Unmaking Abstractions

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Reader's guide

This text is the main written component of the artistic reflection in the PhD research project *Unmaking Abstractions*. It introduces and reflects on the PhD project, providing an overview of its various parts. Additional components of the artistic reflection are presented in an exposition on the artistic research database *Research Catalogue* (hereafter RC). This exposition also contains a presentation of the artistic result in the form of documentation.

Contents

Overview of the RC exposition and the artistic reflection

The exposition on RC includes a presentation of the artistic result in the form of documentation. This documentation is accessible on the *Artistic Result Page* which can be reached from the exposition's landing page by clicking the center square of the unfolded cube. The exposition also includes the artistic reflection, presented on five different pages that can be accessed by clicking the other sides of the unfolded cube.

Artistic Result Page
Documentation of the artistic result and how it was disseminated to the public. This page contains the PDF *Documentation of Artistic Result*, the video *Documentation Two Rocks Do Not Make a Duck* as well as screen recordings of the YouTube tutorials that are part of the artwork *Holder*.

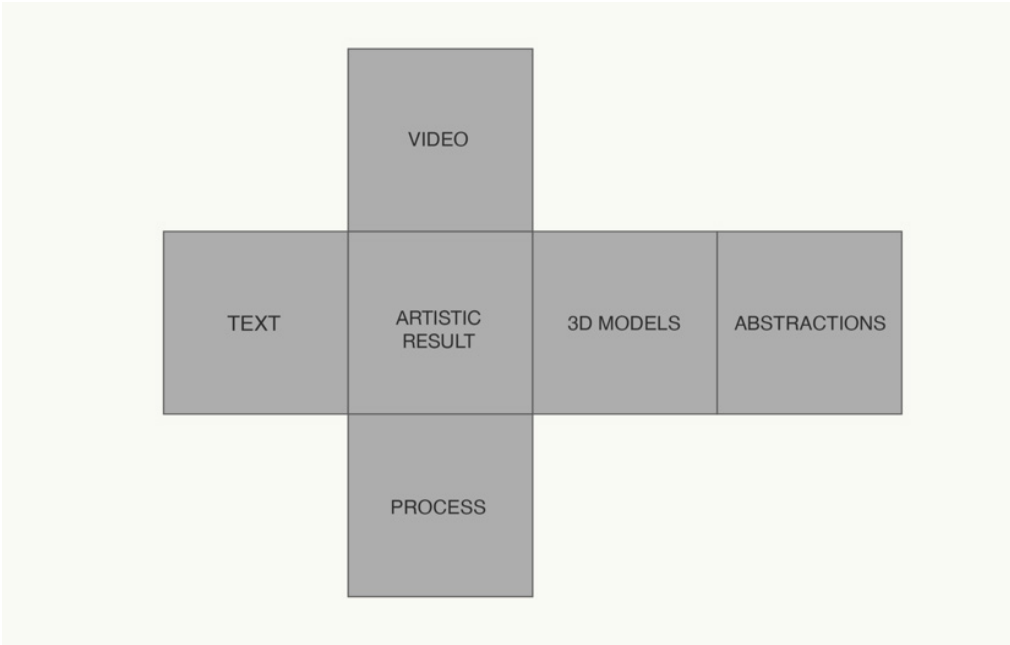
Text page
Unmaking Abstractions (this text), *Questions for YouTubers* and "Simulating Seasons in virtual reality".

Process page
Images of work in progress, studio visits, workshops, lectures and seminars.

Video page
Recorded video conversations, work in progress videos from *Secret Support* and *Explode Mesh* and recordings of the *Open Studio* live program at Entrée.

3D models page
Screen recordings of 3D models.

Abstraction page
Excerpts from texts on abstraction that I have returned to several times in this project, written by philosophers, art historians and media theorists.



Introduction

Synopsis

In my artistic research project *Unmaking Abstractions*, I explore the nature of abstraction in 3D modeling technology. Today, 3D modeling technology has a transformative impact across various fields, including art, architecture, design, manufacturing, healthcare, media, and education. It shapes how people work, what is created, and how we perceive and interact with our surroundings. This technology operates through multiple layers of abstractions, with its use involving numerous abstraction processes. In this project, I use artistic processes to examine the relationship between 3D modeling and these abstractions, guided by the following questions: 1) What is abstraction in 3D modeling? 2) How does it function? 3) How do abstractions in 3D modeling co-evolve with their contexts?

3D models are digital representations of forms in simulated 3D space. As a sculptor working with 3D modeling tools, I approach my area of research from the perspective of three-dimensional form-making. This project positions itself in the intersection between art movements focused on abstraction such as Neo-Concretism, and technology-oriented contemporary art. The main artistic outcome of this PhD project is the aluminum sculptures *Secret Support*, the interactive sculptures and YouTube tutorials *Holder*, the augmented virtuality artwork *Two Rocks Do Not Make a Duck*, the parametric *Interior for Entrée* and the two-part public presentation of the artistic research project taking place at Oseana Kunst og Kultursenter and Entrée.

Working with 3D modeling technology I have encountered processes of abstraction, systems for abstractions and ready-made abstractions. To learn about these intricate layers of abstractions I follow a method I call unmaking. This is a sculptural research approach in which my aim is to bring the abstractions, which appear to be immaterial or difficult to see for other reasons, into a form that can be experienced in an embodied manner by myself and by others. A central approach to unmaking in this project is the translation of forms between screens and physical objects. In this text I will give written accounts of this working method and the aspects of abstraction in 3D modeling which have become visible from it.

By employing sculpture both as a research method and a presentation format, this project seeks to make more visible and concrete, some of the abstractions in 3D modeling technology that take part in shaping working methods, environments and perceptions.

Artistic background and interest in abstraction and 3D modeling

My interest in abstraction developed from how early on in my practice I let tools, materials, spaces and context lead the way in a process-oriented workflow. For example, I might start out with an interest in a topic, and then gather materials, modify them with tools and arrange them in different configurations. The materials, tools and spaces could be related to the topic I was interested in exploring, or just a means of researching something using a hands-on, sculptural approach. The results were often unexpected and unplanned, emerging through the process itself.

This method gradually evolved into a creative strategy that seemed effective, even if I did not initially understand why. Wanting to explore this further, I began to reflect on how my bodily senses shape my perception of, and interaction with, the environment, and how the material, technical and spatial environment itself acts as a force contributing to the creative process. This led me to appreciate embodied engagement as a foundation for human perception and understanding, and sparked a deeper curiosity about how sensory experiences are transformed into abstract concepts. This became a recurring inquiry in my artistic practice and formed its main thematic pillar. It also drew me to the philosophical framework of phenomenology, which I will address in the section titled "Theoretical Frameworks".

When abstractions are made, some qualities are included while others are discarded. Much of the experience and context that was there to begin with is no longer present after the abstraction process. The root of the Latin word "Abstrahere" means to draw away. Based on this, and on how I use this word in my sculptural work and everyday life, I consider the term

"abstraction" to refer to both a process and the result of this process. Something is extracted out of something else, and the result of this action is an abstraction. Which qualities are extracted depends on what perspectives we use. Humans employ different frameworks for abstractions, like mathematics, geometry and the natural sciences, as well as language, economics and public policy. These frameworks and structures can be used both to reduce something complex into something simpler, and as building blocks to create new things. N. Kathrine Hayles refers to these two "moves of abstraction" as the "Platonic backhand" and the "Platonic forehand" explaining that "The backhand goes from noisy multiplicity to reductive simplicity, whereas the forehand swings from simplicity to mulilicity [sic]" (How we became posthuman : virtual bodies in cybernetics, literature, and informatics, 1999, pp. 12,13). I adopt the terms "Platonic backhand" and "Platonic forehand" several times in this text. The source of these terms is quoted on the *Abstraction Page* of the artistic reflection. Hayles does not explain why she uses the term "Platonic", but I understand it to echo Plato's philosophy, where ideal forms (simplicity) are contrasted with their messy, imperfect manifestations (multiplicity).

In the essay "Abstraction and Culture", the American painter Peter Halley notes that "the model, that is to say the abstract model, takes precedence over the specific in all areas of contemporary life. Thus, in the academic world, the psychologist, the economist or the sociologist seek to establish the existence of generalized patterns of behavior that then act as a lens through which to view specific incidents". (2013). Mathematical models, legal frameworks, architectural blueprints, and financial systems are not neutral, but are shaped by the structures applied to create them, and by the contexts in which they are being used. Furthermore, they influence how people work, what they make and how individuals perceive their surroundings.

What abstractions are, how they are used, how they appear to people and how they affect us are of course different for different people. But the ability to "abstract from specific situations to formal representations" is a human capacity shared across people of different ages, cultures and times, which to me makes it a meaningful area of research (Hayles N.K., Unthought: the power of the cognitive nonconscious, 2017, p. 12). In a recorded video conversation between me and programmer Gustav Tresselt, available on the *Video Page* of the artistic reflection, he speaks about how the term abstraction is used within programming, and how abstractions take part in shaping 3D modeling tools and virtual worlds. The conversation also shows how language, and the term "abstraction" itself is an abstraction, changing meaning depending on context. On the *Abstraction Page* of the artistic reflection, I have included text excerpts on the topic of abstraction that have influenced my own thinking on the subject (including the ones by Hayles and Halley mentioned above), and which I have revisited repeatedly during the development of this work. These excerpts also appear in various sections of this reflection, providing insights into specific works, processes, or contexts being discussed.

Abstractions that are engrained in everyday life can be hard to see, as can the effects that they have. Technological development brings about new kinds of abstractions that are often opaque and hidden from our view. I have found that working with sculpture can make these abstractions visible, and as such contribute to a richer understanding of abstractions that are shaping the world today. I will address this further in the section "Unmaking" below.

Working with 3D modeling technology I have encountered processes of abstraction, frameworks and structures for abstraction, as well as ready-made abstractions. In abstraction processes, for example in laser 3D scanning an object, certain elements become extracted out of an object's whole and translated into a different materiality and context, leading to changes in form, function and meaning. Systems for abstraction – such as the coordinate system, basic geometric shapes, polygonal meshes, mathematical principles, and code – can be applied to simplify complex forms (the Platonic backhand). However, these structures can also serve as building blocks for creating new, complex forms without reference to an original object (the Platonic forehand). In both cases – the structures and building blocks that are put into use (polygonal meshes, code etc) influence which qualities are emphasized, they shape the working process, and define the appearance and function of objects created with 3D modeling technology.

Embedded into the 3D modeling tools I work with, I have come across several abstractions that are already made by someone else, like proprietary algorithms, parametric curves and downloadable 3D models. I call these "ready-made abstractions." The concept of the readymade in art traces back to Marcel Duchamp and refers to a prefabricated object that has been elevated in status by being placed in an art context. The term "ready-made" (hyphenated), however, is a much broader term applying to many kinds of objects that are made ready to use, ready to eat or made to a standard size or specification. I view ready-made abstractions in 3D modeling as mathematical labor-replacing capsules, abstractions that somebody has already made before, that shape how something functions and what can be created.

I first learned 3D modeling on a basic level as a sculptor, initially rejecting it as a technical process that kept me desk-bound in a two-dimensional screen-space, away from the physical making process. But after working with 3D modeling more, I noticed that the

virtual[1] 3D environment was one of the elements shaping my work: The convincing display of objects with volumes on a flat screen allowed me to virtually move around, zoom in on, and see my sculptures from different perspectives before making them. The teapots, rabbits, monkeys and other distinct shapes and aesthetic expressions recurring as standards in 3D modeling software pointed to a technological context that I was curious to learn more about. Through using computer numerical control (CNC) machines and 3D printers, I realized that there was much more to the transition from screen to object than simply clicking a button; movement through different digital and material instantiations could change both meaning and form of the objects I made. When I first tried VR, I found it spatially disorienting, but also fascinating how the virtual environment corresponded with my body's movement. This experience was different to my previous encounters with images on screens and it encouraged me to further explore spatial navigation in VR.

These initial experiences with 3D modeling technology through artistic practice made me curious to learn more about this technology and its underlying abstractions. Through my involvement in establishing Aldea Center for Contemporary Art, Design and Technology together with Cameron MacLeod in 2017 this interest developed into a PhD project in artistic research.

Unmaking

I follow a sculptural method that I call "Unmaking". It is a method driven by curiosity and a search with an unknown end, which does not start out with a statement I wish to make. My goal in unmaking resonates with what art historian Sven Lütticken describes in the essay "Living With Abstraction", in which he writes "The aim is not so much to oppose abstraction with concrete facts; rather, it is to make concrete the omnipresence of abstraction" (2013, p. 148).[2] My aim with this project is not to oppose abstractions in 3D modeling. Rather, it is to explore what these abstractions are and become more familiar with them, because they are difficult to see and difficult to understand, and yet they seem to play a significant role in how 3D modeling technology functions. I believe that making abstractions concrete – by transforming them into physical objects that can be experienced through active sensory engagement – is a distinct opportunity I have as a sculptor, allowing me to contribute to my area of research something that is different from other areas of knowledge production.

I understand unmaking as a process of picking apart and reassembling, in which I use sculpture and other artistic media to examine an abstract concept in a making process. I engage with materials, tools and subject matter and receive sensory input, most of which is not consciously reflected upon but nevertheless leads

me to the next step and shapes the work. It is in this developmental stage that I figure out what the work should be, and that I materialize, and make concrete and visible, the abstractions I am examining.

Many of the abstractions I have examined in previous work are so ingrained in my understanding of the world that I have found them hard to notice and to see past my habitual filter, or my worldview. I find that materializing and spatializing an abstract concept through sculptural practice can help me reorient and see an abstraction with a different perspective. It can teach me something about where this abstraction comes from and help me recognize it in new places in my surroundings. I think of this as a phenomenological approach to artmaking and knowledge production and will return to this idea in the section titled "Theoretical Frameworks".

The most important unmaking method in this project has been to translate between digital materialities and other materialities, for example, from a 3D model to aluminum sculptures, or from wooden sculptures to YouTube instructional videos. In 3D modeling technology abstractions are hard to see because they are part of technical processes and constructions that are hidden from view for those who consume products of 3D modeling, and often also from those working with 3D modeling tools. In this project, unmaking processes have helped me notice some of the different abstractions that 3D modeling is built on and to become aware of what is lost and what is added

1. The contemporary mainstream understanding of "Virtual" is exemplified by the Apple Dictionary (v. 2.3.0) entry for Virtual / Computing: "not physically existing as such but made by software to appear to do so: *virtual images*." I agree with this in the sense that the trees that I see in virtual reality are not trees made out of wood and bark and leaves. But the definition is imprecise. As I discuss in the writing on *Secret Support* and elsewhere in the text, I believe all digital and virtual things must have a material embodiment to exist, and therefore that the definition given above sets up a false binary between the virtual and the physical. When I use the word virtual, I refer to something which is made by software to appear to exist, but that still has its own digital materiality.
2. The essay is published in *Abstraction* edited by Maria Lind (2013), and the quote is available on the *Abstraction Page* of the artistic reflection.

in processes of abstraction. For this reason, I have chosen to elaborate on these unmaking processes in this written reflection.

Unmaking is the part of the process in which I figure out what a work should be and is a process I usually undertake alone. In many cases however, the production of the work involves support from others, as I will describe further on in the section "Collaboration". I aim to finish the solitary unmaking process before the stage of involving others, to be able to give clear instructions, to ensure a mutual understanding of how tasks and responsibilities are distributed, and to keep to a budget and timeframe. To facilitate communication with others involved in producing my work, I often create production plans using 3D modeling tools. At this planning stage, the software actively shapes my creative process and approach. The scale and expertise required to produce my sculptures and installations have, in turn, influenced my practice, moving parts of the creative and developmental stages into a 3D modeling environment. This working approach highlights the importance of understanding the impact of 3D modeling tools, not only for my own practice but also for other creative professionals who use them for exploration, development, design, and planning.

My intention is for the results of my artistic research PhD to offer viewers insights I have gained through making the work. Some artworks in this project are therefore made to encourage viewers to become active participants in the processes I experienced during the development of the work. For example, in the *Holder* YouTube tutorials I include online audience and gallery visitors in the process of designing and fabricating sculptures. The work also includes interactive sculptures designed as holders for color samples, welcoming the audience to experiment with color combinations in a way similar to my own process in the studio. In *Two Rocks Do Not Make a Duck* the viewer becomes an active participant engaging with rock-shaped sculptures to find their own way through a new kind of environment composed of sensory input from both virtual and physical objects. My aim to include other people into my own processes of learning about 3D modeling technology is also exemplified by the three workshops I have developed and organized throughout this project, where I teach other artists to work with 3D modeling tools, sometimes using my own artwork as learning examples. The comprehensive descriptions of how the work is made in this text are yet another effort I have made to include an audience in an unmaking perspective.

Aldea Center for Contemporary Art, Design and Technology

In 2018 I established Aldea together with Cameron MacLeod. The start-up phase coincided with the beginning of my research project, which has become shaped by growing alongside and inside this organization. Throughout this text I will return to some of the courses, artists, machines, working processes and collaborations at Aldea that have shaped this PhD project and given me a broad understanding of how 3D modeling technology can be used in artistic practice.

Aldea consists of a studio collective, a gallery space, an international residency program, as well as the region's largest open workshops for working with wood, metal and digital fabrication. My own motivation for starting Aldea was a pragmatic one. During art school in Stockholm, I had built up a sculptural practice of unmaking based on having access to a wide range of professional production equipment. After completing my studies and returning to Bergen, it was not possible to continue this practice without building the workshops that I was missing myself and that were lacking for the creative field in Norway's west coast region.

The artistic direction for Aldea was staked out by my partner and co-founder Cameron MacLeod, who has been the director of the organization since its inception. Informed by Cameron's own artistic background, Aldea's activities, efforts and resources are focused on the relationship between art and new technology. Aldea's approach emphasizes that the unique way artists can contribute to a discourse on this relationship is to work with and explore the technologies in question. A focus for Aldea is therefore to provide production equipment, to research new technological production methods and to share both knowledge and artistic outcomes with the field of contemporary art and with the public, both locally and internationally.

A key component of Aldea's workshops is the digital lab, which has been built up to include 3D printers, CNC machines for wood and metal, a laser cutter, specialized computers, hardware and software for work with VR (virtual reality), CAD (computer assisted design),

photo: Kjersti Kvile

Artificial Intelligence and more. Knowledge about how to use the equipment is shared with Aldea's users through public courses, individual training and by assisting artists, designers and other creative professionals in the production of new work. Aldea's gallery program mainly consists of exhibitions made in our workshops by artists exploring new production techniques, guided by Aldea's workshop technicians.

For my PhD-research Aldea was a defining context as well as my place of work. My direction for what to examine next emerged from being immersed in this environment – learning from experts, working directly with the machines, and observing other artists as they developed new works and practices. Elements of Aldea's physical infrastructure have been a direct inspiration for artworks in the research project. My knowledge and interest in 3D modeling and digital fabrication grew rapidly while attending, developing and organizing courses that broadened my technical and conceptual understanding of these tools. My role at Aldea after the initial start-up phase was mainly limited to writing grant applications and reports. I gradually shifted from building Aldea to using its resources to sustain my practice and to carry out this artistic research project. Every artwork in my PhD-research was made in the workshops and my studio at Aldea, often supported by Aldea's staff and expert users.

Collaboration

Throughout this project I have worked with people who have contributed with various levels of commitment and agency.[3] A consequence of my open-ended unmaking method is that I am a generalist and not a specialist when it comes to making sculptures. The techniques and materials I work with are often new to me and of such variety that I cannot be a specialist in all of them. At times, I need a higher degree of precision than a more open-ended unmaking process allows for, and so I hire experts to do certain jobs. I also need support from others because my sculptures and installations are often too large, both in size and the amount of labor needed to produce them, to make them alone. In such cases I take the role of making a production plan, overseeing the work while participating as part of a production team where I have the necessary competency to do so. The *Process Page* of the artistic reflection documents many such production settings, in most cases including people hired through Aldea.

In some of the working processes I leave certain decisions up to others. For example, when making the *Holder* YouTube videos I have asked the instructors to maintain their usual format and aesthetic expression, while giving precise instructions on which procedural steps the video should include. In the public program at Entrée, I invited people to reflect on topics relevant to my research while leaving it up to the contributors themselves how to approach these topics and in which format. *Two Rocks Do Not Make a Duck* is a collaboration made with Cameron MacLeod where ownership of the artwork and artistic agency is shared between us.

Art context

Unmaking Abstractions is an artistic research project that does not sit comfortably within one single tradition of contemporary art or art history. Rather it exists in dialogue with, and is inspired by, artworks and artistic practices spanning across a range of artistic traditions, approaches and movements. What links these artists more than their assigned label is that they are dealing with specific concerns relevant to my research: the relationship between abstract information, material instantiation and embodied experience; the relationship between abstractions, context and meaning; the way technological tools influence ways of seeing and how things are made.

When I address the individual works of this project later in this text, I have chosen to single out some of the movements, artists and artworks where these concerns are dealt with in a manner that has inspired and contributed insights to the specific work I am addressing. In the following text section, I will introduce some of this artistic context and how it relates to my area of research in broader strokes. I have organized this into two parts: the first addresses artists working with abstraction and the second looks at contemporary artists working with new technology.

The Neo-Concrete movement in Latin America has been the strongest art historical anchor for this research project. This movement's influence on my work can be seen clearly in *Holder*, in the exhibition architecture made for my exhibition at Oseana and in my *Open Studio* at Entrée. The Neo-Concrete artists' focus on sensory engagement and interactivity through geometric visual expression, their interrogation of surface, planes and volumes, as well as into how infrastructures shape perceptions, lays an important formal and conceptual foundation for this research project.

In the Neo-Concrete manifesto, a group of Latin American artists including Lygia Clark, Hélio Oiticica and Lygia Pape take a new stance to geometric art. They distance themselves from concrete art[4], which they

3. In all these forms of collaborations my ethical standpoint is to make clear from the beginning what both sides expect. For example, what someone will get paid, what I will do with the resulting artworks or documented events, and how agency and ownership is distributed. This is agreed upon at the start of a project and in several cases in written collaboration agreements.
4. "Concrete art is abstract art that is entirely free of any basis in observed reality and that has no symbolic meaning. The term was introduced by Theo van Doesburg in his 1930 *Manifesto of Concrete Art*.(…) He stated that there was nothing more concrete or more real than a line, a colour, or a plane (a flat area of colour). (Tate, 2024)

consider having become "dangerously rationalist extreme" (Castro, et al., 2013, p. 70). They reject the idea that forms constitute a universal language and claim that "Rationalism deprives art of its autonomy and replaces the non-transferable qualities of the artwork with notions of scientific objectivity" (p. 71). Instead of universality and rationalism, this group of artists advocates for a participatory and embodied approach to art where subjective, sensory engagement is in focus. I build upon these principles in my artistic research by exploring how the qualities, functions, and meanings of an object change when its form is converted into numerical data.

Similarly, I share with the Neo-Concrete movement an interest in how humans and the structures we create mutually influence one another. For Neo-Concrete artists, the emerging modernist cities of post-World War II Latin America – often built on geometric grids and patterns – became a key motif. Like 3D modeling technology, these cities were shaped by technical and geometric structures, influencing human experience in turn. While many aspects of the modernist city were not designed to accommodate flexible, co-creative engagement by its users, the Neo-Concrete movement's rejection of modernism's universalist impulse can be seen as a resistance to the idea that everyone could conform to the same spaces and routines, instead engaging with and exploring the new urban environment through their artistic practices, sometimes with implicit critiques.

The influence of phenomenological thought on the Neo-Concrete movement is expressed in the references their manifesto gives to this philosophical framework.[5] They call artworks a "being (…) that only reveals itself by a direct phenomenological approach" (Castro, et al., 2013). I understand this approach to mean that the artwork itself emerges as a meeting between object and participant. In the "Theoretical Framework" below I will discuss how I consider both my unmaking method as well as the presentation format of my work to be based on a phenomenological ground that I share with the Neo-Concrete artists.

Phenomenological approaches to art and interrogations of abstraction and embodied perception were key also to minimalist and land art practices in the United States and Europe, coinciding with and coming after the Neo-Concrete movement in Latin America. When I use the term "spatiotemporal" in the descriptions of my own work, I think of this as a legacy from artists working within the movements of Neo-Concretism, minimalism and land art. Their sculptures and installations were made to be moved through and past, and to experience how these objects and environments change as they were seen from different perspectives. In this way these works of art highlight how human perception and experiences are bound to body, time and place. For example, American artist Nancy Holt's *Sun Tunnels* (1973–76) consists of large-scale concrete tunnels placed in the Great Basin Desert of Utah. They are aligned to make the sun shine through them on summer and winter solstice. In that way the installation enables an embodied experience of what is otherwise an abstract, scientific fact – that the Earth has reached its outermost points in its elliptical orbit around the sun. I think this work is a good example of the purpose of both examining and mediating abstractions though art, an approach I strive for in my own practice. Holt is not making a new, scientific discovery about the Earth's orbit around the sun. Instead, she makes the precise, geometric alignment of the Earth and the sun – an event that occurs within a brief time frame and is often understood in a vague and disembodied way – visible, tangible, and concrete.[6] [7] Similarly, for me, I think that what I can contribute as a sculptor examining abstractions in 3D modeling technology is to make them possible to experience through a focused, embodied, and sometimes interactive engagement.

My artistic practice and my research project is one of many instances where contemporary artists build on art historical legacies to continue exploring abstraction. For example, a selection of these practices could be seen in the *NNA* (Ny Norsk Abstraksjon) exhibition that I took part in at the Astrup Fearnley Museum in Oslo in 2015. This exhibition was part of a series of events that occurred around a decade ago, during a period of renewed interest in abstraction within the Scandinavian art scene.

Swedish curator Maria Lind contributed to this resurgence of abstraction in contemporary art through the curatorial project *Abstract Possible*[8] and through editing the book *Abstraction* (2013). This anthology brings together contemporary artistic practice, art

5. They refer to the French phenomenological philosopher Maurice Merleau-Ponty twice, emphasize concepts at the core of phenomenological thinking and use the word "phenomenology".
6. Many people have an embodied understanding of the Earth's position in its orbit around the sun, albeit most of us not of its precise geometrical relations. For example, most cultures have ceremonial celebrations close to summer solstice and winter solstice (in Scandinavian culture the "Sankthansbål" and celebration of Christmas). People do also notice and experience seasonal changes caused by the Earth's position in its orbit. CALENDARS is a research group at UiB that examined how people perceive and effect seasonal patterns in different communities. Throughout this research project I have collaborated with this group on several occasions, including writing the text "Simulating Seasons in virtual reality" for the book *Changing Seasonality: How Communities are Revising their Seasons*, also available on the *Text Page* of the artistic reflection.
7. Another example of spatiotemporal work can be seen in Brazilian artist Lygia Pape's work series *Ttéia* (1991-), made of groups of golden and silver strings attached in diagonal angles across spaces, such as from floor to ceiling. The groups of thread delineate volumes that change along with the viewer's movement through space.
8. The Abstract Possible project consisted of multiple exhibitions and events across several venues in 2012, including "Formal abstraction" presented at Tensta Konsthall, "Social Abstraction" pesented at the Center for Fashion Studies at Stockholm University and "Economic Abstraction" at Bukowskis auction house.

history, curatorial approaches and theoretical reflections on abstraction. Both the book and the curatorial project explore what Lind considers to be three main strands of abstraction – formal abstraction, economic abstraction and social abstraction – and demonstrates some of the richness and span in approaches to abstraction in art. Under the category of formal abstraction, the anthology presents texts such as Alfred J. Barrs seminal "Cubism and Abstract Art" comparing the work of artists including Kazimir Malevich and Wassily Kandinsky with the work of Hans Arp and Pablo Picasso. Barr uses the term "pure-abstraction" to describe artists who make pictures without reference to another object, and "near-abstractions" to describe those who create an abstracted version of an existing object – a distinction reminiscent of Hayles' comparison between the Platonic backhand and the Platonic forehand.[9]

Other texts in the "Formal Abstraction" chapter include the aforementioned manifesto of the Neo-Concrete movement. In the chapter on "Social Abstraction" Lind has gathered text on artists whose act of abstraction is a withdrawal from society to create micro-utopias as acts of resistance. Two of the essays presented in the section "Economic Abstraction" have been important for my own understanding and perspective on abstraction in art.[10] Excerpts from the first one of these, "Living with Abstraction" (2013) by art historian Sven Lütticken appears elsewhere in this text and on the *Abstraction Page*.

In the second of these texts, "Abstraction and Culture" (2013), Peter Halley draws connections between abstraction, epistemology, art and technology, and makes the important point that abstraction in art must be understood in context with the forces of the society in which it exists. He discusses abstraction in economy, science, psychology and biology and points out that abstraction in art is "simply one manifestation of a universal impetus toward the concept of abstraction that has dominated twentieth-century thought" (p. 138) and that "(…) to limit our understanding of the meaning of abstraction (or anything else) to an incantatory recital of its own formal history is a denial – a denial of the myriad connections between culture and other histories and between the artist and the world." (p. 137)

Halley highlights technology as one of the areas in which the phenomenon of abstraction is reflected in contemporary society and claims that "technology in this century has essentially separated itself, step by step, from any relationship to what is commonly thought of as nature" (p. 140). He refers to examples such as how "We take it for granted that we can speak with someone halfway around the world or that it takes just a few hours to travel thousands of miles." (p. 140) pointing out that "Such disjunctions in space and time have also created a world that is both malleable and free from natural referents" (p. 140). Using examples of a middle-class person in the United States or Europe who live in sealed houses, travel in sealed environments of automobiles along abstract pathways of the highway – Halley reminds us that "When one speaks of abstract art, it is essential to remember that it is only a reflection of a physical environment that has become so essentially abstract" (p. 141). A reflection on this topic from the perspective of architecture was presented by sociologist Gabriele de Seta as part of the live program at Entrée, one of the main public presentations of my PhD result. In his lecture, "On Infrastructural Abstraction: Models, Algorithms, Parameters," de Seta draws on Luciana Parisi's theoretical insights from her book *Contagious Architecture* to explain how parametric design in architectural engineering have been used to construct environments that parallel the abstract spaces described by Halley.

My practice draws upon the legacies of artists who engaged with abstraction, each responding to the distinct contexts and eras of their time. Bringing this enquiry into the area of 3D modeling technology, my artistic research project is also situated in a context of contemporary artists who explore the effects of technology on society. Like many of these artists, my research is an artistic exploration of the technology in question. This art context is not a clearly defined field labeled with a movement's name, but rather an area of focus in contemporary art that has become more prominent during a period that overlaps with the timeframe of my artistic research. I consider several projects I have taken part in during this timeframe to be a part of this context. In 2019 I participated in the *Digital Promises* thematic group residency at the Banff Center in Canada. The program was led by artists Fatima Tuggah and Jon Rafman, whose guiding framework for the group was to explore societal effects, hopes and dreams, broken promises, affordances and implications of various digital technologies. The artwork Cameron and I started developing in this residency was later shown in *The Machine is Us* Triennale at the Munch Museum in 2022, a group exhibition featuring artists exploring society's digital transformation.

I believe Aldea makes significant contributions to research, development, and public discourse on the intersection of art and new technology, both within Bergen and internationally. As such, I view Aldea as a vital part of the artistic context in which I am engaged and which I have contributed to building. Many of the results from Aldea's efforts are presented to the public in Aldea's gallery program. Several of the artists that I address in this reflection text have attended Aldea's international residency program, prepared for an

9. "The backhand goes from noisy multiplicity to reductive simplicity, whereas the forehand swings from simplicity to mulilicity [sic]" (Hayles N. K., How we became posthuman : virtual bodies in cybernetics, literature, and informatics, 1999)
10 Excerpts from the second of these, Sven Lütticken's "living with abstraction" is presented elsewhere in this text and on the *Abstraction Page* of my artistic reflection.

exhibition or worked in the workshops. They have made work that contributes to extending contemporary sculptural practice by means of digital fabrication tools and other making methods involving 3D modeling technology. Aldea is part of a larger, global movement of public workshops specialized in digital fabrication that have emerged in many places in the world since the early 2000s, which I will briefly address in the next section of this text, "Technical context – 3D modeling".

Technical context – 3D modeling

The field of 3D modeling technology is rapidly changing. The sculptures, workshops and research done in *Unmaking Abstractions* examine abstraction in 3D modeling technology in the period 2018–2022.

To make a digital 3D model is to use specialized software to create shapes in simulated 3D space. This object, which I refer to as a 3D model without the prefix digital, is built on layers of mathematical abstractions, and it enables multiple abstraction processes. 3D modeling technology is used by artists, architects, designers, and professionals in the industries of engineering, product design, manufacturing, film production and game design, to mention a few. The impact of this technology on both established industries and the creation of new ones is difficult to overstate. For artists, it introduces new methods for developing and planning artworks, facilitates new possibilities in mold-making, casting and sculpture creation, and enables entirely new artistic formats. I will discuss these working methods and techniques throughout this written reflection. Architects and designers rely on the precision and adaptability of 3D modeling technology to collaborate within shared digital environments, visualize projects virtually, and create physical models for presentations. In areas like engineering and manufacturing, 3D modeling supports advancements in prototyping, and small-scale production, where accuracy and customization are essential. In the film industry 3D modeling technology has led to vast changes, for example by replacing costly physical scenography with virtual environments.

Which profession you work in and what you are trying to create determines what kind of 3D models, software systems, hardware, production machines and workflows you employ, as well as which abstractions these technical systems are built on. In this project I have worked mainly with 3D modeling workflows directed towards physical production. All the artworks I have made have employed digital fabrication, which means that something has been produced by feeding input from a computer to a machine, for example 3D printers or a CNC machine. I examine abstractions in several components of the 3D modeling ecosystem; the 3D models themselves, software systems, platforms for online learning communities, machines and hardware used to capture information or fabricate 3D models and more. My project does not intend to give a rigorous, technical overview of all the abstraction processes and ready-made abstractions that I have encountered in this project. Instead, I address those abstractions that have come to the fore through, and affected, the unmaking processes I have undertaken. I aim to make these tangible and concrete by focusing on them in the making process and by enabling a physical encounter with the results of these examinations.

The technological context most crucial for my project is Aldea, whose digital fabrication workshops are part of a larger global movement toward open-access workshops aimed at making these production techniques more widely available. Fellesverkstedet in Oslo has a key role in the Norwegian segment of this field. They generously supported Aldea by sharing knowledge with us throughout our establishment phase, and later by being important conversation partners. The world-wide growth of workshops such as Aldea and Fellesverkstedet was stimulated by the MIT's Center for Bits and Atoms, an interdisciplinary initiative exploring the boundary between computer science and physical science (2024). Headed by Neil Gershenfeld the center launched the FabLab concept in 2001. A FabLab is a small-scale fabrication lab using digital fabrication tools, aiming to democratize access to advanced production equipment. Today there are several FabLabs around the world, an overview of which can be seen in industrial designer and Fellesverkstedet co-founder Jens Dyvik's video documenting his visits to several of these around the world[11]. While many FabLab-like workshops are set up as makerspaces for hobbyists as well as creative professionals, this movement has had a notable impact on artistic practice, particularly in the field of sculpture. Sculptors often produce unique physical objects and work with production teams, communicating through digital drawings. Digital fabrication machines aid in making sculptures by allowing precise prototyping and small-scale production, while also influencing the nature of the work itself. Later in this text, when I discuss the impact of 3D modeling technology on sculptural practice, digital fabrication will play a key role.

Theoretical frameworks

Before discussing the individual artworks, I will outline some theoretical frameworks that have guided my perspective in this research project.

From early on in my practice I found resonance in phenomenological perspectives when thinking about

11 The video can be seen on https://drive.google.com/file/d/0B8t_s65R-GJNUTVVRml4dGRDNUE/view?usp=sharing&resourcekey=0-2XXSCGcpZ36XEAuiiiFyzQ

human perception, body, movement and space. Phenomenology is a philosophical framework that emphasizes how the world is experienced, understood and engaged with by humans through embodied perception and interaction. I consider my unmaking process, my spatio-temporal sculptural work and my aim to include the viewer as a participant as phenomenological approaches to art and knowledge production. I believe a phenomenological approach offers a valuable lens for viewing artistic practice, and artistic research, as impactful and distinctive ways of engaging with, and understanding, the world through sensory-based, embodied experiences.

As described in the previous sections "Unmaking" and "Artistic background and interest in abstraction", my unmaking process is based on material and embodied encounters with elements, and on reflections on these encounters. This practice led me to think more broadly about embodied perception as a basis for understanding, and on the relationship between embodied knowledge and abstract knowledge. Several of my previous works were motivated by curiosity about how scientific facts sometimes seem to contradict my lived experience. For example, it looks like the Earth is flat and that it stands still, while it is a scientific fact that it is a round globe spinning through space with enormous speed. The public sculpture *Parallell* (2015) and video *Distance to Horizon* (2016) are two works I made in an attempt to bridge my experience of the planet's shape and movement with the scientific abstractions used to describe them. These works follow a trajectory from artworks in the landart movement such as Nancy Holt's *Sun Tunnels* (1976), described above.

In *Hva annet er også sant?* (2017) professor in economy and philosophy Frode Nyeng points out that from a phenomenological standpoint there are not two separate worlds, represented by one of true and scientific facts versus one full of false illusions created by our limited, bodily senses. Instead, he explains that the "objects and formal language of science only can be understood from the grounding in our everyday world, and that scientific activity as such must be understood as a knowledge-practice within our world of human actions." (p. 52) This world of human actions, the "lifeworld", is a term central to phenomenological philosophy that I apply in the written reflections about this research project. Nyeng describes the lifeworld as "the immediately experienced world" (p. 53) and "the world given by our everyday, practical relation to the things around us" (p. 52) (my translations). Adopting this perspective, I aim to bring abstractions in 3D modeling technology into the lifeworld of more people than those for whom they are already tangible and known through their professional expertise.

Phenomenological perspectives have also influenced my approach to examining processes of abstraction in 3D modeling, considering what is lost and what

has changed when objects and shapes are translated into numbers, geometry and code. A text written by the German philosopher Edmund Husserl (1859–1938), considered to be a foundational thinker in phenomenology, has been particularly relevant, the following section of which is also included on the *Abstraction Page* of my artistic reflection. In *The Crisis of European Sciences and Transcendental Phenomenology: An Introduction to Phenomenological Philosophy* (1970) (from now on referred to as "The Crisis") Husserl, who also was a mathematician, is critical of how the European natural sciences and the mathematization of nature makes us see nature and ourselves through a mathematical abstraction, obscuring from us the lifeworld itself. He identifies Galileo as a central figure in this shift, tracing the roots of this problem in early 20th-century science back to Galileo's work in the 16th century. In the section "The origin of dualism in the prevailing exemplary role of natural science. The rationality of the world *more geometrico*" Husserl writes: "One basic element of the novel conception of nature has yet to be brought to the fore. In his view of the world from the perspective of geometry, the perspective of what appears to the senses and is mathematizable, Galileo *abstracts* from the subjects as persons leading a personal life; he abstracts from all that is in any way spiritual, from all cultural properties which are attached to things in human praxis. The result of this abstraction is the things purely as bodies; but these are taken as concrete real objects, the totality of which makes up a world which becomes the subject matter of research. (…) In general, we must realize that the conception of the new idea of "nature" as an encapsuled, really and theoretically self-enclosed world of bodies soon brings about a complete transformation of the idea of the world in general. The world splits, so to speak, into two worlds: nature and psychic world, although the latter, because of the way in which it is related to nature, does not achieve the status of an independent world." (p. 60)[12] I think that my own desire to "bridge the gap between embodied experience and

12. On the *Abstraction Page* I have included this and one other quote from *The Crisis*, to which I have returned several times in my thinking around this research project.

abstract, scientific facts through artistic practice," is a consequence of living with a world that, with my contemporary western worldview, has been split in the way Husserl describes.

But phenomenological thinking offers some solutions to this problematic split. As pointed out by Nyeng in the above quote, scientific practice exists within our world of human actions. Moreover, phenomenology emphasizes the necessity to use a multitude of different perspectives and approaches in a pursuit to understand what something is, and not only mathematics or the natural sciences. I believe that art can be one of these approaches, enabling sensory engagement with tools, materials, context and concepts, in ways that are distinct from other professional disciplines. For example, I am convinced that an experience of Holt's Sun Tunnels described above, will enrichen somebody's understanding of relations between themselves, the planet and the sun, even if they know all the scientific facts about summer and winter solstices.

To consider how the underlying abstractions in 3D modeling technology co-evolve with some their different contexts, such as the 3D printing industry, or in online communities or game development, I have found it useful to turn to more recent philosophical frameworks. Several thinkers who have been important to my project, such as Hayles and Donna Haraway, are considered "radical posthumanists" by philosopher Tamar Sharon. I find radical posthumanist perspectives productive because the main objective is not to deem new technologies good or bad, but instead to "radically rethink" what implications they have for human-technology interactions, and how technology shapes perceptions. (Human Nature in an Age of Biotechnology, 2014, p. 17)

According to Sharon, radical posthumanism is "characterized by the view that bio- and enhancement technologies, by undermining the fixity of categories like 'nature' and 'the human', contribute to a deconstruction of narratives based in human uniqueness and call for a radical rethinking of what it means to be human" (p. 17). Radical posthumanism considers technology to be reflexive, as "technologies are both seen as the product of human creativity and a force that shapes human existence" (p. 79).

I consider 3D modeling technology to be both a product of human creativity and at the same time something that shapes human existence. It is with this reflexivity in mind that I have framed the last of my three research questions as an enquiry into "how abstractions in 3D modeling *co-evolve* with their contexts." This line of thought points to the fact that these abstractions contribute to shaping the things we use that type of 3D modeling technology for, and that they are shaped by these contexts. The technological development in the field of 3D modeling can be observed as the constant stream of updates to hardware, software systems and working methods, all of which necessitate new algorithms, code and layers of abstractions.[13]

As described by Sharon, Hayles contributes to challenging the uniqueness of human existence and to thinking through what it means to be human. In her book *Unthought: the power of the cognitive nonconscious* (2017), she discusses cognition as something done not only by humans, but also by technical systems. This is a perspective I have found useful when reflecting on abstraction processes aided by 3D modeling technology. Hayles defines cognition as a "process that interprets information within contexts that connect it with meaning" (p. 22). Using the term "nonconscious cognition," she highlights that there is more to cognition than conscious thought. Nonconscious cognition is a kind of "thinking without thinking" (prologue). It is a rapid, almost instantaneous mode of processing information, much faster than conscious thinking, that humans (and technical systems) perform without being consciously aware of doing so. Hayles cites research showing empirical evidence that nonconscious cognition "in addition to pattern recognition, also performs sophisticated information processing including drawing inferences, creating meta-algorithms, and establishing aesthetic and social preferences" (p. 50). I view non-conscious cognition as a posthumanist extension of the phenomenological concept of "pre-reflective"[14] experience, which refers to immediate, lived experiences that occur before conscious thought. Hayles' concept of "non-conscious cognition" includes both technical systems and plants as capable of cognitive processes, broadening cognitive activity beyond the human mind to both organic and technological entities.

When I engage with materials, tools and other elements of my environment in an open-ended unmaking process, my nonconscious cognition (or pre-reflective experience) plays a crucial role in the development of artworks I had not envisioned. Often the work is something I had not consciously planned beforehand, a result I attribute to this non-conscious or pre-reflective activity. The technical nonconscious cognition of 3D scanners, VR controllers and software systems that I work with helps me gather, sort and interpret large amounts of information. These technical cognizers assist me in digitizing shapes by turning them into abstractions readable by computers, and further translating them into new abstractions that enable forms to be uploaded and shared or turned into physical objects in different materials. In this way the 3D

13. The single event most directly affecting a work in this PhD project was the launch of the Metaverse by Meta in 2021, which I will discuss in the section on *Two Rocks Do Not Make a Duck.*
14. "Prereflective self-consciousness is pre-reflective in the sense that (1) it is an awareness we have before we do any reflecting on our experience; (2) it is an implicit and first-order awareness rather than an explicit or higher-order form of self-consciousness." (Stanford Encyclopedia of Philosophy, 2024)

modeling technologies I engage with act as what Hayles calls "co-cognizers".

I first encountered the concepts of non-conscious cognition, co-cognizers and cognitive assemblages in Hayles' lecture *Computers and Meaning: The Case of Open AI's Text Generating Program* at KMD in the beginning of my research project (2019). She explained how both plants and technical systems have an *umwelt*,[15] which she translated to "life-horizon". I understand this life-horizon to be the environment as it is perceived by the plant, human or technical system, based on their perceptive abilities conditioned by their embodiment. For a laser 3D scanner for example, the umwelt is the hard and opaque surfaces that the scanner can register as reflected laser rays. Much like I think about the "non-conscious" as a posthuman expansion of the "pre-reflective," I think about the "life-horizon" as a posthuman expansion of the "lifeworld."[16]

The Machine Vision research project at UiB was a five year, ERC-funded project headed by Professor Jill Walker Rettberg that applied Hayles' theoretical frameworks in their analyses of how 21. century machine vision is changing our understanding of the world[17]. The research project organized and contributed to several of the lectures, events and workshops I attended at UiB during my artistic research, which enriched my understanding of Hayle's theories and how her perspectives could inform my work. My engagement with the Machine Vision research project also led to further collaborations with its participants, such as with sociologist Gabriele de Seta, who contributed to the *Open Studio* at Entrée.

During the 2020 seminar "Technologies are Us", which included presentations by Jill Walker Rettberg and N. Kathrine Hayles, I wrote an essay exploring how Hayles' theoretical frameworks from *Unthought* can be applied to abstraction in 3D modeling.[18] This essay served as a foundation for several of the reflections on human-technology interactions, viewed through Hayles' theoretical lens, that I present in this artistic reflection text. In addition to "non-conscious cognition" and "co-cognizing" the seminar discussed the term "cognitive assemblages", which I understand as a layered network of human and non-human cognizers where agency and decision making is distributed among its different actors. YouTube learning platforms for 3D modeling tools is an example of a cognitive assemblage I have engaged with in this project, and I think that Aldea and other digital fabrication-oriented workshops can be seen as a form of cognitive assemblages.

Hayles has been the most important thinker to my project, and she generously accepted my invitation to contribute to my live program in the *Open Studio* at Entée where she gave the lecture "A Crisis of Representation: Abstraction and Materiality" (2022). Live streaming from Los Angeles to audience present at Entrée and online, Hayles addressed the role abstraction plays in neural net machine learning processes and the importance of considering materiality and embodiment when interpreting machine generated text.

Initially it was Hayles' writing about abstraction that caught my attention and gave my project what felt like a theoretical anchoring and turning point. In *How We Became Posthuman* (1999) Hayles analyzes the relation between abstraction, information and materiality. She states that "Abstraction is of course an essential component in all theorizing, for no theory can account for the infinite multiplicity of our interactions with the real. But when we make moves that erase the world's multiplicity, we risk losing sight of the variegated leaves, fractal branchings, and particular bark textures that make up the forest" (p. 12). As mentioned earlier in this text, Hayles identifies two abstraction moves as the "Platonic backhand" and "Platonic forehand". "The backhand" is what we know as reduction, or a simplification of complexity. "The forehand" is the building of more complex things based on simplified abstractions. Most 3D modeling technology relies on both these moves – reducing complexity in digitizing processes and building up complex structures – for example using geometrical shapes in a CAD sketch workspace to create objects and environments. Hayles points out that the Platonic forehand and backhand "share a common ideology – privileging the abstract as the Real and downplaying the importance of material instantiation. When they work together, they lay the groundwork for a new variation on an ancient game, in which disembodied information becomes the ultimate Platonic Form. If we can capture the Form of ones and zeros in a nonbiological medium – say, on a computer disk – why do we need the body's superfluous flesh" (p. 13).

I understand Hayles' thinking here to resonate with Husserl in reminding us that everything cannot be translated into numbers, and that if we imagine that this is possible, we risk losing sight of important things or can even end up in transhumanist[19] worldviews in

15. *Umwelt* was discussed with reference to Jesper Hollmeyer's book *Signs of Meaning in the Universe* (1996).
16. Reflecting on the artworks in this project I have seen that both phenomenological and posthumanist ways of thinking can shed light on the work in question, and that their perspectives overlap. It is outside the scope of this PhD project to discuss the relationship between the theoretical frameworks of phenomenology and posthumanism in depth. When I discuss the different art projects in the following text, I have chosen to refer to the frameworks or ideas that has been most influential to my art making and reflection process.
17. See for example PhD researcher Linda Kronman's text "Intuition Machines: Cognizers in complex human-technical assemblages" addressing the stakes of using of machine vision to aid human decision making.
18. "Technologies are Us: Feminist Perspectives on Posthuman Futures" was a three-day intensive course on feminist thinking about technological development, organized by Nordic Centre of Excellence on Women in Technology Driven Careers and Centre for Women's and Generd Research (UiB).
19. A transhumanist worldview envisions enhancing the human condition through advanced technologies, aiming to transcend biological limitations and achieve greater physical, cognitive, and emotional capacities

which uploading consciousness is considered possible and desirable. This transhumanist vision of the future, with proponents like Hans Moravec, Ray Kurzweil, and today, Elon Musk, is rooted in the Cybernetics movement that emerged in the 1940s and 1950s. This movement conceptualized systems – including human minds and bodies – as informational entities that could theoretically be digitized and separated from material embodiment.

I do not, however, think about Hayles' reflections on abstraction as a critique or moral judgement of 3D modeling technology or any other set of abstractions. Instead, it seems to me that Hayle's point is that "moves of abstraction" should not be used naively without a critical analysis of how they work, an analysis in which materiality, embodiment and other context must be considered.

In an abstraction process something is extracted out of something else and expressed in a new form or material instantiation. Hayles accompanies several new materialist thinkers[20] in calling attention to the importance of material instantiation, including that of seemingly bodiless, digital information. The meaning of an abstraction depends on the context it is embedded within. Hayles points out that there is no such thing as bodiless, abstract information, therefore the meaning of information must be understood in relation to its material context – both the material the information is instantiated in and its environment (1999, pp. 12,13). To me such perspectives have reminded me that when I examine processes of abstraction in 3D modeling, I must be aware of the digital materialities and embodiment of the elements I work with, and to consider what is added by the technology in question and not only what is lost. I have been less focused on proving, or pointing out, the existence and importance of digital materiality, as I think that this has been done in convincing ways by both artists and thinkers before me.[21] After my midway assessment in 2019 I realized that my project's initially stated focus on "the relationship between the virtual and physical in sculpture production" set up a binary distinction that I did not believe in, and that it indicated a discussion about digital materiality and new materialism that was not my main focus. After the midway assessment I therefore changed my stated area of research to focus on abstraction in 3D modeling.

Along with other contemporary thinkers Hayles decenters the human subject and rejects the idea of a fixed, stable human with a boundary between itself and the world. This attitude towards human subjectivity as something fragmented and fluid was popularized by Haraway in her "Cyborg Manifesto" (1991), described by Sharon as a foundational text for radical posthumanism. Hayles and Haraway share a strong emphasis on context and embodiment, topics at the core of Haraway's seminal essay "Situated Knowledges" (1991).[22] Rejecting both social constructivism and doctrines of objectivity Haraway argues for a feminist objectivity which recognizes the partial perspective of the researcher as well as their context, but at the same time strives for "a no-nonsense commitment to faithful accounts of a 'real world'" (p. 187). This kind of feminist objectivity is compelling to me as an artist-researcher both in terms of how I do research and what I study: In practical terms I reflect on my own standpoint and studio work without limiting my concerns to artistic processes. Furthermore, I think that I can only reach a faithful account of abstraction in 3D modeling through a hands-on engagement with the technologies and workflows that I study. In Haraway's words "Understanding how these visual systems work, technically, socially, and psychically ought to be a way of embodying feminist objectivity" (p. 190). On a theoretical level "Situated Knowledges" also unpacks some of the key questions in my work, as the essay shows how the embodiment and situatedness of tools – whether they are made to look at something, make scientific illustrations or create other objects – take part in shaping the way that people look at the world.

20. Elisabeth Grosz, Jane Bennett, Karen Barad, Luciana Parisi are some of the thinkers Hayles refers to in the chapter "The Cognitive Nonconscious and the New Materialisms" in *Unthought*.
21. See previous footnote for theoretical approaches. Artworks dealing with digital materiality will be discussed later in the text.
22. "Situated Knowledges" became a theoretical frame I shared with colleagues in the artistic research program Petrine Vinje, Ida Falck Øien, Rosalind Goldberg, Lisa Badouin Lie, Sara Eliassen and Signe Becker through an in-depth study of the text together. Part of our group performed a public reading of "Situated Knowledges" at the Artistic Research Forum in Oslo. See images of this event on the Process Page.

Artworks

Having outlined the artistic, theoretical, methodological and technical foundations of this project, I now turn to the individual artworks.

Secret Support

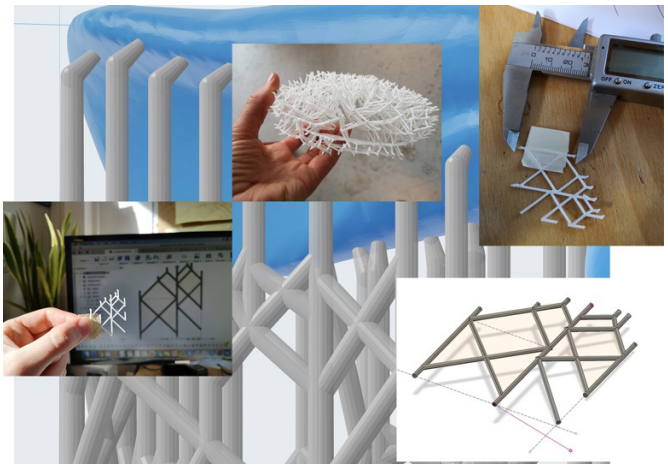
Secret Support (2019) is a series of seven aluminum sculptures. Their shapes are based on fragments of support structures that hold an object in place while it is printed on a Formlabs 3D printer.

In *Secret Support* I examined the abstraction process of translating a shape into numbers as well as an algorithmic abstraction used to automatically generate the 3D printed support structures. The unmaking process highlighted that a main function of 3D modeling software is to assist us in making abstractions necessary to digitize a shape. It also made visible how proprietary algorithms act as hidden, ready-made abstractions within 3D modeling technology, influencing the 3D printing industry. Moreover, the creation of *Secret Support* underscored that the 3D model format serves as a specific instantiation of an abstracted shape, with unique qualities such as scalability and easy transferability into new materials.

The inspiration for making *Secret Support* came from looking at support structures that came out of the Formlabs resin printer at Aldea. I found them interesting because, unlike the half-timbered houses, industrial scaffolding and cranes I had looked at in previous sculptural work (e.g *Riegelbau* (2011), *Terra Nullius* (2011) and *Sao Paulo* (2012)), their shapes did not appear more modular or uniform than their technological predecessors.[23] In these previous sculptural examinations I had noticed a kind of streamlining and standardization in the structures' forms that were connected to technological development and specialization of labor. The shapes of the Formlabs support structures had odd variations, were customized to fit each object and required no human labor, neither in the design nor manufacturing process.

The Formlabs support structures are automatically generated in the printer's slicer (3D printing software) Preform and made to hold the object in place during the printing process. It seems like a magic trick when you click the "auto-generate supports" button and instantly get a precise scaffolding fitting your specific object. The software then converts the object and its supports into G-code, with "G" standing for geometric, referring to how the system specifies the machine's movements along the x, y, and z axes. This framework of abstraction serves as an interface between the digital model and the machine, enabling virtual objects to be translated into physical ones. In the case of the Formlabs 3D printer, it transforms the G-code into plastic material by shooting laser beams into a tray of liquid resin and hardening it onto a build plate. The build plate slowly pulls out of the tray, making the code emerge as an object of dripping plastic held up by support structures.

I wanted to understand the process and technology behind these structures better. Following my method of unmaking, my approach was to go through the practical steps of physically remaking fragments of the printed supports. I wanted to bring them into a more human scale, to enlarge them in size to allow for a more active bodily and spatio-temporal engagement by myself and the viewer. My plan was to export the 3D model of the structure from Preform, adjust its scale, and generate production plans for new sculptures. This plan illustrates a key function of 3D modeling technology: the ability to manipulate shapes, as expressed by computer scientist Ivan Sutherland, a pioneer in the field. He notes, "The objective of most computer-graphics programs is easily stated: to represent objects of some kind and to provide a means for manipulating them" (Computer Displays, 1970).[24]



23. Terra Nullius (2011)is a series of wooden sculptures based on industrial cranes used in the coal mining industry in Longyearbyen, *Riegelbau* (2011–20) is a series of wall-hung wooden reliefs based on Swiss half-timbered houses and *Sao Paulo* (2012)is a photograph of a large aluminum scaffolding in the shape of a Christmas tree in the process of being constructed by workers climbing in the structure.
24. While Sutherland was discussing Computer Graphics, a branch of 3D modeling technology focused on the virtual representation of objects, this statement also applies to 3D modeling technology in general, as it involves creating and altering shapes for both virtual and physical applications.

My plan quickly failed because exporting the 3D models of the support structures turned out not to be possible in Preform. After researching online forums and contacting Formlabs directly, I learned that the export function had been intentionally disabled. Disabling export functionality for the support structures contributes to keeping the Formlabs printers in what is called a closed 3D printing system. In this context, a closed 3D printing system means that users must use the company's own slicer Preform to operate their printers, their own brand of expensive resin to print with and ideally their own post processing machines for curing and washing the print. By preventing the export of auto-generated support structures as 3D models, Formlabs ensures that users cannot bypass the system by uploading the model into other software and printing it on a different printer.

Another element keeping the shapes of the support structures confined within the closed Formlabs 3D printing system is that the algorithm generating the structures has been patented as proprietary information. This was the first ready-made abstraction I encountered in this research project, created by someone and re-used by others. Although hidden from view, it plays a crucial role in shaping how users interact with these systems, influencing both the process and final outcome.

The closed system of the Formlabs printers leads to high costs and several user restrictions, but also ensures reliable printer performance and consistent print quality. This aligns with the company's focus on capital-intensive industries like engineering and manufacturing. However, the price and user restrictions make the printers less available and attractive for hobbyist makers, artists and those dedicated to open-source tools. At Aldea, despite these limitations, the Formlabs resin printer is an important component in an ecosystem of machines. It is used for high-precision 3D printing without layer traces, prints that require special material attributes, and to experiment with and test the affordances and limitations of resin 3D printing.[25]

The support structures I examine in *Secret Support* were designed to remain inside a closed 3D printing system and were therefore difficult to take out of it. To make the working drawings needed for the enlarged version of these shapes I had to recalculate the lengths and angles of all the different parts of the plastic fragments. Scaling and manipulating the shape of the structures would be an easy task for any CAD software if I had a working 3D model wherein the form was already expressed as readable numerical data. But without the option to export such a model from Preform I first had to manually redraw the shapes in the software Fusion360.[26]

I measured the printed plastic structures with a caliper and drew them in Fusion360's sketch area. Holding the plastic pieces in front of the screen, I estimated by eye if my drawing matched each physical object. From a selection of geometric sketch tools, I used the straight lines and attributed inherent values for length, angles, relation to other sketch elements and position on 2D grid. The laborious, manual and imprecise process of extracting the form of this plastic object as numerical data and transferring it to a digital sketch can be seen documented on the *Video Page* of my artistic reflection. After finishing the sketch, I could use the software's assistance in scaling the forms and extruding the lines into volumes, from which point I could create the 1 : 1 scale drawing needed for the welder to do his job. Performing this time-consuming, manual process of measuring and drawing the shape myself made clear where I was missing assistance from 3D modeling technology and thereby another one of its main functions; to serve as a co-cognizer that supports users in the abstraction process of converting shapes into numbers.

During the unmaking process, the shapes of the *Secret Support* sculptures went through a series of material translations between numbers, screen, and object. Hayles' reflections on abstract information and material embodiment provided a key framework for understanding this process, leading me to view the 3D model format as one way a shape's information can be embodied, where embodiment includes both materiality and medium. Hayles emphasizes that information must have a material embodiment to exist and cannot be seen as independent from it.[27] This perspective aligned with my experience of making the sculptures: the shape of these support structures had different attributes and visibilities depending on how it was embodied. As an algorithm it could automatically adapt to fit any shape, as a plastic object I could hold it in my hand and look at it, as a finished physical sculpture I could walk around it and see it from different angles. In the format as digital drawing and a 3D model, qualities such as the possibility for scaling and shape manipulation were necessary to take the object to the next step in the making process. This flexible quality, rooted in its numerical nature, allows the 3D model to serve as a practical tool across professions, supporting tasks such as adjusting shapes, scales, and preparing for production stages in fields like architecture, design, and art.

25. In the 3D printing industry, the closed system of the Formlabs printer is contrasted by the open system of the highly successful filament printers made by Prusa. The four Prusa printers at Aldea are our most frequently used printers. We can choose any supplier to buy material from or even make our own filament from recycled prints, a method Aldea has experimented with. 3D models of the Prusa 3D printers can be downloaded for free online, allowing users to 3D print machine parts and make their own printers. Users share design improvements online and, in this way, contribute to making the printers more reliable, precise as well as to maintain their position as a market leading filament printer.
26. Fusion 360 is Computer Assisted Design (CAD) program used by professionals in fields of engineering, design, manufacturing, art, and more. It is the software I have used the most myself in this PhD-project and I will reflect on it the section about the artwork "Holder".
27. From p. 12–13 in *How We Became* Posthuman, presented in the section "Theoretical Frameworks" and on the *Abstraction Page* of my artistic reflection.

In the process of turning a shape into a 3D model, something is both added and lost. As addressed in the section "Theoretical Frameworks" Hayles' discussion on abstract information and embodiment does not indicate however that materiality is all that counts, nor does it deem abstractions good or bad. Rather, she explains how abstraction is a necessary component in all theorizing, and not problematic in itself. The problem arises with the assumption that these abstractions – in the example she discusses, the zeros and ones – are the foundational elements of an entire reality, and that they are independent from their material embodiment. This perspective resonates with Husserl's warning in *The Crisis* about the "complete transformation of the idea of the world in general" (p. 60). Husserl reminds us that not everything can be reduced to numerical representation, and that doing so may lead us to lose sight of essential aspects of human experience. In *Objects at Hand*, I draw on the perspectives of Hayles and Husserl to make visible what is gained and lost as objects are translated into numbers and new material contexts through laser 3D scanning and 3D printing.

The meaning of the material existence of seemingly immaterial information has been demonstrated not only by thinkers like Hayles, but also by several contemporary artists who make work that make visible aspects of technology that are normally hidden from our view. For example, Oslo based artist Ayatgali Tuleubek created a sauna using heat generated by computers mining crypto currency (*Groundbreaking Computational Methods for Generating Heat and Value,* 2020, in collaboration with Michael Rasmussen). Swedish artist Nina Canell shows us the sculptural side of information transmission by displaying slices of huge cables (*Brief Syllable (Weak)*, 2015) and Irish artist John Gerrard makes the cloud a bit more tangible by depicting the gigantic datafarms where servers are located in the desert (*Farm (Pryor Creek, Oklahoma)* 2015).

Drawing the shape of the Formlabs support structures by hand brought to mind a part of the early history of 3D modeling which I got to know through making the video piece *How To Make a Utah Teapot* (2016).[28] This story serves as an example of the impact an iconic ready-made abstraction in 3D modeling technology can have, and of how abstractions in 3D modeling co-evolve with their contexts. At the Utah University in the 1970s computer graphics researcher Martin Newell was looking for an item "which would move emerging 3D computer graphics from spheres and cubes into the domain of recognizable, real-life things" (Lehmann, 2012). The ceramic Melitta Teapot available at his home was perfect for this task, and together with his students he digitized it by measuring and drawing its shape as x, y, z coordinates on graph paper. The model was made accessible for other researchers to download and use, at a point in time when downloadable 3D models were scarce. The accessibility of the model, as well as its shape being useful for testing various functionalities in 3D modeling software such as texture mapping, reflection and rendering, contributed to making the teapot an icon of computer graphics. To this day one encounters the Utah Teapot as one of the standard shapes in many kinds of 3D modeling software, seemingly out of place between squares, cylinders and spheres.

In his book *Image Objects* (2021), Jacob Gaboury examines the reflexive relationship between ready-made abstractions and the field of computer graphics, highlighting the Utah Teapot as one of five technical objects that have profoundly shaped this domain. Discussing the development of computer graphics in the 1970s, he notes that "Over the course of the decade, computer graphics researchers began to standardize the means by which simulated objects are constructed and displayed" (p. 87). The Utah Teapot played a key role in this standardization process, influencing the field and contributing to what Gaboury describes as the transformation of the computer from a calculating machine into an interactive medium.

The way in which the Utah Teapot 3D model has been shaped by the scientific environment is also directly recognizable in the shape of the Utah Teapot itself. During a presentation, Newell's colleague James Blinn swapped out the z-coordinates of the teapot. This resulted in the shape becoming more squashed than it had been at first, a preferred look for the computer scientists who decided to keep it this way. The Utah Teapot therefore has a slightly altered shape from the original Melitta Teapot.

Secret Support was shown in four different exhibitions during the PhD project and acquired by the collection of KODE art museum in Bergen.[29] These contexts activated different physical and conceptual aspects of the sculpture series. At Hovedøya in Oslo in 2020 *Secret Support* was exhibited as part of the annual Coast Contemporary event, curated by Tanja Sæter.[30] The sculptures contributed to shaping the framework for a public discursive program and exhibition with the title *Constructing Structures.* The event gathered artists and art workers to reflect on the matters of age, gender, equality and the lack of buildings to house the history of women in the art world (Sæter, 2020). In addition to showing my work and presenting my artistic research project, I led a reading group based on the book *Support Structures* (2015) by Celine Condorelli and Gavin Wade, that I will return to in the reflection on the interior I made for Entrée.

28. *How to Make a Utah Teapot (2016*) is a video work showing ceramicist Anne Lise Karlsen using a potter's wheel to throw a porcelain version of the Utah Teapot.
29. Vevringutstillinga (2019), Coast Contemporary (2020), KODE (2022), Oppløyste Abstraksjonar (2022).
30. Coast Contemporary is an annual event gathering artists, art workers and the public. It usually takes place as a journey along the Norwegian coast on the Hurtigruten cruise ships, with stops along the west coast on the way. In 2020 the cruise was replaced by a gathering at the Hovedøya island in the Oslofjord, due to the many restrictions following the ongoing Covid-19 pandemic.

Summary for Secret Support

In *Secret Support* I examined abstraction in 3D modeling by unmaking the proprietary algorithm used to automatically generate support structures on a Formlabs 3D printer. This process made visible the following aspects of my research questions 1) what is abstraction in 3D modeling, 2) how does it work and 3) how does it co-evolve with some of its contexts. Making the artwork led me to the following reflections:

1.
The unmaking of *Secret Support* involved the translation from plastic fragments to digital drawing. This highlighted two primary abstraction processes in 3D modeling: the extraction or separation of an object's shape from the rest of the object's qualities, and the translation from form to numerical data. The algorithm automatically generating the support structures in the Formlabs slicer software Preform is an example of a ready-made abstraction, designed by someone and reapplied by Formlabs 3D printer users. Like most digital fabrication machines, the Formlabs 3D printer relies on G-code as a system of abstraction which facilitates the translation from a digital model to a physical object.

2.
The time-consuming manual process of translating the support structures into numerical data and digital drawings made visible to me that a key function of 3D modeling software is to serve as co-cognizers, aiding in such abstraction processes and in further manipulations and translations of shapes. In the making of *Secret Support*, the software system Fusion 360 assisted my preparation for physical production by recalculating and manipulating the shape and scale of the support structures, exemplifying how a central purpose of representing a shape as a 3D model lies in this format's potential for further manipulations. The many translations undertaken in this work – from plastic fragment to screen to sculpture – demonstrated that the information about this shape was always instantiated in a format and material which was decisive for its functionality. As an algorithm the form could adapt to any object before 3D printing, as G-code the form could be translated into a plastic object, as a piece of plastic I could hold it in my hand, as a digital working drawing shape and scale manipulations were possible, and as a physical sculpture it could be experienced in a spatio-temporal manner. The significance of the embodiment of seemingly immaterial, digital information is addressed in the work of contemporary artists such as Ayatgali Tuluebek and John Gerrard, who make visible and tangible the material side of server farms and data mining.

3.
The proprietary algorithm I examined in this work is an example of a ready-made abstraction in 3D modeling that affects the context of the 3D printing industry by contributing to making the Formlabs printers a closed 3D printing system. Closed 3D printing systems restrict user options, ensure printer consistency and are expensive to work with, making them more accessible and attractive for cost-intensive industries and less for artists. The Utah Teapot is a key ready-made abstraction in 3D modeling technology, which has been argued to make a significant impact on the field of computer graphics, and by extension on 3D modeling technology as a wider field (Gaboury, 2021).

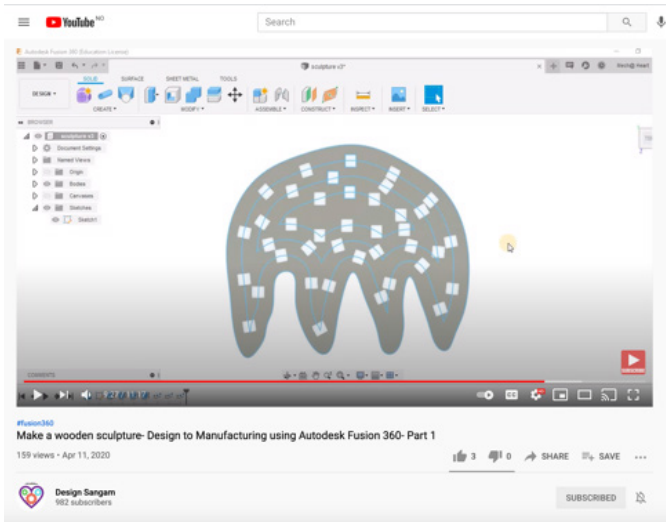
Holder

Holder is a work consisting of three interactive sculptures accompanied by YouTube instructional videos.

In the making of *Holder*, I examined how creating CAD drawings based on geometry and mathematical calculations affect functional and aesthetic features of objects made with such software systems. I also engaged with the YouTube learning community for CAD to find out if the repeating styles, objects and characteristics of their tutorials are caused by abstractions in 3D modeling.

The three sculptures included in this work are functional holders for tape rolls, aluminum tubes and painted wood samples. They were displayed on custom-made tables and the gallery visitors were invited to rearrange the objects to create their own color combinations and compositions. The YouTube tutorials demonstrate how to digitally design the sculptures in Fusion360 and how to produce them with a CNC machine. The tutorials were made by the owners of the YouTube channels MechatHeart, MufasuCAD and ProductDesignOnline and posted on their respective channels. When *Holder* was shown at TagTeam Studio and Oseana, the tutorials were presented as video works on screens together with the sculptures.

The function of the *Holder* sculptures is inspired by the workshop environment at Aldea. In the initial phase



of building up our wood workshops Cameron created tool holders made to keep our equipment organized, movable, visible and easily accessible for workshop users. Like the Aldea tool holders, my sculptures were made on a CNC machine from solid wooden boards with slots milled into them to hold specific items.

Instead of holding workshop tools, I designed *Holder #1* and *Holder #2* to hold color samples that I use to find color combinations in my studio. These samples are anodized and spray-painted aluminum tubes used for *Secret Support,* and painted wooden sticks used for previous works. In my studio practice I work with the samples by putting them next to each other, adding, removing and replacing pieces to consider how the colors affect each other and what associations the different combinations give. I aim to linger in a state of non-conscious cognition, seeking combinations of colors and materials that avoid evoking clear associations with any specific place, style, or environment, as my intention is not for the color combinations to serve as symbolic representations or abstractions of something else. Since individuals bring their own associations to color combinations, this process remains inherently subjective. Usually, the combinations I work with include a span from bright to dark and from saturated to unsaturated, and something that stings my eye slightly. *Holder #3* is designed to hold a collection of tape rolls I have gathered from hardware stores on work and vacation trips around the world over the years. To me they have served as a mix between 'hardware color palettes', 'sculpture-research souvenirs' and practical tools.

Creating the work *Holder* started by designing and producing the sculptures at Aldea. In the following paragraphs I will describe the parts of the unmaking process which highlighted effects of geometric and mathematical abstractions in the Fusion360 design workspace. The process can also be seen demonstrated in the YouTube tutorials available on the *Video Page*.

I first examined how CAD sketching tools affect aesthetic expressions by testing out how my own hand-drawings changed when digitized with CAD. I made several quick, single-movement hand drawn lines on a series of A4 pieces of paper and chose a selection that could function as outlines for the sculptures. I imported images of the drawings before tracing over the lines with a set of points using the "spline tool", a standard CAD workflow for digitizing a simple drawing or floor plan. The co-cognizing software turned the points I had marked on the 2D grid into a mathematically expressed Bézier curve, with adjustable handles that function like changeable parameters. The result is a smooth line, no longer with the expression of drawing by hand, but one shaped by a tool deeply embedded in the history of design technology. Originally created by the French engineer Pierre Bézier for designing cars in the 1960s, this curve has since been widely adopted in software such as Adobe Photoshop, Adobe Illustrator,

and CAD – a ready-made abstraction that has influenced the smooth look and function of digitally designed objects for over half a century.

After drawing the outlines of the sculptures, I proceeded to make the slots for the tape rolls and color samples. Sketching in Fusion 360 works by the logic of creating shapes with basic geometric shapes like straight lines, arcs, circles and rectangles, and then modifying these with mathematical calculations and constraints. I think of this way of building up more complex objects from simple elements as a move with the "Platonic forehand" described by Hayles. The look and function of the Fusion360 sketch workspace recalls vague memories from geometry lessons in school, and of some of the calculations that the software must perform to assist me in making these shapes. Features like "mirror" mirrors a shape, "dimension" lets you enter dimension value to automatically draw the element in given size. "Fillet" rounds off a sharp corner and "offset" creates a line offset by given value to reference line. By applying constraints, I could make sure the different elements aligned with each other and the grid as horizontal or vertical, parallel, tangent, symmetrical or perpendicular to a given reference. For *Holder#2* I extruded cylindrical slots for the aluminum tubes following lines that were multiplied and distributed across the surface using the rectangular pattern function. For *Holder#1* I created slots for the wooden sticks by copying rectangles using the pattern-along-path function, on paths first generated using the offset function. Drawing the many slots for tape rolls, aluminum tubes and wooden sticks was easy because of the effortless repetition of shapes enabled by Fusion360. The parametric features of the software system made it easy for me to make perfectly sized pockets for the objects. I measured the tape rolls, aluminum tubes and wooden sticks to find the correct size for the slots in the sculptures and added these values as user parameters. After test milling one pocket at the time, I could update the whole design simply by swapping these values in a table. All of these steps can be seen in the *Holder* YouTube tutorials on the *Video Page* of the artistic reflection.

The unmaking process of the *Holder* sculptures up until this point highlighted some of the visual and functional characteristics created by abstractions in CAD 3D modeling software. The software is built on a logic of making shapes from simple geometric forms that can be manipulated using different mathematical calculations. This encourages designs with copied elements, patterns, geometric shapes and smooth curves. The parametric features in the software also allowed me to prototype and produce wooden sculptures with a speed and level of precision I would not have been able to achieve by hand.

In my *Open Studio* at Entrée, I continued exploring the Bézier curve and parametric design through a practical workshop, a lecture, and by creating the interior for the space. The lecture *On infrastructural abstraction: Models, parameters and algorithms* was presented by Sociologist Gabriele de Seta, who discussed geometric and mathematical form-making through the lens of Luciana Parisi's book *Contagious Architecture* (2013). The lecture is available on the *Video Page* of my artistic reflection (2022).

Parisi examines parametric architecture and parametric design, where mathematical algorithms are used to generate the shapes of buildings and structures, enabling these forms to change based on selected parameters. In contrast to CAD's parametric functionality, which adjusts specific features based on fixed parameters, Parisi's parametric architecture leverages parametric inputs to adapt the design, creating forms that evolve dynamically. She highlights how this development of design and architecture parallels advancements in informatics and computer science, by directly applying algorithms and cellular automata[31] as form-generating principles. De Seta discusses Parisi's view that, while code and algorithms are abstract, they are also physical objects when realized as surfaces and structures. As built structures they reveal inherent limitations – the incompleteness and incomputable aspects of these designs. In my understanding, Parisi's concept of "the incomputable" suggests that computational systems cannot calculate or predict every aspect of physical form. Thus, objects produced purely through computational logic will inherently carry a degree of unpredictability or irregularity, exposing the gap between digital abstraction and material realization.

After designing the sculptures, I started working on the YouTube tutorials. Watching such tutorials was how I learnt 3D modeling myself, and I noticed repeating aesthetic expressions and characteristics in this online community. The exercise object used was often a wrench, a car part or another functional, industrially produced object, the background music sounds like it comes from the 90s and the YouTube instructors represented a very homogenous group of people; usually white, male, European or American, between twenty and fifty years old. I became curious about the standards in these tutorials, and if they were caused by abstraction in 3D modeling. I wanted to examine them more closely, exploring possibilities for breaking away from them. The aforementioned Utah Teapot and other standard 3D models were especially interesting to me, as they showed how a seemingly random object can acquire new significance, influencing an entire technological field and demonstrating how abstractions in 3D modeling co-evolve with their contexts.[32] The stories

31. In the lecture De Seta describes Cellular Automata as graphical representations of simple rules that are able to create things that develop randomly, and are seemingly alive out of code, and as the idea that one can obtain something as complex as life from a tiny bit of code.
32. Another example is "3DBenchy", a 3D model of a boat used to test 3D printer performance and to adjust printer settings.

behind these objects also showed how ready-made abstractions in 3D modeling could provide valuable entry points for understanding the situatedness and historical development of 3D modeling technology.

I reached out to the creators of the YouTube channels MechatHeart, Product Design Online, and MufasuCAD, all of whom teach their followers how to use Fusion 360. Together, these channels represent a range of cultural backgrounds and audience sizes, providing valuable perspectives for my effort to better understand this global community. In short questionnaires presented on the *Text Page* of my artistic reflection they answer questions about their background and interest in 3D modeling education. The host of MechatHeart became a 3D modeling educator to combine her background in mechanical engineering with her role as stay-at-home parent in India, reporting that the YouTube channel has been an important steppingstone for new professional opportunities. The Indonesia-based owner of the channel MufasuCAD, with more than 200.000 followers, shared that the channel served as a significant source of income for him. The US-based host of Product Design Online explained that his passion for teaching others drives the creation of his videos, which has also opened the doors to new connections and resources. On the question about which example objects they use in their tutorials they mentioned screwdrivers, Lego, pen stands, photo frames, keychains, mechanical parts and other things they had ready to hand. One of them answered that they chose objects that were used globally and found it beneficial if students already had a visual perception of the object.

I commissioned the YouTubers to each make a tutorial demonstrating how to 3D model and fabricate the sculptures *Holder#1*, *Holder#2* and *Holder#3*. They received detailed instructions on the procedural steps for the tutorials, aiming to guide their followers in designing the sculptures in Fusion 360 and producing them on a CNC machine. The tutorials were also intended to be useful for anyone wanting to learn Fusion 360 and included explanations of software functionality used in the design and manufacturing process, such as employing the circular pipe command, setting up the CAM environment, and simulating tool paths. I asked the YouTubers to keep the instruction videos in the same style and format as their other tutorials, with the same type of voice over, music, graphic design and editing. I also asked them to publish the tutorials on their own channels, because I wanted this work to engage with and circulate in the online 3D modeling community, and not just to study it from the outside.

In exploring whether abstractions in 3D modeling contribute to the typical characteristics observed in informal CAD tutorials, I draw on Hayles' concept of Cognitive Assemblages – "collectivities through which information, interpretations and meanings circulate."[33] According to Hayles, Cognitive Assemblages sometimes lead to "a certain homogenization of behavior" (2017, p. 125). I think about the informal YouTube platforms for CAD as a cognitive assemblage, a layered network of human and non-human cognizers, and will in the following paragraph address two examples of how abstractions in 3D modeling affect cognizers within this network.

While designing the *Holder* sculptures in Fusion 360, I found that the co-cognizing software's geometric and mathematical framework promotes the creation of objects characterized by copied elements, patterns, symmetry, geometric shapes, and smooth curves. In the questionnaires, the YouTubers shared that they often chose readily available objects from their surroundings, like pen stands, photo frames, and mechanical parts. Another criterion for selecting these objects from the world of product design seems to be their alignment with CAD software's geometric abstraction framework, where the "Platonic forehand" transforms simple geometric forms into complex 3D shapes. This alignment makes these objects easy to reproduce in Fusion 360 by combining basic geometric shapes and extruding 2D drawings into 3D forms. A comment on one of the *Holder* tutorials by @letsplayagame226 reflects how the asymmetry of *Holder #2* broke with their assumptions for something created in this software system, illustrating how CAD users expect designs to align with the software's inherent mathematical logic: "Why not draw one spline and mirror it. That's only logical", read the comment (ProductDesignOnline, 2021). My impression that example objects are often selected for their fit with the software's abstraction framework is also supported by the fact that many CAD YouTube tutorials are titled by the software function demonstrated, rather than the name of the example object.

The YouTube platform is another cognizer in this assemblage which uses a ready-made recommendation algorithm to sort through vast amounts of data to help people find what it considers to be relevant content, with the aim of making them continue watching videos. The algorithm is based on the assumption that people want more of the same. If the learner has watched a tutorial titled "How to model a wrench in Fusion 360" or searched for "pipe command fusion360" it is likely that she will get similar suggestions for her next tutorial.[34] In discussions with ProductDesignOnline about the YouTube tutorial for *Holder#2,* he shared that he carefully considered the title to maximize views, based

33. Description of term "cognitive assemblages" by N. Kathrine Hayles in personal communication, September 26, 2020, in response to follow-up questions after Technologies are Us seminar.
34. This suggestion algorithm has been argued not only to send people into 'rabbit holes' of confirmation bias, but even to radicalize people online. See for example the podcast series "Rabbit Hole" (The New York Times, 2020)

on his understanding of how YouTube suggests videos and filters search results.

The above analyses of the YouTube CAD tutorials as a cognitive assemblage suggests that the geometric framework in CAD software leads to example objects coming from the world of product design, and that this characteristic may be reinforced by the algorithmic abstractions on the YouTube channel. However, to confidently determine the extent to which abstractions in 3D modeling contribute to the recurring elements and styles observed in YouTube CAD tutorials, both in terms of example objects and other features, I believe a more systematic and different type of research would be necessary.[35]

Since the tutorials were published on the YouTube channels they have been watched thousands of times. This online presence of the *Holder* project has allowed me to step outside the art context. It made it possible to include people who would not encounter my work in a gallery setting in the process of making my sculptures, and to give them the possibility to physically reproduce the sculptures without copyright restrictions.

In this project, the strategy of stepping outside the art context has allowed me to reach a wider audience, to introduce something slightly off-course into a standardized format, and to explore how abstraction in CAD 3D modeling co-evolves within the context of online tutorials. Engaging the art audience as active participants follows a legacy of artistic practice that I will address shortly, while the approach of 'working with' the technology field, rather than merely 'observing from the outside,' is inspired by the collaborative methods used at Aldea.

Over the years, Cameron has built an interdisciplinary community that includes programmers, developers, and others working primarily in the technology and engineering sectors. This community contributes in various ways, such as running courses, exploring the potential of new software and machines, and developing the digital infrastructure needed to support our workshops. This hands-on, collaborative approach reflects Aldea's principle of integrating technology directly into creative and artistic practice, enabling us to actively shape and get a nuanced understanding of the tools we work with.

An example of the exchange between technology and art facilitated by Aldea occurred in 2021 through an exhibition and workshop. For her solo show *Miasma Protoplasma*, Linda Morell worked in Aldea's workshops using Kodon software to create 3D models in virtual reality before producing sculptures with a CNC machine and 3D printers. Previously, she had primarily focused on manual sculpting in materials like clay. Kodon allows users to sculpt by holding VR controllers, offering a more intuitive workflow than traditional desktop 3D modeling. The software translates hand movements into x, y, z coordinates and voxels[36] in virtual space, making them readable for the computer. These models can then be manipulated and fabricated in different materials with 3D printers and CNC machines, both techniques employed by Morell.

Kodon is developed by the Bergen-based company Tenklabs whose team visited Morell's exhibition and could see how their software – usually used for computer games was applied to make sculptures. In a recorded conversation available on the *Video Page* of my artistic reflection Tenklabs founder Gustav Tresselt discusses abstraction in programming and its use in virtual world creation, linking it to the exhibition's themes. In conjunction with Morell's show, we organized a four-day workshop at Aldea with KMD and Tenklabs where participants learnt to create 3D models in VR and digitally fabricate them. Open to artists and students, the workshop featured presentations by Morell and Tresselt, a VR modeling demo by Tenklabs' Brianda Rivas Tovar, and a 3D printing course from KMD's Fredrik Salhus.

Stepping outside the art context to involve and benefit from people's knowledge and experience in other fields is a common artistic strategy, and not only amongst artists working in areas such as social practice, participatory art or relational aesthetics. However, at one point the idea of involving people in an activity, and thinking of that activity as the artwork itself, was groundbreaking and new.

Lygia Clark (1920–88) and Charlotte Posenenske (1930–85) were artists that contributed to a reinvention of artistic practice between the late 1950s- and 70s in Latin America and Europe. I like to imagine what these artists could have done with CAD 3D modeling software, its geometric workspace, and with its possibilities for participation and digital fabrication.

Posenenske's minimalist, sculptural examination of systems, structures and industrial production methods is in many ways a predecessor to my own interest in how standard shapes, frameworks and objects in 3D modeling co-evolves through user participation. Posenenske made works for mass production, sold her work for material costs, rejected cultural and formal hierarchies, and sought to circumvent the art market. Excerpts from Posenenske's manifesto highlights how method, intention, form and political concerns come together in her work: "The things I make are changeable (…) they can always be rearranged into new combinations or positions, thereby altering space. I leave this alteration to the consumer, who thereby again and again participates in the assembly process. The simplicity of the basic geometric forms is beautiful and suited to demonstrate the principles of rationalized alteration.

35. This would likely involve analyzing a larger dataset of objects and videos across various channels to determine whether abstraction in 3D modeling directly causes the patterns I have observed, or if other factors also contribute significantly.
36. A voxel, short for "volume pixel," is the three-dimensional equivalent of a pixel, representing a single point in a 3D grid of data.

(…) I make series because I do not want to make individual pieces for individuals (…)The series can be prototypes for mass-production (…)They are less and less recognizable as "works of art" (…) I find it difficult to come to terms with the fact that art can contribute to nothing to the solution of pressing social problems" (Posenenske, May 1968).The manifesto was written in the wake of the May 68 events of civil unrest in Europe and expresses Posenenske's concerns with the socio-economic issues of the time. Disillusioned by art's inability to address social concerns Posenenske left the artworld in 1968 and retrained as a sociologist, ultimately working with labor unions and specializing in assembly line production.

In Latin America the Neo-Concrete movement started exploring participatory approaches to art as early as the late 1950s. During his lecture at my *Open Studio* at Entrée, Brazilian curator Felipe Pena pointed out how this movement has been overlooked in the Western art canon. He explained how this movement was a forerunner to artists working with minimalism in the US and Europe, and in fields of relational aesthetics and other forms of participatory art. Pena's lecture, available on the *Video Page*, focuses on Lygia Clark, the most prominent artist of the movement. Clark's practice inspired the work *Holder* and this research as a whole.

Pena outlines a commonly understood trajectory of Clark's practice, situating it within the social, political and economic landscape of Brazil of the post-World War II era. In a time of economic growth and optimism Clark started her career making formal, geometric paintings. In the late 1950 she started breaking the plane and moving into three-dimensional works and sculptures. This led to a new series of works meant to be interacted with by the audience, the most well-known example of which is the *Bichos* (1965) series.This shift coincides with the establishment of Brasília as Brazil's new capital city, a modernist city described by Pena as an environment made for cars with huge futuristic buildings, windows and open spaces. Pena explains how this context influenced Brazilian artists to create art in public spaces, often with political intentions. Helio Oiticica, for instance, called for art that engaged with social and political issues, emphasizing the importance of participation and direct engagement. Lygia Clark's work gradually shifted from art object towards "propositions" – a set of actions for participants to engage in. Using things like scissors and paper, wearable suits or goggles with mirrors the participant's senses would be activated through touch, vision and embodied interaction. As Clark became interested in therapy and healing these propositions became part of a therapeutic practice that occupied Clark for most of her remaining career.

Initially I imagined *Holder* as a continuation of Clark's interactive sculptures *Bichos,* a proposition made possible with 3D modeling tools and online participation. I considered making YouTube tutorials that demonstrated how to 3D model and fabricate the *Bichos* sculptures with CAD software and digital fabrication tools. However, I chose not to for reasons I will address shortly, after pointing out some similarities between these artworks and 3D modeling technology.

The *Bichos* series were made of metal plates hinged together to form sculptures that could be folded and shaped by the audience into new compositions. As pointed out by Pena in his lecture, the objects were not made for visual contemplation, and only became activated as artworks when interacted with. Hypothetically, the shapes of the foldable parts could easily be redrawn with the geometric sketch tools in fusion 360 and used to demonstrate features like the hinge-function in Fusion 360. A lecture given by Clark to architecture students in Belo Horizonte in 1956 makes me think she would have been excited about the new possibilities that 3D modeling tools bring to participation and co-creation of spaces and forms: "In my view this is the most revolutionary thing that will be presented tomorrow, when new techniques and malleable materials are available for the artist and the architect to plan the future habitation of man (…) totally dynamic and changeable according to taste and whims and its own functional nature." (Clark, Lecture at the Escola Nacional de Arquitetura, Belo Horizonte)

Bichos represents a shift in the artist's practice of breaking the two-dimensional surface of the canvas and moving into three-dimensional space. CAD modeling works by extruding flat sketches into volumes, and digital fabrication continues this two- to three-dimensional transition by turning virtual representations of three-dimensional space on the flat screen into physical objects in three-dimensional space.The short video *Looking for a Neo-Concrete painting* on the *Video Page*, is a reflection on 2D and 3D in CAD and in the Neo-Concrete movement and is made as a screen recording of my screen while navigating around a polygonal 3D model in simulated 3D space. Another parallel between Clark's practice and 3D modeling is how her works such as the *Bichos* series exist in three different scales – as table pieces to manipulate by hand, as human sized objects, and as proposals for large-scale public artworks, some of which were realized after the artist's passing.This flexible scale of the *Bichos* sculptures mirrors the infinite scaling possible with CAD software. In the sketch workspace both geometric shapes, mathematically expressed curves and vectors can easily be recalculated to any scale by the software. These similarities have to do with the fact that CAD tools share with the Neo-Concrete movement a framework of simple geometric forms as building blocks to create new shapes.

Despite all the geometric and participatory connections between the *Bichos* series, 3D modeling tools and online learning platforms, it did not seem right to follow my initial idea and contribute to the reproduction of the

work of a deceased artist who was not able to approve or reject my proposal. This dilemma raised ethical questions about the digitization of artworks, which I will address in the written reflection on *Objects at Hand*.

Art history is full of artworks that share with CAD modeling the simple, geometric drawings as a formal starting point, and that could be digitized as 3D models with just a few mouse clicks. In most cases this would not only be ethically questionable, but also pointless, because it would strip the artwork of key qualities relating to its embodiment and context. These include the possibilities for spatio-temporal and embodied experience, the material qualities of the work, the specific context in which it exists (for example a collection), and the authenticity of the artwork. On the other hand, involving an audience in the digital replication of artworks could engage them in a participatory exploration of geometric formal language, echoing the interactivity in Lygia Clark's *Bichos*. It could also provide a means to bypass the elevated status of the art object and hierarchies that Posenenske rejected and sought to circumvent.

Instead of digitizing *Bichos*, I chose to create and use my own sculptures as example objects for the *Holder* YouTube tutorials. The finalized work remains inspired by the interactive element of *Bichos* and parallels the idea of sharing part of the studio process with an art audience. Clark's balsa wood, cardboard and masking tape versions of the sculptures titled "Study for Bichos" illustrate how she initially developed the hinged sculptures as sketches in her studio. (Pèrez-Oramas & Butler, p. 187) Once completed and remade as aluminum sculptures, the *Bichos* sculptures served as a compositional framework that enabled the audience to continue the artist's exploration of form and to become co-creators of her work.

Through the *Holder* YouTube tutorials, I shared both the process of learning to use 3D modeling tools, and the steps involved in creating a sculpture in Fusion360 and fabricating it on a CNC machine. This part of the artwork was engaged with by thousands of people online via the YouTube channels MechatHeart, MufasuCAD, and Product Design Online. The sculptures exhibited at TagTeam Studio in Bergen and Oseana allowed me to share with the gallery visitors my approach to finding color combinations by arranging color samples and experimenting with formal compositions through adding, removing, and testing different constellations of objects.

Summary of Holder

The process of making the interactive sculptures and video tutorials in the work Holder highlighted the geometric and mathematical frameworks used to create objects in CAD 3D modeling. By engaging with the informal YouTube community for CAD learning I examined if these structures of abstraction contribute to repeating characteristics of YouTube CAD learning videos. My research questions 1) what is abstraction in 3D modeling, 2) how does it work and 3) how does it co-evolve with some of their contexts led me to the following reflections.

1.
Working with CAD 3D modeling involves using geometric shapes, mathematical principles, and ready-made abstractions like the Bézier curve to design and create objects; complex forms are constructed from these simple geometric and mathematical building blocks. However, the process can also move from complexity to simplicity. For instance, to create the outlines for the *Holder* sculptures, I converted a handmade drawing on paper into a mathematically and geometrically expressed digital sketch – a software-assisted version of translating form into numbers, as I previously did manually in *Secret Support*. I see these geometric and mathematical building blocks in CAD as structures of abstraction that can operate both in the 'Platonic backhand,' where existing elements are simplified, and the 'Platonic forehand,' where new elements are created from geometric and mathematical foundations. The Neo-Concrete movement similarly applied a geometric framework as a formal starting point, and utilized its manipulability, such as scaling and translation between two and three-dimensional space, in a manner reminiscent of CAD 3D modeling software. While working with these fundamental geometric shapes the movement rejected claims of universality and embraced interactivity and audience engagement as an act of co-creation. This participatory approach, manifested in Lygia Clark's *Bichos*, inspired the interactive element of the *Holder* YouTube tutorials and sculptures, and aligns with my view of 3D modeling technology as a tool that, despite its abstract foundations, develops in close connection with its users.

2.
The geometric and mathematical frameworks for abstraction in CAD software contribute to shaping the visual and functional characteristics of things made with it. They encourage geometric shapes, symmetry, pattern, and smooth curves. The software's parametric features and ability to translate digital drawings into G-code enable digital fabrication of objects with a speed and level of precision difficult to achieve in manual work processes without highly skilled craftspeople or large production facilities.

3.
The main context of 3D modeling technology that I engaged with in *Holder* was the informal YouTube learning community for CAD 3D modeling. My impression is that the geometric and mathematical framework of CAD

software, combined with the YouTube recommendation algorithm, contributes to creating a set of standardized exercise objects and possibly other repeating characteristics of in the CAD YouTube community. But this question would require more in-depth and possibly a different kind of research to confidently answer. In his lecture *On infrastructural abstraction: Models, parameters and algorithms*, Gabriele de Seta highlighted further reflexive dynamics between abstractions in 3D modeling technology and its users. Drawing on Luciana Parisi's perspectives he noted how contemporary architecture and design practices have been shaped by the possibilities of algorithmic, parametric design, and identified this as an influence rooted in computation and informatics.

Objects at Hand

Objects at Hand (2022) is a series of 11 acrylic plaster sculptures.

This work builds further on my research in *Secret Support* where I saw that the shape of an object can be extracted from the object's embodiment and context, and transferred between digital and physical materialities. In the unmaking of *Objects at Hand* I examined effects of abstraction processes taking place using a laser 3D scanner and 3D printer, as these tools assist an object's journey and contextual shift from a reverse engineering[37] office in India to an art exhibition in Norway. I aimed to make the effects of the different abstractions, such as changes in shape, materiality, function and meaning, visible in the finished work.

A motivation behind this work was to learn more about the process of laser 3D scanning and the geometric structure of polygonal 3D models. I saw laser 3D scanning as a clear example of abstraction in 3D modeling, as its primary aim is typically to capture only the external form of an object, without considering any of its other properties. In laser 3D scanning the captured form is commonly converted to a polygonal mesh, a standard geometrical structure used to express the form of 3D models, which so far had not been a focus in my research.

The abstraction processes I undertook while making this work included removing an object out of its environment, separating the object's shape from the rest of its qualities, capturing an object as point cloud data using a laser 3D scanner, converting files to polygonal meshes and into G-code for 3D printing before using traditional mold-making techniques to cast the objects in acrylic plaster. This process highlighted how extracting information from the shape of an object and expressing this as a 3D model enables things like uploading, sharing, modifying, and digitally fabricating a shape. In this section, I will highlight ways in which these affordances of the 3D model contribute to developments in the contemporary field of sculpture. I will also discuss artistic practices that emphasize how the abstraction of culturally valued objects into 3D models raises ethical questions.

To begin the reflection on this work, I find it helpful to reiterate what I understand abstraction to be, and to repeat some of Hayles' and Husserl's perspectives that I have previously referred to. The root of the Latin word "abstrahere" means to draw away. Abstraction can be both the process of extracting something out of something else, as well as the product of such an action. What is extracted depends on which perspective and structure is being employed. A 3D model can be the result of abstracting the shape of an object from the rest of the object's qualities, but a 3D model is also built on systems for abstractions – like the coordinate system

37. Reverse engineering in the context of 3D modeling technology is the process of analyzing and digitizing a physical object as a 3D model.

– and ready-made abstractions – like proprietary algorithms and Bézier curves. In *How we became posthuman* Hayles pointed out that materiality and context must be considered in order not to "lose sight of the particular bark textures and fractal branches that make up the forest" and that when the Platonic backhand and forehand works together, a foundation is laid for a new version of an ancient game where disembodied information takes privilege over material reality (pp. 12–13). In *The Crisis* Husserl shows that to view things merely as geometry or math is to "abstract from the subjects as persons leading a personal life (…) from anything that is in any way spiritual, from all cultural properties which are attached to thins in human praxis." With these perspectives in mind my goal was not to demonstrate what was already obvious – that the objects from Shashikanth's office were not the same after going through abstraction processes of laser 3D scanning and further manipulation – but to examine in what way the layers of abstractions involved in these processes changed them.

I continued working with mechanical engineer Sirisha Shashikanth who had made one of the *Holder* YouTube tutorials. She had recently started working in a reverse engineering company in India's technology capital Hyderabad. Reverse engineering is the process of digitizing the shape of a physical object with the purpose of using the 3D model for quality inspection, in AI or VR applications, medical engineering and other purposes. Shashikanth speaks about this process, her own professional background and the technical processes of laser 3D scanning in a recorded conversation that can be found on the *Video Page*.

When I reconnected with Shashikanth, she had recently started working for a company that had purchased a new laser 3D scanner. She and her colleagues were learning to use it by practicing on objects readily available in their work and home environments. Looking at the Utah Teapot and the CAD YouTube exercise objects I had seen that seemingly coincidental objects could contribute to shaping software tools, working practices and be an entry point to learning about these. Following this enquiry, I was interested in Shashikanth's training objects and asked to purchase the scanned 3D models and to use them in this work. The eleven objects were: a 3D scanner handle, a Logitech computer mouse, an automobile component, teacup coasters, an Ikea hammer, a Donkey Kong figurine, coasters embedded in a miniature wooden house, a vacuum cleaner head, a Ganesh Idol, a motorcycle helmet and a toy car.

In the video interview Shashikanth takes me through the process of laser 3D scanning the 11 objects. The abstraction process starts already by extracting the object from its surroundings and positioning it in a way that makes it possible for the scanner to reach multiple sides of the object. The scanner captures the outer shape of the object by shooting laser beams that bounce back and are picked up by the scanner's sensor. The laser signals are converted into point cloud data, which is a set of x, y, z coordinates in a 3D coordinate system. Compared to other kinds of 3D scanning like Photogrammetry, a laser 3D scanner captures the shape of an object with high detail but is less effective at capturing information like color and photographic surface detail. Because of this, laser 3D scanners are often a preferred method for reverse engineering and other work where accuracy of shape is the main priority. Another limitation with laser 3D scanning and most other kinds of 3D scanning is that it only captures the outside shape of the object and not the smaller bits it is made up of. As Shashikanth explains in the video the conversation, they must often disassemble the components of an object before scanning it.

After Shashikanth completed the laser 3D scanning, the scans were converted from point cloud data into Standard Triangle Language (STL) files and shared with me online as downloadable files. STL is a standard 3D model format which only contains information about the surface shape of the object, and, unlike point cloud data, it is a format which can be read by most kinds of 3D modeling software. An STL file is made up of a polygonal mesh consisting of vertices (x, y, z coordinates), edges (lines between the vertices) and faces/polygons (planes between the lines).

The abstraction processes up until this point had been to isolate the object from its surroundings, to separate the shape of the object from the rest of the object, to capture the shape as point cloud data while simplifying it as one whole object, and finally to convert that data into a polygonal mesh.

The effects of these abstraction processes became visible when I opened the files on my computer. The objects had no color or image textures, and the scale of the objects was lost. The shapes of the objects looked like a web of triangular surfaces with several holes in it, an example of which can be seen in the hammer 3D model available on the 3D Models Page. Objects consisting of multiple parts were represented as one single component. The geometric detail level of many of the models was not optimal. In some cases, the number of faces was too high for the computer to process them, or so low that the polygons became clearly visible. I did not perceive these shape alterations as a problem, since my aim was not to accurately reproduce the original object, but to make sculptures that carried traces of the abstraction processes involved in their making. I chose to limit the modification of these imperfect meshes to what was necessary to make the following printing and casting processes possible: The models had to be scaled, the holes in the meshes had to be closed and the complexity of some meshes had to be reduced.

Scale. Maintaining the scale of a 3D model in format conversion and transfer between software platforms is

a common challenge caused by mismatches or inconsistency of units and settings between different files and software. As an example, a model may use inches as scale unit, while the software is set to read scale in millimeters. Instead of trying to figure out which miscalculations had taken place in my case and reverse these, I rescaled the objects to fit the size of the Prusa 3D printer. This made the objects come out in scales unsuitable for their function and not matching each other. For example, the computer mouse was as long as the hammer and much too big for a person's hand. The objects originally all had a connection to bodily scale – the hammer and computer mouse were tools for the hand, the helmet fitting a person's head, the teacup coasters made to fit a cup that fit a person, and so on. When the objects lost this human scale, they became unfamiliar and, in some cases, difficult to recognize. By making the scale distortion of the objects obvious I sought to highlight the scalability of shapes as a characteristic of the 3D model, a characteristic that can be attributed to how the x, y, z abstraction of 3D model can take on any scale unit.

Mesh holes. The 3D models had holes in the mesh because the scanner had not captured the whole surface. When this happens in laser 3D scanning it can be caused by reflective surfaces on the object that make the laser rays bounce away from the scanner's sensor, transparent surfaces that the laser rays do not reflect off but pass through, the scanner's inability reach parts of the object, as well as beginner mistakes in scanner operation. Experienced users of laser 3D scanners can work around these issues using different techniques, but the segments of missing information in these scans were interesting to me because they exposed how the scanner works, and how it extracts information about the shape of the object from the object's whole. A 3D printer cannot print an object whose parts are not connected, and it would be very difficult to cast the objects in acrylic plaster if they had too many negative spaces. The 3D model therefore had to be repaired by closing the holes in the mesh. 3D modeling software can automatically generate new polygons to close these holes of missing information. The software closed the holes by filling in the lowest number of polygons to connect to the existing edges, resulting in triangular and flat surfaces appearing where the holes had been. As I had seen both with Preform in the making of *Secret Support* and with Fusion360 in the making of *Holder*, the co-cognizing 3D modeling software helped me create abstractions – in this case geometric triangles replacing the missing information about the shape. In the finished sculptures these triangles and squares, larger in size than the polygons in the rest of the shape, became visual traces of the laser scanning process, the automated processes carried out by the software system and the geometrical construction of the 3D model.

Polygon detail level. In our video conversation Shashikanth explains how they experimented with different hardware and software settings in the process of scanning the object and converting the point cloud data into meshes. This resulted in some models having an extremely high polygon count, making them impossible for the computer to process, while in other cases, the polygon count was so low that the polygons were visible on the object's surface. The overly complex models were remeshed to reduce the polygon count to make them manageable, while I chose to keep the low-poly models as they were.

In the 3D printing software PrusaSlicer, the models were divided into layers that the printer would follow to build the shape with plastic filament. The exported G-code, read by the printer, contained instructions on where and how fast the printer head should move and specified the thickness of each extruded plastic layer. On nearly horizontal surfaces of the object, the spacing between lines became more pronounced, revealing the layering effect. The fine lines in the finished sculptures highlight an effect of the G-code abstraction framework: the expression of forms as sliced and layered artifacts.

I chose not to stop the unmaking process after printing the 3D models, but to use the 3D prints to create silicon and plaster molds and cast the final objects in acrylic plaster material. I was not satisfied with the material selection of the 3D printer, and I thought that scale and shape distortions of the objects would be less expected and thus more noticeable in a material that was not typical for 3D printing. Moreover, bringing mold making and casting into this project also makes visible the overlap between traditional casting methods and 3D modeling in regard to abstraction; Mold making is another way of extracting the shape of an object, and casting into this mold is another way of materializing this abstraction. Also traces from the mold making and casting were visible in the final sculptures, as lines indicating where the two-part molds were joined together, and as small bubbles of air that had been caught in the material during the casting process.

The abstraction processes that the objects underwent altered their shapes, sizes, colors and materiality. But also meaning and function changed as the shape was transported between contexts. Some of the objects Shashikanth sent me remained unidentified until my recorded conversation with her. In part because of the distortions the objects had undergone, and in part because of my own lack of familiarity with those objects. For example, I did not understand what the teacup coasters were, because their distorted scale removed the association to teacup, and because I don't use coasters very often myself. The conversation with Shashikanth revealed how our different cultural backgrounds made us see several of the objects differently. She described that at her office in Hyderabad the Ganesha idol was placed at the entrance because it is

considered auspicious to pray to Ganesha before you start a task (Shashikanth, 2021). I was unaware of this symbolic meaning of the idol, which I believe was also lost on most people seeing the Ganesha object in the context of my art exhibition at Oseana. When I expressed my concern to Shashikanth, about the act of reproducing the Ganesha idol as being insensitive to those who have a religious and cultural connection to it, she explained that replication of Ganesha idols is traditionally done by anyone, using a range of different techniques, and often at a large scale.

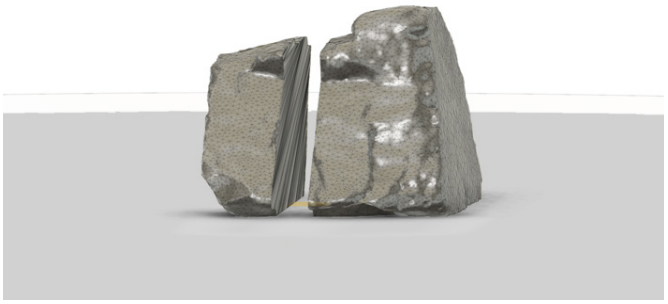
In sum, the abstraction processes the objects had undergone led to manipulations in form, loss of color, materiality and scale. The altered shapes, scales and new materials removed the objects from their original functions as hammer, computer mouse, motorcycle helmet and so on. A geographical and cultural recontextualization enabled by the 3D model's ability to being uploaded and shared resulted in further changing the meaning and function of the objects.

The process of making *Objects at Hand* also revealed how many of the qualities and properties of the 3D model are tied to its underlying abstractions. In the following paragraphs, I will highlight some ways in which these properties of the 3D model – its capacity to be shared, uploaded, manipulated, and translated into new material embodiments and contexts – have transformed and influenced my work and that of other contemporary artists working with sculpture.

3D modeling software is increasingly being used by artists as a tool for planning production and visualizing how artworks will integrate into indoor and outdoor environments. In 2023 I took part in developing and organizing the workshop "How to visualize art in public space" at Aldea. In the workshop we invited the Swiss artist duo Lang/Baumann who shared with us from their extensive body of art in public space how they use 3D modeling tools for both visualization, production plans and installation planning. The artists shared with us how they used 3D modeling software not just to visualize the final work, but also to estimate and plan the heights and angles for lifting works into place with large cranes. Working with large-scale public work requires the ability to communicate plans clearly, something 3D modeling tools can help with. When part of the planning for an artwork is being done with the assistance of a software system, its inbuilt geometric shapes, triangular meshes and mathematical tools will contribute to defining a framework for this creative process, and to shaping the results. An example from my own work is the public art project *The Moon, the Drop and the Diamond* (2024). I 3D scanned large rock boulders, used the "plane cut" feature in Fusion360 to plan how to cut the rocks in half, exported production drawings for the quarry production facilities who then did the cutting. What the software did not account for was the oval patterns created by the diamond chain as it sawed through the rock, forming gradually shrinking shapes from the initial circumference to the final pull-through. Neither could it tell me how popular the rocks would become for kids to climb on. The models of the sliced rocks were imported into a live updating 3D model used by architects, project managers and construction workers to coordinate placement with other elements on the public square, to make a concrete foundation in the ground and to plan the installation procedure.

Another part of sculpture-making practice being influenced and further developed by abstraction in 3D modeling technology, more specifically by digital fabrication, is mold making and casting. In *Objects at Hand,* I used 3D printed objects as positive shapes to build the negative mold around, and in previous works I 3D printed thin plastic molds that were melted away using a heat gun. The latter method made it possible to produce elaborate molds with very little manual work and with the possibility of making complex shapes without splitting the object into intricate multipart molds. This method was shown to me by glass artists and Aldea digital lab manager Patrícia Šichmanová, who has developed several of her own techniques by merging methods in digital fabrication and casting.

Ceramic artist Heidi Bjørgan is another Bergen based art practitioner who saw how the affordances of 3D modeling tools could be used in her own practice. She had an existing vessel that she wanted to produce multiple versions of at double its size. Aldea supported Bjørgan in recreating the object as a 3D model, scaling it and 3D printing it. She then used the printed object to make a plaster cast for a new series of ceramic sculptures which in the end varied in shape from wobbly or collapsed to perfect geometric objects. The work was



The artwork *The Moon, the Drop and the Diamond (2024)* and the 3D model used to create it.

exhibited as a final homage to the American ceramicist George Ohr (1857–1918), "whose vibrant glazes and wobbly vessels made him seen as a failed ceramicist by his contemporaries" (my translation) (Studio, 2020).

Nicolas Lamas is another artist who worked at Aldea and explored the possibilities of merging 3D printing and casting, while also further developing his use of readymades. In his practice, the classic readymade art object meets what I call the ready-made abstraction in 3D modeling. Many of Lamas' works appear to be meaning-generating juxtapositions of readymades. I think about his work as a play on abstraction and context, like a game where the idea about what something is and what it means changes in relation to its environment. When a shoe with strange, bone-like artifacts is placed inside a fridge, as in the work *Posthuman Ecologies* (2023), the unusual relation between these objects and their environment makes me, as a spectator, start making my own narratives about this object-context constellation. At Aldea Lamas developed new ways of creating such meaning-generating juxtapositions using 3D modeling tools. He used 3D models found online and combined them in 3D modeling software by merging the shapes together as one intersecting form. This would not be possible with physical objects and shows how having the shape of an object extracted as an empty shell brings about new formal and conceptual opportunities for sculpture-making. Lamas' new, digitally combined objects were then 3D printed as thin molds and cast in acrylic plaster following the method I described above, as what the artist called "hybrid forms that allude to processes of growth, change, and decay" (Lamas, 2023).

In recent years, several contemporary artists have made works that highlight ethical concerns and dilemmas that occur when culturally valued artefacts become abstracted as 3D models using 3D scanners. In 2015, German Iraqi artist Nora Al-Badri, along with her collaborator Jan Nikolai Nelles, carried out the project called *The Other Nefertiti*. The work involved secretly scanning the famous bust of Queen Nefertiti, which is on display at the Neues Museum in Berlin, and making the 3D scan available to the public (Vulliamy, 2016). The scan is easily accessible online and can, for example, be found on Wikipedia's list of common 3D test models. Scanning and sharing the model was a protest against Western museums taking artifacts from abroad and claiming them as their own. Al-Badri's project brings attention to the idea that digital models are not a valid replacement for the original objects and contributed to a public discourse about who has the right to possess and display cultural heritage.[38]

38. See a report on digital archaeologist Roger Michel 3D scanning the Parthenon Marbles at the British Meuseum in an effort to increase the likelyhood of returning the original objects to Greece: https://greekreporter.com/2024/06/18/3d-parthenon-marble-replicas-real-ones-returned/

The work of Austrian artist Oliver Laric's has also addressed how the abstraction and digitization of objects by 3D scanning can bring up questions regarding authenticity and ownership of objects. In the 2014 exhibition Yuanmingyuan3D at Entrée in Bergen Laric presented 3D prints of marble columns from the Old Summer Palace in Beijing. The marble columns were 3D scanned while on display as part of the collection of KODE art museum in Bergen before being uploaded to the website yuaminguan3d.com. On his website threedscans.com people can download the digitized marble columns as well as scans from collections of several other museums around the world and use them without copyright restrictions. In recent years several large museums have begun to offer digital models of objects as a way to share their collection with the public, such as the British Museum, The Smithsonian Institute in the US and the Rijksmuseum in Amsterdam.

American artist Morehshin Allahyari also engages in discourses similar to those explored by Al Badri and Laric. Her work *Material Speculation: ISIS* aims to reconstruct 12 cultural artifacts destroyed by ISIS during the war in Syria in 2015, and her project *Digital Colonialism* addresses "colonial powers in relationship to technologies such as 3D printers and 3D scanners and their use/misuse in the reconstruction of endangered or lost artifacts and cultural heritage of the Middle East". (Allahyari, u.d.) In collaboration with Daniel Rourke, Allahyari also created *The 3D Additivist Manifesto* (2015), a playful and inventive collection of contributions that speculates on the medium of 3D printing, featuring works from over 100 artists and theorists reflecting on the potential and cultural impact of 3D printing technology.

Summary of Objects at Hand

In the work *Objects at Hand*, I examined and made visible the effects of abstraction processes and abstraction structures employed when the shape of an object is transferred between physical and digital materialities using a laser 3D scanners and 3D printing. My research questions 1) what is abstraction in 3D modeling, 2) how does it work and 3) how does it co-evolve with some of its contexts led me to the following reflections.

1.
To capture the shape of an object with a laser 3D scanner is an abstraction process in 3D modeling technology. Like the etymology of the word abstraction points to – something is extracted out of something else. The result of laser 3D scanning is an abstraction in the form of point cloud data, which in this unmaking process became further translated using frameworks for abstractions such as a polygonal mesh and G-code.

2.
The abstraction processes of laser 3D scanning, conversion to polygonal model, mesh repair and conversion to G-Code means that something is both lost and something is added when comparing the 3D model to the scanned object. The object's shape, size, color and materiality has changed, and the meaning and function of the objects have changed due to the contextual shift from an office in India to an exhibition in Norway. The work of artists like Nora Al Badri and Oliver Laric shows that extracting the form of culturally significant objects into numerical data raises ethical questions around ownership, authenticity, and cultural heritage. Their work underscores the importance of material embodiment and context as unique properties that are often lost in the digitization process.

3.
The unmaking process of *Objects at Hand* highlighted abstractions that a 3D model is built on gives it special affordances which affect sculptural practice. It allows a shape to be manipulated, copied, uploaded, shared and materialized in digital fabrication processes. It has provided artists with new tools for work such as visualization, production and planning artwork in public space, tools which are not merely functional but also affect creative processes. Affordances of the 3D model have extended the possibilities in mold making and casting, exemplified by artists developing their practices at Aldea such as Nicolas Lamas.

Two Rocks Do Not Make a Duck

Two Rocks Do Not Make a Duck (2022) is a site-specific, interactive, augmented virtuality artwork made in collaboration with Cameron MacLeod.

In this work, I built on previous projects that demonstrated how abstraction in 3D modeling enables the translation of an object's shape across different materials. In *Two Rocks Do Not Make a Duck* we used this possibility to create duplicate physical and digital versions of the same objects and environments. With the help of VR[39] technology, we synchronized these duplicate shapes in time and space. This merging of physical objects and virtual environments is called augmented virtuality (AV).[40] *Two Rocks Do Not Make a Duck* explores the artistic potential of augmented virtuality and the new forms of sensing it enables. In the following text, I will discuss how downloadable assets, 'gaming physics', and other ready-made abstractions used as building blocks in virtual environments influenced this work. I will examine how these abstractions evolved alongside advancements in industries working with VR, augmented reality (AR)[41], and game engines during the development of our piece, and how these changes impacted our work.

The first version of the work was developed and presented in the Rocky Mountains at the Banff Center for Arts and Creativity in Canada in 2019, where Cameron and I took part in the five-week *Digital Promises* thematic residency together with other artists working with digital technologies. The program was led by artists Fatima Tuggah and Jon Rafman, whose guiding framework for the group was to explore societal effects, hopes and dreams, broken promises, opportunities and implications of various digital technologies. Another version of the work was shown at Arboretet University Gardens in Bergen in 2023, in a group show dealing with how people experience seasons. In conjunction with that presentation, I wrote a book chapter in the book *Changing Seasonality* (2024), which can be found on the *Text Page*.[42] In the following text section, I will focus on the version commissioned by MUNCH as part of the Triennale *The Machine is Us* (01.10 – 11.12.2022), a group exhibition featuring 25 artists exploring society's digital transformation. This version of the work was made with the assistance of developer Jonathan Nielssen, interaction designer Jørgen Steinset and

39. Virtual reality (VR) is an immersive digital environment experienced through a VR headset.
40. Augmented virtuality (AV) is when elements from the physical world are brought into a virtual environment. In an AV game it could for example be a physical golf club that the user holds in their hands, that is also visible in VR space.
41. Augmented reality (AR) is a technology that overlays virtual elements on a physical environment, altering what people see and interact with. A well-known example is *Pokémon Go*, where virtual Pokémon appear in real-world locations through the smartphone screen.
42. Parts of "Simulating Seasons in virtual reality" is reproduced or paraphrased in this text section on Two Rocks Do Not Make a Duck

Aldea Digital Lab Manager Patrícia Šichmanová. The complexity of the software systems and the digital fabrication techniques we used, the scale of the physical installation and the scope of the project made it unattainable for me to be hands-on in most of the making of this work. My unmaking process was therefore different in this project. Assisting other people as best as I could while learning from them replaced my typical hands-on exploration of tools and materials. Decisions about how to develop the work were not made in an intuitive, sculptural workflow, but instead through conversations with Cameron.

Two Rocks do Not Make a Duck consists of a three-dimensional floor, three rock-shaped sculptures with VR-trackers[43] and a site-specific virtual reality environment. The piece is experienced by one user[44] at the time wearing a VR headset and interacting with the piece by walking on the floor and moving the rocks. A video documenting this interaction can be found on the *Artistic Result Page* of my artistic reflection. Each time the piece is shown the virtual environment is recreated to match the location outside of the exhibition space. When a user put on the VR headset at MUNCH, they saw a simulation of Bjørvika and downtown Oslo that corresponded to the window view from the exhibition space located on the ground floor of the museum. The Akerselva river, Oslofjord and other geographical landmarks were there, but no buildings or objects made by humans. A simulated nature-version of the cityscape remained. The user could move through this simulated landscape by moving around in the installation, the walls of which functioned as movement boundaries in the virtual world as well. People were asked to take their shoes off to feel the shape of the three-dimensional floor under their feet and how it corresponded to the virtual ground seen in VR. In the VR headset they also saw virtual versions of the rocks, and when they picked them up the movement of the digital 3D model and the physical object was synchronized with the help of VR trackers. By moving the rocks, the user could experience changes in the virtual environment. If they moved fast the changes would happen quickly and if they moved slowly the changes would happen slowly. If they didn't interact with the rocks the VR environment would remain unchanged.

One of the rocks changed the weather from blue skies to overcast, rain showers and thunderstorms. Another rock changed the time of day and moved the sun across the virtual sky. When the experience started the sun would be in the same place in the virtual scene as outside the windows in the museum, a synchronization that would be broken by the user's interaction. If people put the rock down at nighttime, they would remain in a night scene until that rock was moved again. The third rock changed the time of year and would take the users through different virtual seasons of the simulated Bjørvika landscape. Leaves would grow on the trees in spring, change color and blow off in fall, and precipitation would change from rain in summer to snow in winter.

The user's sensory perception from hands, feet and body moving through space came from the physical installation, while the visual perception came from the virtual environment. From this experiential perspective it makes sense to call the augmented virtuality format a mixed reality, which is a term used to describe the merging of real-world environments with computer generated ones. In *Two Rocks Do Not Make a Duck*, the mixed experience of the user becomes possible by duplicating physical and virtual elements and synchronizing them in time and space using VR-trackers.

Three main elements in this piece exist as physical-digital duplicates: the rocks, the surrounding landscape and the ground. In the following paragraphs I will go through the process of making these elements and highlight some of the ready-made abstractions which affected the result. These ready-made abstractions include digital 3D terrain maps, downloadable assets and 'gaming physics'.

But before I address the ready-made abstractions in the piece, I will take one step back to point out that the abstraction process began even before we started assembling these building blocks. We realized early on that to make a virtual environment which looks real is something quite different than trying to simulate the natural world in a scientifically accurate way. Our knowledge, budget, time, and the point of view from where the user was standing limited what was possible and meaningful to simulate. In the recorded conversation with Gustav Tresselt, available on the *Video Page*, we discuss the issue of simulating reality in VR. He pointed out that the process must begin with figuring out what one's main goal is and then choosing which elements to simulate. In our case, one of the things we wanted to achieve was to let the users see the Bjørvika landscape at different times of year. We had to choose which environmental events to simulate and to focus on these seasonal markers, such as snow in winter and leaves falling in autumn. This selection was an abstraction process, resulting in a simplified version of what seasons are.

To create a virtual topography of Bjørvika we used digital landscape models made by the Norwegian Mapping Authority, who have digitized most of Norway with laser scanners flown across the country. The digitized landscapes are made available to download for free, aimed at uses like assessing risk of flooding and landslides or planning infrastructure.[45] We converted

43. A VR tracker is a piece of hardware with sensors on it that communicates to the computer where it is located in the space. The trackers can be attached to physical objects, whose movements then can be tracked in the virtual scene.
44. I apply the term "user" to describe the person experiencing the AV work. This term describes their role as activators of the work and is commonly used in the technology field of AV.
45. More about digitized terrain maps of Norway on https://www.kartverket.no/api-og-data/terrengdata

the digitized terrain from The Norwegian Mapping Authority into a polygonal model readable by the 3D computer graphics game engine Unreal Engine (UE). This gave us a good approximation of the landscape in VR; The Akerselva river mouth was positioned correctly in relation to the Oslo fjord and the islands and hills in the distance could be seen by looking in the direction of their physical counterparts.

The title *Two Rocks Do Not Make a Duck* refers to a Canadian saying which means that you need more than two rocks to make a path-showing cairn. I think of the cairn as an object linking abstract representation of landscape and the embodied experience of it. Cairns have been used both to show the way through a landscape on the ground, as well as a tool in traditional map making. Cartographers used cairns as visual markers to measure angles between points and to use this information to make trigonometric calculations by adding the distance between two of the other points in the triangle.[46] Similarly, the mathematical principle of trigonometry is also applied in current laser 3D scanning technology.[47]

From a contemporary, western, adult person's perspective, abstract representations of nature have taken precedence over the direct experience of the environment as a source of knowledge. Going back to my previous examples – most of us perceive the Earth as round and fast-spinning even if it looks like it is flat and feels stationary. Reflecting on Husserl's idea of a world divided by the scientific worldview of the 20th century, I see the cairn and the AV format as two elements connecting abstract landscape representation with embodied experience. The cairn is an object used in both cases, and the AV format enables spatio-temporal experiences of digital 3D maps.

Both paper maps and digital 3D maps play a role in shaping our understanding of the landscapes they represent, influenced by the information they include, and the technological medium used to convey it. In her essay "Situated Knowledges" (1991) Donna Haraway points out how technologies for seeing and sensory augmentation, such as microscopes and telescopes, are not neutral devices but are shaped by power relations which influence what we see. *Proxistant Vision* is a notable and award-winning artistic research project carried out in Norway by Synne Tollerud Bull and Dragan Miletic which shows how technological representations and mediations of landscapes shape our perception of them. In their research Bull/Miletic examine how the machine vision technologies of drones and satellites allow us to see near and far simultaneously, and how this affects our worldview.[48] Creating *Two Rocks Do Not Make a Duck* allowed us to explore and gain an initial understanding of how some underlying abstractions of the augmented virtuality format might influence perception and experiences of landscapes in this medium, some of which I will discuss shortly. However, a broader and deeper understanding of how this new technology shapes ways of sensing and understanding is beyond the scope of my research at this point.

We imported the digitized landscape into Unreal Engine (UE), a game engine, which is an advanced software system used to create photorealistic images and real-time renderings in industries like gaming, architectural visualization, and VR. The landscape appeared as a thin, curved surface devoid of any human-made elements, providing a base on which we could build by adding 3D models, dynamic components, and interactive features.

The 3D models of trees, plants and rocks that we used to build up the virtual environment are usually referred to as assets in the context of game engines. Most of them were downloaded for free from the online 3D assets library Quixel. Quixel is a Swedish company that makes assets from photogrammetry scans of objects, a process where multiple photos are taken from different angles of an object before this image data is converted into a 3D representation. The 3D model is then optimized by altering its mesh and texture with the purpose of reducing its file size. This file size reduction is especially important when the 3D models are going to be used in VR with real-time rendering as the user moves through the environment. The optimization makes sure that the 3D models take up as little as possible of the computer's graphics card capacity and processing powers. A recurring conversation with the developers working on this project was how to spend this 'computational budget', and how to reduce the 'computational cost' of assets and interactive features.

The work done by Quixel in capturing objects and optimizing the 3D models is time-consuming and requires specialized knowledge and equipment. To build our 3D models from scratch would require time and resources not available to us. The common practice we followed was therefore to combine objects from such archives of ready-made abstractions and build up our simulation from those.

Browsing Quixel's 3D asset archives shows that the availability of 3D models is shaped by market demands, making 3D assets a form of abstraction in 3D modeling technology that evolves with its context. For instance, the "Trending Assets" section includes items like

46. See for example https://www.riksantikvaren.no/siste-nytt/pressemeldinger/freder-kulturminner-for-kart-og-oppmaling/: "Varder ble bygget på trigonometriske punkter og hadde en viktig funksjon som siktemerker ved oppmåling. Fra midten av 1800-tallet ble det vanlig å markere vardens sentrum med en bolt, før byggingen av varden startet. Det trigonometriske punktet Lofotodden inngikk i trianguleringen for kystrekken nordover fra Trøndelag i tiden 1829 til 1833."
47. More about trigonometry in laser 3D scanning: https://georgepavlides.info/research/LaserScanningAndTriangulation.php
48. See more about the Proxistant Vision project on https://proxistantvision.net/

"Curated Stone Facade," illustrating Quixel's role in supporting architectural visualization. This industry increasingly uses game engines for creating detailed, real-time 3D environments with complex lighting and ready-made models that fit seamlessly into various spaces. As architectural materials expand, both Quixel's library and Unreal Engine (UE) become more valuable tools for this field.

These dynamics also play out on a larger scale. In 2019, Epic Games, the creator of UE, acquired Quixel and made its assets free for UE users. For us, this meant an influx of ready-made 3D models for VR scene development. Access to a comprehensive, high-quality 3D asset library is a significant factor for many professionals choosing Unreal Engine over other software. This acquisition highlights the role of pre-made 3D assets in guiding industry trends in fields such as art, architectural visualization and game development, comparable to how Formlabs' proprietary algorithm for generating support structures contributes to shaping user options in the 3D printing sector. Unlike Formlabs users, who cannot modify, export or choose a different support algorithm, UE users can import 3D models from other systems. However, the seamless integration of Quixel assets within UE encourages building virtual worlds with these pre-made elements. Just as CAD tools shape the traits of designed objects, 3D asset libraries influence the characteristics and patterns of virtual environments.

For our simulation of Oslo's natural environment, it was beneficial that Quixel is based in Sweden and that their database therefore offered several "Nordic Forest" assets. As these libraries expand with more categories and better variety and quality, it may become less obvious that these virtual objects were created by somebody somewhere, and they might instead appear as endless virtual representations of anything we can imagine. However, this quickly becomes more difficult to achieve when considering movement, change, and interactions between elements.

The Quixel 3D models of plants that we used in our scene were captures of only a brief moment in the lifecycle of a plant. To make this plant grow its leaves from buds to full size or to let the leaves fall off and blow in the wind we had to modify the 3D model. Jørgen Steinset, the interaction developer who worked on the piece, explained to me that the 3D model of a tree is typically built up by three layers: a stem, branches, and leaves. These had to be programmed to respond differently to time passing. In fall, a gradually expanding 'invisibility texture mask' on the leaves would make them disappear, while the branches and stem remained unaffected. In some cases, it was challenging to make all these parts behave separately and together in the way they should. In an earlier version of the scene, the stem of the tree was affected by the wind in the same way as the leaves, which made it look like the tree was swaying in some material much denser than air, like a large underwater plant.

UE software functionality and plugins were used to make other elements move in a realistic way. "Ultra Dynamic Sky" simulated the movement of clouds, "Volumetric Clouds" made it look like the clouds interacted with sunlight, "Fluid Flux" is a plugin simulating water in motion and interaction with objects, and "SpeedTree" is a system simulating a virtual plant's growth. These features are built up as complex layers of algorithms, geometrical and mathematical abstractions, and were adapted to our scene by adjusting different parameters. In an exhibition text from the MUNCH Triennale where our work was exhibited, about the artwork of artist Harun Farocki (1944–2014)[49], the ready-made abstractions controlling the movement and dynamic changes in simulated environments are described as "physics of the gaming world" (MUNCH, 22). The four-part video installation *Parallell I–IV* (2014) "traces how computer games have developed from primitive cartoon graphics to immersive, hyperrealistic environments over thirty years" (MUNCH, 22). Harocki's work highlights how algorithmic abstractions and mathematical calculations affect the development of nature simulations, by defining the movement elements such as water, skies and wind. The work makes visible how the physics of the gaming world gives shape to the landscapes and representations of nature in movies, games and other virtual environments, and by extension to our augmented virtuality artwork *Two Rocks Do Not Make a Duck.*

Advancements in 'gaming physics' and asset libraries were just some of many areas in AR and VR industries that saw significant progress from 2020 onward. In 2021, Facebook announced the "Metaverse," a plan to integrate virtual reality into everyday life, accelerating technological development in a manner that directly impacted our work. What seemed like daily hardware and software releases continuously changed what was possible to create in VR and what would be the best working procedure. I recall discussions with developers about whether we should integrate the new UE plugin "Ultra Dynamic Sky," offering real-time, dynamic weather and lighting systems, allowing us to simulate day-night cycles, weather conditions, and atmospheric effects. We also saw several VR headset makers rushing to release new products in time for the Metaverse launch, and purchased one from the Finnish company Varjo, which greatly improved the VR experience by reducing the common effects of disorientation and motion sickness often caused by other headsets.

The physical elements of the artworks were made at Aldea using digital fabrication workflows, and by experimenting with the possibilities of shifting between

49. Harun Farocki was a German artist who made works critically interrogating the film medium, the power of images and their technical construction.

digital and physical materialities enabled by the underlying abstractions of the 3D model. The primary structure for abstraction used here is the coordinate system where a 3D model is represented by numerical values (x, y, z coordinates) in a virtual 3D space. This abstraction structure is fundamental to most 3D modeling software, as well as fabrication processes like CNC machining and 3D printing, which rely on these coordinate systems to translate digital designs into physical objects.

The digital model for the floor was made in Quixel Mixer[50] by blending a set of ready-made textures of gravel, forest floor and rock surfaces. The 3D model of the floor was then prepared for manufacturing in Fusion360, exported as G-Code and milled out in layers of high-density fiberboard on the CNC machine before it was sprayed with acrylic plaster. Finally, the 3D model of the floor was imported into the VR environment and positioned where the user would move around in the installation.

The shape of the floor of our installation had first existed as a virtual model, then recreated as a physical floor with a CNC machine. The surrounding Bjørvika landscape had been translated from physical landscape to digital 3D terrain. For the rocks we tried both directions of this translation. At Banff I sculpted rocks by hand and 3D scanned them using a laser 3D scanner. For MUNCH, we chose to use rocks scanned by Quixel, aiming to match the realistic appearance of the rest of the virtual environment, and to produce sculptural versions of those. We picked out and downloaded 3D models from a library of high-quality scans of beach rocks, boulders, cliffs, gemstones, granite, mossy rocks, sandstone, volcanic rocks and more.

Quixel assets are optimized to display the objects as digital 3D models on screens, and not to manufacture them. Part of the optimization done by Quixel is to lower the number of polygons in the 3D model, making it absorb less of the computational budget. The detailed look of these simplified structures is still maintained by applying textures such as a depth map. A depth map is a greyscale image layered on top of the geometric structure of the 3D model which helps the software render and display the objects as a detailed object, with lower computational power than rendering a high-poly mesh would require. In digital fabrication the machines only reproduce the geometrical shape of the object and not things like depthmaps or other textures. To make physical rocks with a high level of detail corresponding with what the user would see in VR we therefore needed the geometrical structure itself to be more detailed than the downloaded Quixel models were. We achieved this by first re-meshing the models to increase polygon count and then added detail to the surface by converting the depth map data into geometry. This depthmap-to-3D-structure conversion is an example of how we used the abstractions 3D models are built on to develop new experimental methods for object-making in the AV format.

After optimizing the 3D models for physical production, we used them to create negative shapes of the rocks and printed those as plastic molds on the 3D printers. The molds were then filled with acrylic plaster and a Styrofoam core to make them light enough for people to lift, but still heavy enough to give the feeling of holding a rock in your hands.

Two Rocks Do Not Make a Duck was installed on the ground floor of MUNCH in front of a window overlooking the downtown Bjørvika area and some of its most significant landmarks like the Akerselva outlet into the Oslofjord. The floor and the rock shaped sculpture had to be synchronized in time and space with the 3D models in the VR scene. The rocks had VR trackers attached that signaled to the computer where to move the virtual rock in the scene's 3D coordinate system. The synchronization between the floor in the installation and in VR was done on-site by visually estimating and making small adjustments until the virtual and physical floor perfectly aligned. The VR environment was synchronized with the outside landscape by using map data from the downloaded map and matching that by pointing the headset North and manually entering found local coordinates as headset location. The synchronization of these duplicate physical and digital landscapes and objects allowed people to experience a mixed reality where touch and movement came from the physical installation while visual impressions came from the VR scene. I was able to peek into what this experience was like for some of the users through a logbook kept by the MUNCH hosts. They wrote down how people interacted with the work and some of the comments and questions people had in response to the work. The following paragraph paraphrases and summarizes some of these logbook entries.

People seemed to really like the starry nights and the changing of seasons, and some spent a long time sitting down on the floor, moving the rock just incrementally. One girl reacted to the piece with a laughing-fit, while two ladies in their 50s called the experience boring and wanted something more action-packed. A man in his 70s and his son experimented a lot with the piece. They lay down, sat on one of the rocks, moved multiple rocks simultaneously and built several ducks (cairns). A middle-aged couple from Italy were intent on balancing on top of the rocks, which they both managed to do on top of the day/night rock. Many people asked about the technology behind the nature-simulation and commented on how being in the simulation made them feel. Several people mentioned that the virtual landscape reminded them of their place of birth. Some people did not recognize that the landscape in VR was a simulation of their current outside location, while others enjoyed identifying the surrounding landmarks. One woman in her 50s expressed her

50. Quixel Mixer is a software tool used to create and apply textures to 3D meshes.

disbelief at how much time this must had taken to film and was even more astonished when she learned that what she was not experiencing a film but a computer simulation. Another woman felt scared and alone, while others were less convinced, noting for example that the fjord should freeze over in the winter. One person commented that it is interesting to think about how much the landscape is affected by humans, and in a review of the show a critic wrote that "all of a sudden the digital world appears more natural than the real." (Holtvedt, 2022)

Summary of Two Rocks Do Not Make a Duck

In this work I examined how the underlying abstractions of the 3D model make the augmented virtuality format possible and how ready-made abstractions like 3D maps, downloadable assets and gaming physics shape virtual environments. My research questions 1) what is abstraction in 3D modeling, 2) how does it work and 3) how does it co-evolve with some of their contexts, led me to the following reflections:

1.
The process of abstraction in this work began by choosing which environmental elements to simulate and not. From there, we constructed a simplified representation of nature using ready-made abstractions like digital 3D maps, downloadable assets, and gaming physics. The digital 3D map served as a starting point, defining which information was included or omitted in this abstracted landscape, upon which we built the virtual scene. The 3D assets like trees, rocks and ground determined what the virtual environment looked like, and the gaming physics of the software system determined how elements in the virtual world behaved and interacted with each other.

2.
The numerical abstractions within the 3D model make the augmented virtuality format possible. These abstractions, such as x, y, z coordinates and depth maps, enabled the digital and physical duplication of the installation's rocks, landscape, and floor. This involved translations both from digital to physical and vice versa: With digital fabrication we created physical versions of the virtual 3D rocks. By employing digitized terrain maps and the UE plugin Ultra Dynamic Sky we created virtual representations of the physical outside environment. VR technology allowed us to synchronize these virtual and physical elements. Augmented virtuality, as a format, exists through the integration of technologies like VR and digital fabrication, both of which rely on, and are coordinated through, the numerical abstractions of the 3D model. This format enables a new kind of mixed sensing, where users can interact with both physical and virtual worlds simultaneously, and where what they perceive is determined by layers of abstractions.

3.
This project's timeline coincided with rapid technological advancements in VR which affected what we could make and how to make it. These advancements were triggered by events such as Facebook's announcement of the Metaverse in 2021 and highlighted the reciprocal development of 3D modeling technology and the industries it serves. The growth of platforms like Quixel and their influence on what can be built in virtual environments reflect the needs of industries like architecture visualization, gaming, and entertainment. These industries drive the creation of new assets, and in return, those assets define the possibilities for designers and developers. Similarly, the "gaming physics" presented in Farocki's work *Parallell* determines how virtual elements change and interact with other elements, and how nature is represented in movies, such as how water moves or how wind affects a tree. In our project the UE-plugin Ultra Dynamic Sky was an application of gaming physics, determining how clouds moved across the sky, simulating day-night cycles and changing weather patterns.

Public presentation of Unmaking Abstractions

The public presentation of my PhD project *Unmaking Abstractions* took place in the venues Entrée in Bergen and Oseana Kunst og Kultursenter (Oseana) in Os from 05.02. – 13.03.2022.

At Oseana I presented most of the works from the research project in a classic exhibition format, enabling people to experience and interact with the work in a spatio-temporal manner. At Entrée I organized a series of live events with external contributors that I called *Open Studio*, offering a discursive entry point to themes of my research and facilitating a view into the processes behind it. Both public presentations were curated by Entrée's founding director Randi Grov Berger.

photo: Bent René Synnevåg

Part one: Exhibition at Oseana

The exhibition *Oppløyste Abstraksjonar* included the works *Secret Support*, *Holder* and *Objects at Hand,* which were exhibited in a custom-built exhibition architecture and artwork titled *Explode Mesh*.

In this section, I will address decisions made regarding the presentation and mediation of the artworks at Oseana, including the selection of space, choice of specific artworks, and how the presentation of the artistic result as well as new artworks were created to suit this particular venue. I will also point out further similarities between the geometric structures in 3D modeling, specifically in polygonal models, and work made Latin American artists in the post-World War II era, that became visible while making the architecture.

After visiting different venues in and around Bergen together with Grov Berger, I chose Oseana for their exhibition space large enough to present several sculptural works and installations, for the institution's capacity to host and mediate exhibitions and for their generous flexibility in allowing me to occupy a space that is normally only used to show their permanent collection. A reason for choosing to display most of the main works made in this research project in one solo exhibition was to let my research topic emerge as a dialogue between the works. The work *Two Rocks Do Not Make a Duck* was not shown at Oseana because it was a site-specific piece commissioned by MUNCH for a Triennale taking place some months after the exhibition at Oseana.

The exhibition space is situated at the waterfront in Os, with one long, curved wall consisting of windows from floor to ceiling. It is separated from other parts of the venue's functions by an internal glass wall as well as by one straight plastered wall running the back-length of the room. With transparent glass walls making up most of the physical boundaries of the large space, it made the exhibition area seem undefined, and there were not enough solid walls to support or present the works. To hang the works directly on the few solid surfaces and to put them directly on the floor would not give a good distribution of objects in the space or frame the works in a beneficial manner.

To navigate these spatial qualities, I chose to build an exhibition architecture that could hold and carry the works, and that could define the exhibition space as well as the individual pieces. The exhibition architecture included *Explode Mesh #1*, a three-meter-long wall used to hang *Secret Support #7*, and *Explode Mesh #2*, a ten-meter-long wall used to define the space and to hang *Secret Support #1-* and *#6.* Additionally, three podiums were used to lift and visually isolate *Secret Support #2*,*- #6* and *Objects at Hand* from the wooden floor. The shapes, colors and materials of the sculptural walls and plinths were also made to visually tie together the works within the exhibition and to tie the exhibition at Oseana to the *Open Studio* at Entrée. Some of the stools from the Entrée interior were used in the presentation of the *Holder* YouTube videos, the blue laminate surface from the furniture at Entrée reappeared on the floor pedestals, and the yellow color from the exhibition architecture echoed the color in *Objects at Hand*.

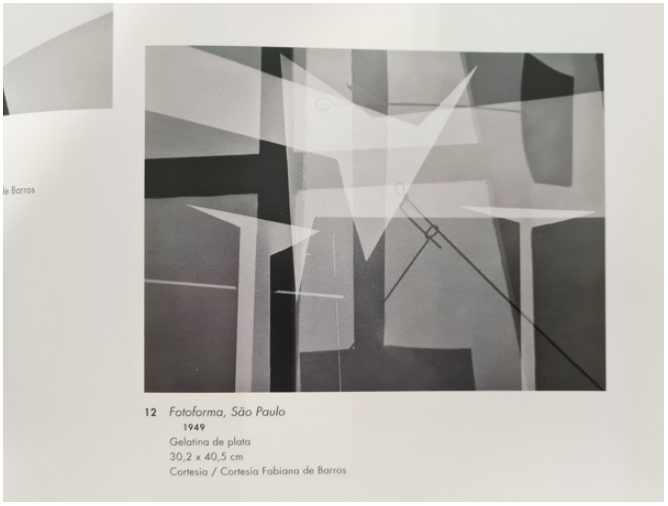
My process of developing the exhibition architecture illustrates how 3D modeling software can serve as a tool that blends planning with creative exploration. The polygonal structure inherent in the 3D models materialized in the installation, offering an opportunity to engage with this foundational geometric structure of the 3D model in an embodied, physical way. In the recorded video conversation with Sirisha Shashikanth, available on the *Video Page*, I take her through the process of making this exhibition design and present 3D models of the space and the exhibition architecture. Screen recordings from navigating these 3D models can also be found on the *3D Model Page* of my artistic reflection.

I found the shape and composition for the exhibition architecture by importing polygonal models from *Objects at Hand* into Fusion360 and navigating around them in simulated 3D space. Zooming in and out on these triangular meshes, changing their scale, cutting out extracts of, distorting and orbiting around them followed up an experimentation with the malleability of polygonal meshes that I began with *Objects at Hand*, all processes made possible by the mathematical and geometric abstractions the mesh is built on. The size and angles of the polygons of the *Objects at Hand* 3D models varied a lot because they had been converted from point cloud data with certain missing segments that had been automatically filled in by the software. The mesh's variation in polygon size and non-uniform pattern made it possible to find a mesh fragment that both had an interesting composition and that could function as a large wall. I chose some small extracts of the polygonal mesh from the hammer 3D model in the *Objects at Hand* sculpture series – originally smaller than a fingernail – and rescaled these triangles to become larger than the human body. This manipulation of the triangular mesh accentuated the floating scale of the 3D model, which was also expressed in the objects' disconnection from human scale visible in *Objects at Hand*.

Seven triangles from the middle section of the big wall were copied to create the smaller wall. I was surprised to learn that this repetition of forms was something I had to point out for people to see, perhaps because the two walls were positioned adjacent to each other making them impossible to see head-on at the same time. Or it could have been because the high-contrasting colors and open versus closed triangles created new formal compositions within each of the walls that were more visually dominating than the outline of the seven triangles. With odd angles such as 89.7 degrees, the triangular pieces would have been nearly impossible to produce without the assistance of CAD software translating these forms and their cut paths into G-Code for the CNC machine, which precisely cut out all elements before they could be painted and assembled in place.

The fabricated triangles of the polygonal hammer mesh were scattered across and stacked up against the walls in Aldea's project space, to me expressing how unmaking abstractions is both a process of picking apart and putting together again. Searching for a Norwegian approximation of *Unmaking Abstractions*, I titled the exhibition *Oppløyste Abstraksjonar*, with the word "oppløyste" pointing to the picking-apart element of unmaking. In retrospect I have thought that the title rather should have been *Ombygde Abstraksjonar* (rebuilt abstractions), reflecting also the constructive nature of unmaking.

While navigating the polygonal models in simulated 3D space my screen seemed to display a continuously changing Neo-Concrete painting. It reminded me of the black-and-white photographs of manipulated and almost unrecognizable geometric structures of the modernist city I had seen in the exhibition *Constructed Vision – Abstract and Concrete art in Latin America from the collection of Ella Fontanals-Cisneros* at Haus Konstruktiv in Zürich in 2011, the exhibition that initially introduced me to the work of the Neo-Concrete movement. The exhibition included several photographs of this kind, for example the series *Fotoformas* (1949) by



Geraldo de Barros, *Fotoformas* (1949)

Screenshot from polygonal 3D model

Brazilian painter and photographer Geraldo de Barros, where geometric forms and structures, shadows and what looks like photo-manipulated elements blend together.

The video works, sculptures, installations and paintings of the exhibition *Sites of Abstraction* interrogated the relation between surface and volume, the grid structure, and the effect that the urban landscapes expanding in modernist Latin America during the 1950s had on sensory experience and people's relation to their environment. Revisiting these art works highlighted how my inquiry into 3D modeling technology follows a trajectory from the Neo-Concrete artists, as artistic research into infrastructures that shape our surroundings and the way they are perceived. In a curatorial exhibition text written by Juan Ledezma he describes how artists in the exhibition considered the city as a dynamic object "whose form and content shift through its process of perception" and describes photographs in the exhibition as "the product of a form of seeing mediated by a technical structure", (Ledezma, 2010, pp. 221, 222)

The communication of the exhibition at Oseana was done with the local context and art audience in mind. The mainly Norwegian-speaking audience range from dedicated Oseana members to peers and colleagues in the professional art field, to children and their families stopping by on their way to or from concerts or movies in the Oseana culture house. Randi Grov Berger wrote a short mediation text in both Norwegian and English introducing the audience to key topics of my research. An iPad with the artistic reflection website[51] was made available at the entrance of the exhibition along with information about the live program running in parallel with the exhibition in the *Open Studio* at Entrée. In-depth information about the project was also communicated in a conversation between me and the curator at the exhibition opening and during several guided tours of the exhibition by Oseana staff and by myself.

Part two: Open Studio at Entrée

Open Studio took place at Entrée in Bergen city center and ran parallel with the exhibition at Oseana from 05.02 – 13.03.2022. It consisted of a public program of lectures, workshops and performances put together with the aim to unpack questions and reflections from my artistic research project together with colleagues, peers and audiences.The interior was custom-built to host the gallery's year-long program of discursive art events. During the time of the open studio, it was filled with processual objects from my research, such as casting molds, color samples, sketches and books. I rearranged the objects in the space to fit the current events, for example highlighting museum shop versions of Lygia Clark's *Bichos* sculptures during the lecture on her work. My artistic reflection website was made available to the audience on an iPad in the gallery

photo: Bent René Synnevåg

as well as a short mediation text introducing the topics of my research, the exhibition at Oseana and the live program at Entrée.

In the next section, I will describe the interior created for Entrée, focusing on its modular flexibility and how the shapes were influenced by abstractions in CAD software, such as parametric features and the Bézier curve. I will also provide a brief overview of the performances and workshops that took place, focusing on the contributions that were particularly valuable to my project's reflections, which have not yet been addressed.

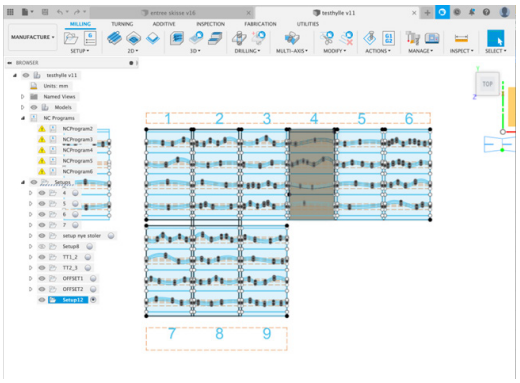
Interior for Entrée

From fall 2021 to fall 2022 Entrée ran a program focused on socially engaged practices, including workshops, performances, lectures and talks. In addition to being one of the artists in this program (with my *Open Studio*), I was invited to redesign Entrée's white cube interior, transforming it into a space that can accommodate the artists and events taking place throughout that year.

Developing the interior made visible how the parametric features of CAD and the Bézier curve facilitated the creation of flexible and adaptable elements that could be rearranged by the user by being split up into smaller sections or packed away. It also demonstrated how digital fabrication with a CNC machine enables advanced, cost- and material-effective prototyping and small-scale production.

To facilitate the discursive program of Entrée, Grov Berger wanted to transform the white cube into a space with shelves from floor to ceiling, a large table in the middle and seating. Given the variety of events and formats planned, I designed an adaptable interior that artists could modify as needed.The space functioned both as a sculptural, modular, interactive installation and as

51. My artistic reflection was originally made and presented to the public in the form of an interactive website. KMD later requested a different format for the artistic reflection, and the content of this website was therefore migrated and adapted to the platform Research Catalogue.



a practical interior. Most artists who presented at Entrée during this period actively engaged with the installation, while others chose to remove most of its elements.

The shelves were hung on cleats and could be moved around. A cleat system consists of two profiles that fit into one another, where one part is hung on the wall, and the other part is attached to an object. The inspiration for this flexible system came from the workshop interiors at Aldea where we hang most of our tools on such structures. The exhibiting artists had cleats available to cut up at desired lengths which they could use to attach to their own objects. Examples of different elements that were added as cleat-hung structures along the way were coat hangers, holders for rope hooks, a pin board and a wooden board used as a projection canvas. The wall-mounted cleat profiles were also used as mini-shelves to display flat objects, to hang things from with paper clips and to attach large painting canvases.

The shelves' curved shapes and color contrasting the walls made them a visually present element in the space. In some events, such as the Bergen Art Book Fair, shelves were installed to form one long unit at the bottom cleat row. In other events, like the artist book exhibition *SIGLA BINDA* the shelves were evenly distributed across the walls all the way to the ceiling. In some cases, such as the exhibition by artist Marco Bruzzone, the artists chose to remove all the shelves and used the wooden cleats to directly hang paintings, sketches and more.

The table was made in four parts that could be combined in different ways to create a large rectangular table, a large table with curved edges, two medium sized rectangular or curved tables, or serve as four single modules. Both the tables and shelves were made to be easily stowed away in the gallery's limited storage space, by making the elements stackable and table legs detachable.

To give shape to the shelves I used the parametric Bézier curve, the ready-made abstraction whose effect on the look and function of digitally designed objects had become visible to me in the making of the *Holder* sculptures. Continuing my examination of this mathematically expressed curve in this interior meant materializing it as physical objects, sanding it, painting it, and creating a surrounding environment with it. In Fusion 360 I used Bézier curves to divide a rectangle in two pieces that had one curved edge and three straight edges. I chose two values for the start and endpoints of the Bézier curve and adjusted the spline handles to create various curved lines between them. By defining the start and endpoints of the shelves' lower curved edges as user parameters, half of the shelves matched their lower edges, enabling them to be positioned to form a continuous line, as exemplified in the SIGLA BINDA exhibition. The divided rectangle boards were used as a top and bottom part for the shelf and their width was of standard plywood size. These design choices, afforded by the Bézier curve, enabled a compositional flexibility with the shelf elements, while making it possible to use the full plywood sheet and reduce material waste and cost in the project.

The stools were made at two different heights, the highest providing a comfortable working height for workshops, the second made for sitting during lectures. Stool height is an example of a value I entered as a user parameter in Fusion360 which allowed me to quickly update the design by changing this value. In the same way the stool seat size, table width- and height, material thickness, distance between cleats and other parameters could be adapted after testing how the different parts fit together into a 3D model I had made of the space. The parametric functionality in Fusion360 made it easy to test out different design options and create physical, modular elements with chosen and tested variations in shape, size and function. In Patrícia Šichmanová's workshop "Parametric Design in Fusion 360" she taught the participants how to create parametric designs by using the interior as an example exercise object. Gabriele de Seta's lecture "On infrastructural abstraction: Models, parameters and algorithms" offered a theoretical perspective on parametric design, addressing both the Bézier curve and examples of interactive architectures where people's movements become parameters for a changing space.

After completing the digital drawings and developing prototypes for the interior elements, my role in the production shifted between supervising the process and being an active member of the Aldea production team. The CNC machine at Aldea was especially useful for cutting the curved shapes of the tables and shelves before assembly, as it could reproduce various versions of the curves without the need for new templates or manual adjustments. This flexibility is one of the key advantages of digital fabrication in small-scale custom production, where precise and detailed designs can be created efficiently without requiring costly templates or setups. In this context, CNC milling was a cost-, material- and time-saving method for producing this custom-made interior consisting of 36 shelves, a table in 4 parts, and 16 stools of two different heights.

I chose to color the interior at Entrée in a combination of light grey stain on the plywood walls, a dark blue stain and black paint on the shelves, a bright, blue laminate surface for the table and stool tops and a burgundy

hardwood imitation stain on cleats and furniture legs. My non-conscious cognitive approach to finding this combination was as previously described – to search for a combination I could not quite put my finger on and with a color that stung my eye slightly – in this case the burgundy mahogany imitation. The high contrast in colors combined with the expressive Bézier curves made the interior not only shaping the functional use of the space, but also giving it a distinct aesthetic characteristic.

After the end of Entrée's yearlong discursive program, the gallery sold all the shelves and stools. Many of these ended up in people's homes and artist's studios, and the tabletops were recycled to make new objects. This was a way for Entrée to regain some of the production costs, to avoid material waste and for parts of this project to continue circulating in people's home and work environments.

Creating a space and a support structure for artworks and art events while overlapping art, interior architecture and design can be seen in other contemporary artists such Celine Condorelli and Sol Calero. Condorelli is a French Italian artist and architect who has made artworks, curated exhibitions and done extensive research on both the formal qualities of support structures and what they support. In the exhibition *Corps á Corps* at the Institute of Modern Art in Brisbane (2017), she created works based on the history and theory of exhibition design. The objects displayed were at once support structures for art works and at the same time sculptures in themselves, an approach that I adopted when making the exhibition architecture for Oseana.

Venezuelan artist Sol Calero is another notable practitioner bridging disciplines of art and design who, shortly after my interior at Entrée had been dismantled, transformed a senior's canteen in Bergen into a colorful and vibrant space with plastic plants, tiled patterns and room dividers reminiscent of beach bungalows. The project was commissioned as part of Bergen Assembly and used as a key gathering place for events during the Triennale's duration. Since then, the interior has remained in the canteen, contributing to its increasing popularity among Bergen locals.

Performance by Sidsel Christensen

Open Studio with Public Program at Entrée

The Open Studio ran in parallel with the exhibition at Oseana and included contributions from people who had already influenced and supported my project as conversation partners, thinkers and practitioners. In the following brief summaries, I will highlight some of the input that provided valuable new insights into my research and influenced my reflections abstraction in 3D modeling technology, with focus on elements not already covered in previous parts of this written reflection. Three of the five contributions were video recorded and can be watched on the *Video Page*.

12.00–16.00, Saturday 12. February 2022
Workshop in parametric design by Patrícia Šichmanová

Images of this workshop can be seen in the Documentation of artistic result PDF.

Patrícia Šichmanová is a Bergen-based glass artist from Slovakia. Through her work as digital lab manager at Aldea, Šichmanová offered valuable support to my PhD research by sharing her knowledge and assisting in digital fabrication, mold-making and casting of elements in the works *Two Rocks Do Not Make a Duck* and *Holder*.

Šichmanová introduced the use of parametric design in the 3D-modeling software Fusion360. The workshop was run as one of Aldea's many practical courses for artists and other creative professionals, this time situated at Entrée instead of Aldea. The purpose of the workshop was to give the participants an experiential understanding of what parametric design is, how they can use it in their own work as well as how parametric design is a form of abstraction in 3D modeling shaping CAD workflows and outcomes. Another purpose of the workshop was to include the participants into parts of my own working process through repeating steps I had taken to digitally design the installation surrounding them there. As example exercise objects I therefore asked Šichmanová to use the tables that the participants were gathered around during the workshop.

13.00, Sunday 13. February 2022
On Infrastructural Abstraction: Models, Algorithms, Parameters – a lecture by Gabriele de Seta

A recording of the lecture is available on the Video Page.

Gabriele de Seta is a sociologist and a research leader at the Center for Digital Narratives at UiB. I got to know Gabriele and his work through his Postdoctoral Research at the UiB, where he was part of the ERC-funded project "Machine Vision in Everyday Life".

De Seta's lecture was delivered live at Entrée as the second event in the program and offered thoughtful theoretical and philosophical perspectives on parametric design, algorithms and computational abstraction, providing several new entry points to my research as a whole, to specific work examples and to the topic of parametric design which had been practically explored in the previous day's workshop. Drawing on Luciana Parisi's *Contagious Architecture* (2013), he extended the conversation about parametric design to other aspects of abstraction in 3D modeling and my research project. Starting from the interior at Entrée and the objects on display – such as the 3D printing support structures, parametric interior, and Bézier curve – De Seta explored how models, algorithms, and parameters act as infrastructural abstractions that shape and permeate our environments. Framing the sculptural objects at Entrée as illustrative examples of these abstract infrastructures he offered a new conceptual framework through which to view this work.

De Seta discussed what Parisi frames as a "double fallacy" in relation to computation, emphasizing her argument that it is insufficient to view algorithms solely as closed cybernetic loops or as cellular automata (complex structures evolving from simple input). Parisi argues instead that computation should be understood through the lens of the incomputable, meaning it is impossible to predict a system's outcome before it is applied. De Seta pointed out *Objects at Hand* as example of this unpredictability, observing how the material effects of the abstraction processes these objects underwent could not be fully anticipated. This observation also circles back Hayles' previously addressed emphasis on the material instantiation of abstractions, arguing, "It is this materiality/information separation that I want to contest – not the cellular automata model, (…) or a host of related theories in themselves". (1999, p. 12)

Gabriele de Seta and I have continued our exchange on topics related to this lecture, for example in 2023 when we collaborated on planning and executing the three-day *Replicator Workshop* as part of the BEK symposium *The Only Lasting Truth is Change*. The workshop was designed to explore emerging methods for generating 3D models, using a selection of early-stage generative AI web tools to test and experiment with new approaches to 3D modeling.

19.00, Friday 25. February, 2022
A Crisis of Representation: Abstraction and Materiality – a Lecture by N. Kathrine Hayles

According to the wishes of the author a recording of this lecture has not been published.

Professor N. Kathrine Hayles is a literary critic and theorist. Her writing includes the books *How We Became Posthuman* and *Unthought*, both providing key concepts and ways of thinking shaping my research project. Hayles is known for breaking new ground at the intersection of the sciences and the humanities.

Hayles generously accepted my invitation to participate in the live program at Entrée. She called in from Los Angeles to give her live video lecture to the people gathered at Entrée and to an online audience attending the live stream. The event and following conversation were moderated by artist and main supervisor Eamon O'Kane. Hayles introduced her talk by using the laws of physics as an example of an abstraction of reality that doesn't take into account what she calls the noise of materiality. She proceeded to point out how many computer scientists think of the computer as an abstract machine, not considering its material instantiation. Building on these examples she transitioned to the main subject of her lecture, discussing which abstractions are used in neural nets, and how materiality (re)- enters the picture.

In spring 2022, at the time of Hayles' lecture, machine learning neural nets were becoming a widely discussed topic, due to what Hayles called "with no doubt the most successful language generator so far". Referring to the groundbreaking paper "Attention is all you need" (Ashish Vaswani, 2017) Hayles explains how the transformer model GPT-3 (general pretrained transformer) works using the key concept of attention. The model assigns probabilities to words in sequences, and attention provides both focus and context, which, as Hayles stated, "turns out to be crucial for understanding written text". Hayles then explained which abstractions are at play when a transformer model learns language, highlighting both the similarities and profound differences to how humans learn. "Both the machine and child use indexicals and relations between indexicals to build maps of abstractions, but for a child those indexicals are enriched in a whole variety of ways with sensory input, sensory information, that are part of the embodied, embedded learning". In contrast, Hayles pointed out that "for the transformer, the indexicals are not associated with any form of embodied learning, rather, they are manipulated through matrix math." She further explained that "The transformer has no direct knowledge of the human, no embodied experience. All it knows is a series of abstractions that have gone through mathematical manipulations. So, it can infer relations between symbols, but these relations are inferred from the mathematical relationships"

The conviction that direct knowledge of the human lifeworld is something which cannot be conveyed or abstracted into mathematics brings me back again to Edmund Husserl and *The Crisis*. I see the crisis that Hayles refers to in the title of her lecture - "A Crisis of Representation: Abstraction and Materiality" - as an extension of the crisis Husserl identified. Hayles moves on from the abstraction in physics addressed by Husserl to highlight new forms of abstraction in neural networks, such as those used in GPT-3. My understanding of Hayles' lecture is that the crisis of representation is that the machine generated language doesn't represent embodied and experiential knowledge from the human lifeworld, even if it might appear to. What is abstracted with GPT-3, or as Hayles describes it "refracted through the mind of a non-conscious machine", seems to be the meaning and content of written language.

Proceeding to describe possible dangers and risks involved in such a process Hayles explains that "as a result, when it creates a sequence of words as its output, there is a systemic fragility of reference." Referring to examples of machine generated text she shows that this fragility of reference can lead to completely non-sensical results, such as a computer stating that it enjoys watching the wild animals in the forest, and that the animals' seeming acceptance of the computer makes it happy. Hayles points out that taking such statements at face value is naïve and ignore profound differences in materiality. She advocates for a critical, nuanced approach to engaging with machine-generated content, leaving us with four key points: 1) Materiality always matters, 2) combinations of neurons and mathematics in neural nets create new kinds of abstractions, 3) New modes of abstraction open new possibilities for texts as well as 4) New opportunities (and dangers) exist for literary criticism with machine texts.

As large language models become increasingly powerful tools for text generation, I find Hayles' reflections valuable for considering how to engage with this technology in a responsible manner. In my experience of using ChatGPT-4 as a co-cognizer for editing, it is effective for synthesizing my own text segments up to a couple of pages in length, helping eliminate unnecessary words and arrange them in a sequence that enhances readability. This makes sense, as the predictive nature of the model makes it generate plausible-sounding responses based on probability of one word coming after another. However, if I attempt to use it to extend an analysis or to generate new, meaningful content, the results often display the fragility of reference addressed by Hayles in her lecture; The model produces statements that are untrue and nonsensical, stemming from the fact that the model doesn't actually understand concepts, facts, or language in a way that is connected to the human lifeworld, but rather mimics patterns of human language without these abstractions being grounded in human experience.

15.00, Saturday 5. March, 2022
Lygia Clark and the Neo-Concrete movement – a lecture by Felipe R Pena

A recording of the lecture is available on the Video Page.

Felipe R Pena is a Brazilian curator and founding director of the gallery Cavalo based in Oslo and Rio de Janeiro. Pena was an important conversation partner in the process of making *Holder* and supported my development of Holder by acquiring museum shop versions of the *Bichos* sculptures.

Calling in from Rio De Janeiro for this online presentation live screened at Entrée, Pena offered a perspective on Lygia Clark and the Neo-Concrete movement's significant place in art history seen from its place of origin. The lecture provided important art historical context to the work *Holder* and contributed greatly to forming my written reflections on that work; about participatory practice, embodied interaction, inclusion of audience in elements of studio practice, as well as on topics of scale and relation between 2D and 3D. These reflections are presented mainly in the text sections about *Holder* and about the installation architecture made for Oseana.

Thursday 10. March at 18.00
Where are we now? Where are we now? Where are we now? – a Performance Lecture by Sidsel Christensen

A recording of the performance lecture is available on the Video Page.

Sidsel Christensen is an artist and a colleague in the artistic research PhD program at KMD. In her project "INTERDIMENSIONAL ARTISTIC REFLECTION: Speculative movements through Spatial, Digital and Narrative Media" Christensen investigates how scientific/mathematical models of physical dimensions and their interrelationships, can be used as a generative tool in contemporary art. Christensen has been a close colleague in the PhD-program and we shared many conversations about each other's research and our shared interests in posthumanist perspectives on art and life.

Christensen carried out her performance lecture in a crowded space on a March evening as the final event of the live program at Entrée. She started the performance by reflecting on the space we were in, its virtual counterpart as a 3D model, the rope structure of a three-dimensional cube she had inserted into it and the layered dimensions connecting this spatial situation to her own topic of research. Gradually the performance shifted into a narrative about a woman Christensen had met, captivating the audience whose minds drifted off to the story's other time and place while they were asked to pull on the ropes to help dismantle the structure.

Summary

Making art is a way for me to examine, understand and relate to my surroundings. Abstraction has always been my main interest as a practicing artist. Working with sculpture I aim to make the abstractions shaping the world more concrete. In this artistic research project, I have chosen to focus on abstraction in 3D modeling, a technology with transformative effects across a range of professions, which I have gotten to know through my sculptural practice and through my participation in the establishment of Aldea Center for Contemporary Art, Design and Technology. I follow in the footsteps of many artists before me working with sculpture and dealing with questions of abstraction. I have taken with me the concerns and enquiries of these artists and revisited them using 3D modeling technology. I have also examined new questions that come up with the new types of abstraction that 3D modeling technology enables and is built on. Using 3D modeling software, YouTube tutorials, augmented virtuality, digital fabrication techniques and other sculpture-making methods I have examined and aimed to make more visible and concrete what abstraction in 3D modeling is, how it works and how it co-evolves with some of its contexts.

Abstraction in 3D modeling can both be a process as well as the structures and technical building blocks that 3D modeling technology is built up by. Through this PhD research I have come to think of many of these building blocks as ready-made abstractions. I have followed an unmaking method to pick apart these abstraction processes and ready-made abstractions. The result of these sculptural examinations is the artworks *Secret Support*, *Holder*, *Two Rocks Do Not Make a Duck*, *Entrée Interior*, *Explode Mesh*, two exhibitions and a live program presented to the public in 2022 as well as an exposition presented on RC in 2024.

By creating this body of work, I have gained insights that I will attempt to summarize in the following paragraphs. But first I wish to point out that a central element in examining abstraction is to become aware of its limitations. When something is extracted out of something else, something is lost. When this something is expressed in a new form, something else is added. Therefore, an abstraction of something is something else than the thing itself. This also applies to the writing about artworks and to making written conclusions of artistic research. This is a process of abstraction, where the text is something else than the artworks themselves. Some of the things that cannot be experienced through the writing of artworks is the artworks' materiality, their spatio-temporal qualities, how the works relate to one-another in a space, and to the space where they are exhibited, their interactivity and tactility as well as the subjective and in-context meeting that each individual person has with them. I think about these elements as the non-transferable qualities of artworks that the Neo-Concrete movement address in their manifesto. Some of the things that are added to the artwork through my writing about it is my own perspective, and how this is shaped through the structure of my second language, English, as well as by the structure of the Norwegian Artistic Research Program and its implementation at KMD.

It seems necessary, however, to nuance the idea of the written reflection as a mere abstraction of an artistic result. Along with other components of this artistic reflection, such as processual images, videos, and 3D model recordings, the written and image-based descriptions of elements not visible in the exhibited work help to illuminate further aspects of my research. Furthermore, there are aspects of writing that correspond with the process of unmaking. As unmaking allows me to pick apart and create new sculptural versions of something I seek to understand more deeply, writing about this body of work has similarly been a process of picking apart, reworking, re-articulating, and reflecting, leading to insights that were previously unarticulated, and enriching my own understanding of the project.

The unmaking of *Secret Support* highlighted that two main abstraction processes in 3D modeling is the extraction, or separation, of the shape of an object from the rest of the object, and the translation from form to numerical data. The many translations from screen to physical object and back again highlighted that the shape of this object always was instantiated in a material and a medium, and that this embodiment was decisive for what could be done with it – also underscoring the special attributes of the 3D model format. As an algorithm the form could adapt to any object for 3D printing. As G-code the form could be translated into a plastic structure. As a piece of plastic I could hold it in my hand, as numerical data it could be transformed into a digital working drawing and 3D model enabling shape and scale manipulations. These attributes make 3D modeling a highly valuable technique across many professions.

A ready-made abstraction in 3D modeling that I examined in *Secret Support* was the proprietary algorithm used to generate support structures holding an object in place while being printed on a 3D printer. The algorithm is part of Formlabs' closed 3D printing

system, and an example of how algorithmic abstractions take part in shaping the 3D printing industry. The proprietary algorithm is also an example of how abstractions often are opaque, hidden from our view and inaccessible. Following my unmaking process in a pursuit to learn something about the structures generated by the algorithm, I went through a manual process of recreating the shapes in digital form. The labor involved in this unmaking process highlighted that translating shapes into digital abstractions is something that 3D modeling tools does for me – 3D modeling software act as co-cognizers that assist us in making abstractions of shapes, making these shapes readable by different software systems and digital fabrication machines.

In the unmaking of *Holder*, I developed interactive sculptures and videos to examine the geometric and mathematical frameworks used to create objects in CAD 3D modeling software, and to look for connections between these frameworks and the standard characteristics I had observed on informal YouTube CAD learning tutorials. I view the geometric and mathematical building blocks in CAD as frameworks for abstraction that can be used both with the "Platonic backhand", where existing elements are simplified as geometry and mathematics, and with the "Platonic forehand", where new drawings and objects are created from geometric and mathematical foundations. The Neo-Concrete movement similarly applied a geometric framework as a formal starting point, and utilized its manipulability, such as scaling and translation between two and three-dimensional space, in a manner reminiscent of CAD 3D modeling software. While working with these fundamental geometric shapes the movement rejected claims of universality and embraced interactivity and audience engagement as an act of co-creation. This participatory approach, manifested in Lygia Clark's *Bichos*, inspired the interactive element of the *Holder* YouTube tutorials and sculptures, and aligns with my view of 3D modeling technology as a tool that, despite its abstract foundations, develops in close connection with its users.

In *Holder*, one abstraction process I examined involved translating a handmade paper drawing into a digital sketch using the Bézier curve. I then transformed this sketch into a 3D model using the software's mathematical tools, and ultimately into a physical object by converting the 3Dmodel to G-code sent to the CNC machine. I observed that CAD software, as a co-cognizing tool built on a framework of geometric and mathematical abstractions, encourages repetition, patterns, and geometric shapes. The Bézier curve, as a ready-made abstraction, significantly shapes the aesthetics and functionality of digitally designed objects. I further explored the Bézier curve and Fusion 360's parametric features in the interior created for Entrée, where I saw that they enabled iterative, rapid prototyping with a CNC machine, as well as precision and material efficiency beyond what could be achieved by hand.

To reflect on how abstraction in CAD modeling co-evolves with the context of YouTube learning videos, I used Hayles' concept of cognitive assemblages to consider how abstractions affect the different cognizers in this layered network of people and technologies. I saw that both the YouTube recommendation algorithm and the geometric tools in the design workspace may lead to a standardized type of exercise objects that comes from the world of product design. However, I would need to do more, and perhaps a different kind of research, to answer confidently how abstractions in 3D modeling affect the YouTube CAD learning environment. In his lecture "On infrastructural abstraction: Models, parameters and algorithms", Gabriele de Seta drew on Luciana Parisi's perspectives to highlight a reflexive dynamic between abstractions in 3D modeling technology and its users, noting how contemporary architecture and design practices have been shaped by the possibilities of algorithmic, parametric design, an influence rooted in computation and informatics.

In the sculpture series *Objects at Hand*, I built further on my work from *Secret Support* where I had seen that key abstraction processes in 3D modeling is the extraction, or separation, of the shape of an object from the rest of its qualities, and the translation of this form into numerical data. I worked further with Sirisha Shashikanth, one of the YouTubers behind one of the *Holder* videos, to examine an abstraction process starting with laser 3D scanning objects from her reverse engineering office in Hyderabad, India. The objects were first turned into point cloud data by the scanner, then converted into different kinds of abstractions such as polygonal meshes and G-code. The finished sculptures made by 3D printing and casting bear traces of the abstraction processes the original object had gone through. Large triangular shapes revealed where the scanner had not been able to capture all shape information and showed that the point cloud data had been converted into a triangular polygonal mesh. Lines from the 3D printer articulated the layered nature of an object expressed as G-code, and the object's mismatching scales in relation to each other indicated how scalability is an attribute the 3D models numerical nature. The abstraction processes that Shashikanth's objects underwent altered the original shapes, sizes, colors and materialities, and enabled a geographical and cultural recontextualization. A result of this recontextualization was that the function and meaning of the objects were changed. The work of artists like Nora Al Badri and Oliver Laric shows that extracting the form of culturally significant objects into numerical data raises ethical questions around ownership, authenticity, and cultural heritage, underscoring the importance of material embodiment and context as unique properties that are lost in the digitization process.

The unmaking process of *Objects at Hand* highlighted both affordances and challenges arising from abstraction in 3D modeling. Translating an object into a 3D model allows its shape to be manipulated, copied, uploaded, shared and materialized in digital fabrication processes. These affordances of the 3D model have changed how people work in existing professions such as architecture, engineering, design and the film industry, and it has opened up for new ones like Computer Graphics and VR. In sculptural practice the possibilities given by abstraction in 3D modeling has provided new tools for work such as visualization, production and planning artwork in public space and it has extended the possibilities in mould making and casting.

The augmented virtuality artwork *Two Rocks Do Not Make a Duck* was made in collaboration with Cameron MacLeod. My examinations of abstraction in 3D modeling in this project builds on my previous work which showed me that abstraction in 3D modeling makes it possible to transfer a shape between physical and digital materialities. In this artwork we utilized this attribute of the 3D model to create duplicate virtual and physical versions of the same shape. With the help of VR hardware and software the duplicate objects were synchronized in time and space. In the making of *Two Rocks Do Not Make a Duck* we explored the artistic potential of this new augmented virtuality format and the new kinds of sensing it enables. We saw how both abstraction processes and ready-made abstractions contribute to shaping experiences of VR environments.

The abstraction process in this work began by selecting which elements to simulate and not, resulting in a simplified representation of a natural landscape focused on elements like seasonal markers. 3D maps created using lidar scanners provided a good approximation of the terrain's shape, but excluded most other information about Bjørvika, for example of its buildings or the tourists strolling between them. Downloadable assets and gaming physics are ready-made abstractions which has been created by the gaming industry and other industries using game engines to create virtual environments. These ready-made abstractions affect what type of objects we see in VR environments and how these objects behave, for example how virtual wind affects a virtual tree. This project's timeline coincided with rapid technological advancements in VR which affected what we could make and how to make it. These advancements were triggered by events such as Facebook's announcement of the Metaverse in 2021 and highlighted the reciprocal development of 3D modeling technology and the industries it serves.

In the artistic research project *Unmaking Abstractions*, I have used sculptural unmaking processes to make visible and concrete what abstraction in 3D modeling technology is, how it works, and how it co-evolves with users and context. Through each artwork, from *Secret Support* to *Two Rocks Do Not Make a Duck*, I examined the complex interplay between virtual forms and physical embodiments, as well as the collaborative dynamics between users and the tools they employ. By bringing questions of abstraction – previously explored by movements like Neo-Concretism, land art, and related practices – into the realm of 3D modeling, this project addresses a technology built on layers of abstraction that affect how people work, what they create, and how they interact with and perceive environments.

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Bibliography

Allahyari, M. (u.d.). *Morehshin Allahyari*. Hentet February 7, 2022 fra http://www.morehshin.com/

Ashish Vaswani, N. S. (2017). Attention is all you need. *Proceedings of the 31st International Conference on Neural Information Processing Systems* (ss. 6000-6010). Long Beach: Curran Associates Inc.

Castro, Clark, Gullar, Jardim, Souza, Pape, . . . Weissmann. (2013). Neo-Concrete Manifesto. I M. Lind, *Abstraction* (ss. 70-73). London and Cambridge: Whitechapel Gallery and The MIT Press.

Celine Condorelli, G. W. (2015). *Support Structures.* Sternberg Press.

Center for Bits and Atoms. (2024). *Welcom to FabCentral*. Hentet fra About: https://cba.mit.edu/about/

Clark, L. (1965). Bichos. *Bichos.*

Clark, L. (2014). Lecture at the Escola Nacional de Arquitetura, Belo Horizonte. I L. P.-O. Cornelia H. Butler, *Lygia Clark* (s. 55). New York: The Museum of Modern Art.

Daniel Rourke, M. A. (2015). *The 3D additivist manifesto.* self published, Online.

Dinkins, S. (2021, November 20). On Love, Data and Technologies Rooted in Care. *The Only Lasting Truth is Change Symposium*. Bergen: Bergen Center for Electronic Art.

Gaboury, J. (2021). *Image objects: an archeology of computer graphics.* Cambridge, Massachissetts: The MIT Press.

Glotzer, A. (2023, November 3). *Roundtable Learning*. Hentet December 17, 2023 fra https://roundtablelearning.com/bridging-the-knowledge-gap-with-virtual-and-augmented-reality/

Halley, P. (2013). Abstraction and Culture. I M. Lind, *Abstraction* (ss. 137-142). Cambridge and London: The MIT Press.

Haraway, D. (1991). A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century. I D. Haraway, *Simians, Cyborg and Women.* London: Free Association Books.

Haraway, D. (1991). Situated Knowledges. I D. Haraway, *Simians, Cyborgs, and Women.* London: Free Association Books.

Haraway, D. (1991). Situated Knowledges. I D. J. Haraway, *Simians, Cyborgs, and Women – The Reinvention of Nature* (s. 190). London: Free Association Books.

Hayles, N. (2020, 09 23-25). Ethics and the Posthuman: A Feminist Perspective. . Bergen: Center for Women´s and Gender Research, University of Bergen.

Hayles, N. K. (1999). *How we became posthuman : virtual bodies in cybernetics, literature, and informatics.* Chicago and London: The University of Chicago Press.

Hayles, N. K. (2017). *Unthought: the power of the cognitive nonconscious.* Chicago and London: The University of Chicago Press.

Hayles, N. K. (2019, 11 21-22). Computers and Meaning: The Case of OpenAI´s Text Generating Program. *Digital Narrative Network Conference*. Bergen: The Electronic Literature Organization and Faculty of Fine Art, Music and Design, University of Bergen .

Hayles, N. K. (2022, February 25). A crisis of Representation: Abstraction and Materiality. *A crisis of Representation: Abstraction and Materiality*. Bergen: Entrée, Open Studio / Magnhild Øen Nordahl.

Holt, N. (1976). Sun Tunnels.

Holtvedt, A. (2022, Oktober 02). Overambisiøst på Munchmuseet.

Husserl, E. (1970). *The Crisis of European Sciences and Transcendental Phenomenology. An Introduction to Phenomenological Philosophy.* (D. Carr, Red.) Evanston: Northwestern University Press.

Kronman, L. (2020). Intuition Machines. *APRJA, 9*.

Lamas, N. (2023). Exhibition text for "non-human-matters". Bergen: Aldea.

Lütticken, S. (2013). Living with Abstraction. I M. Lind, *Abstraction. Documents of Contemporary Art.* (ss. 142-150). London and Cambridge: Whitechapel Gallery and The MIT Press.

Ledezma, J. (2010). The Sites of Abstraction: Notes on and for an Exhibition of Latin American Concrete Art. I M. d. palma, *Los sitios de la abstracción latinoamericana. Colleción Ella Fontanals-Cisneros* (s. 221).

Lehmann, A.-S. (2012). Taking the Lid off the Utah Teapot, Towards a Material Analysis of Computer Graphics. *Zeitschrift für Medien- und Kulturforschung*.

Lind, M. (2013). *Abstraction. Documents of Contemporary Art.* London and Cambridge: The MIT Press.

Martin Heidegger, W. L. (1977). *The Question Concerning Technology and Other Essays.* New York and London: Garland Publishing.

Morell, L. (2021, June 15). Artist presentation. *VR to 3D printing workshop*. Bergen: Aldea.

MUNCH. (22, 10). *MUNCH*. Hentet 06 14, 24 fra www.munchmuseet.no

Nordahl, M. Ø. (2011). Terra Nullius.

Nordahl, M. Ø. (2011–2020). Riegelbau.

Nordahl, M. Ø. (2012). Sao Paulo.

Nordahl, M. Ø. (2016). *How To Make a Utah Teapot.* Hordaland Kunstsenter, Bergen.

Nordahl, M. Ø. (2024). Simulating Seasons in Virtual Reality. I A. W. Scott Bremer, *Changing Swasonality, How Communities are Revising their Seasons* (ss. 127-132). Bergen: De Gruyter.

Nyeng, F. (2017). *Hva annet er også sant?* Bergen: Vigmostad & Bjørke .

Parisi, L. (2013). *Contagious Architecture. Computation, Aesthetics, and Space.* (Vol. In the book series Technologies of Lived Abstraction). (E. M. Brian Massumi, Red.) Cambridge and London: The MIT Press.

Pèrez-Oramas, L., & Butler, C. H. (2014). *LYGIA CLARK - The Abandonment of Art 1948 – 1988.* New York: The Museum of Modern Art.

Posenenske, C. (May 1968). Manifesto. *Art International no.5*.

ProductDesignOnline. (2021). *YouTube Product Design Online*. Hentet December 6, 2023 fra https://www.youtube.com/watch?v=JOrn4BejMq8

Seta, G. D. (2022, February 13). Infrastructural Abstraction - Models, Parameters, Algorithms. *Open Studio Live Event Program*. Bergen.

Sæter, T. (2020, September, October 15-18). *Coast Contemporary*. Hentet January 27, 2022 fra https://coastcontemporary.no/archive-2020

Sharon, T. (2014). *Human Nature in an Age of Biotechnology.* Maastricht: Springer.

Shashikanth, S. (2021, December 20). A Conversation With Sirisha Shashikanth. (M. Ø. Nordahl, Intervjuer)

Stanford Encyclopedia of Philosophy. (2024). *Stanford Encyclopedia of Philosophy*. Hentet fra Pre-reflective self-consciousness: https://plato.stanford.edu/entries/self-consciousness-phenomenological/

Studio, T. T. (2020, October 31). *Tag Team Studio*. Hentet May 3, 2024 fra https://tagteam.cargo.site/Heidi-Bjorgan

Study.com. (2024, 09 07). *Study.com*. Hentet fra https://study.com/academy/lesson/distributed-cognition-definition-theory.html

Sutherland, I. E. (1970, June). Computer Displays. *Scientific American*, s. 73.

Tate. (2024). *Tate*. Hentet fra Art term: https://www.tate.org.uk/art/art-terms/c/concrete-art

The New York Times. (2020). *Rabbit Hole [Audio Podcast].* Hentet fra https://www.nytimes.com/column/rabbit-hole-podcast

Tools, C. (u.d.). *The jolly 3D printing torture-test*. Hentet December 6, 2023 fra https://www.3dbenchy.com/about/

University of Bergen. (2024). *Machine Vision*. Hentet fra https://www.uib.no/en/machinevision

Vulliamy, E. (2016, February 25). Artists "steal" Queen Nefertiti bust by secretly scanning and releasing 3D printing data online. *The Independent, UK edition*.