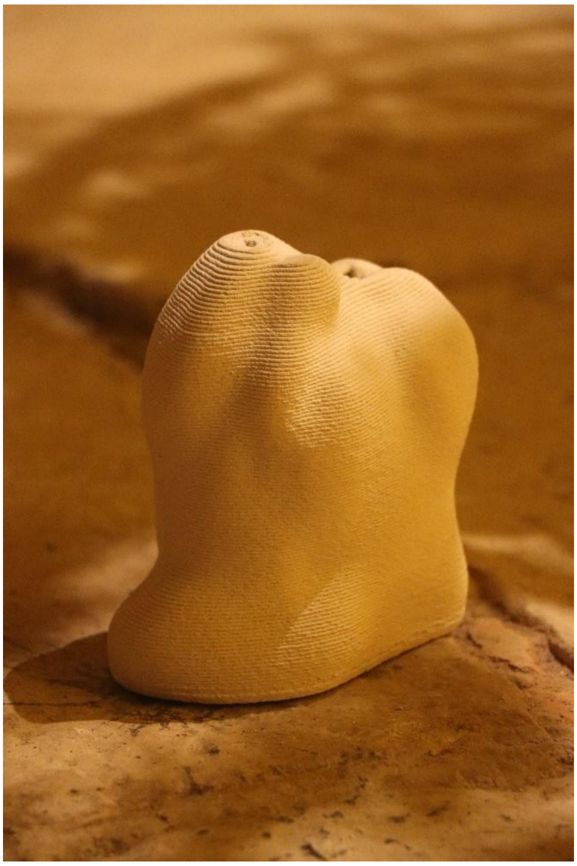


Figure 4.8, 4.9 and 4.10 - Visceral Bodies Exhibition, 2025

Figure 4.11 and 4.12 - Visceral Bodies Exhibition, 2025

Figure 4.13 - Visceral Bodies Exhibition, 2025

Figure 4.14 and 4.15 - Visceral Bodies Exhibition, 2025

Figure 4.16 and 4.17 - Visceral Bodies Exhibition, 2025

Figure 4.18 and 4.19 - Visceral Bodies Exhibition, 2025

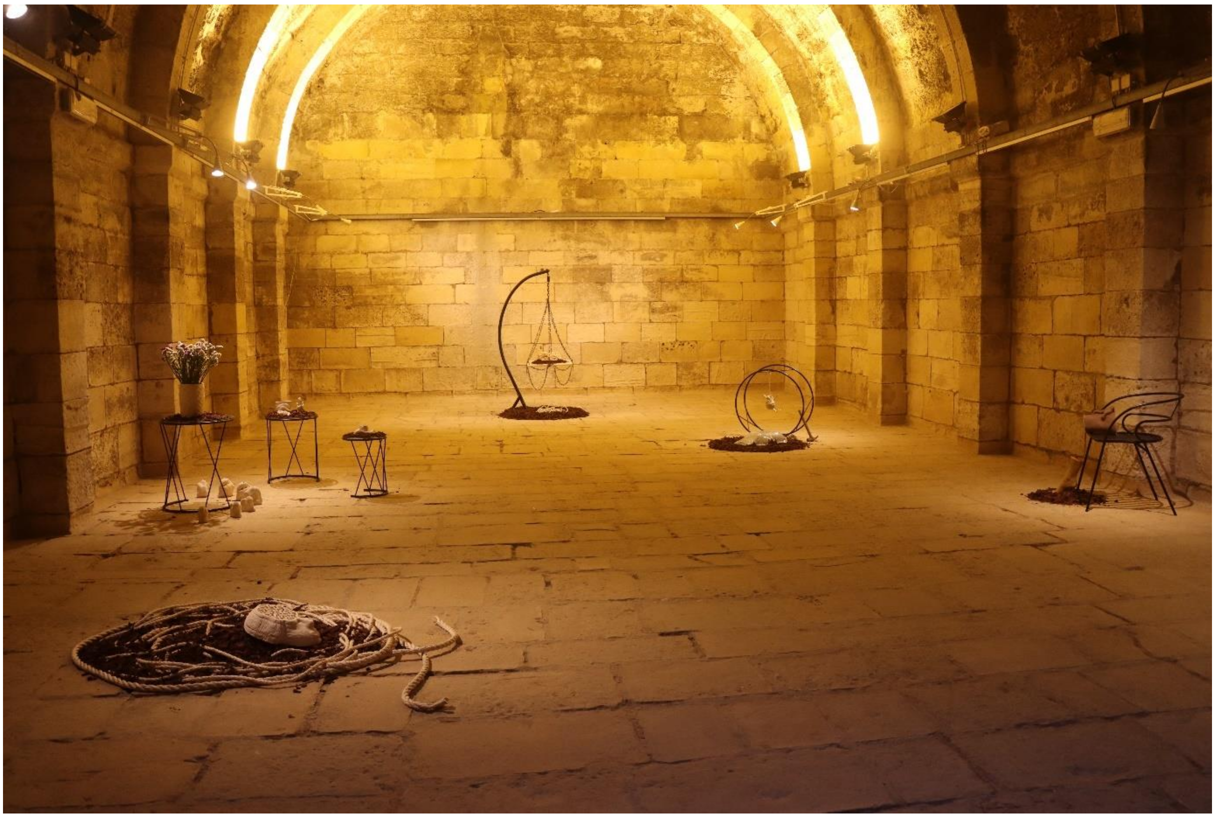


Figure 4.20 - Visceral Bodies Exhibition, 2025

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