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SCIENCE, TECHNOLOGY AND SCULPTURE

An investigation into the technification of sculpture

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RESUMO

A taxa sem precedentes de desenvolvimentos científicos e tecnológicos no século XX causou uma reação em cadeia de disrupção em escala global. Após a eletrificação da civilização vieram os aparelhos eletromecânicos e a tecnologia de processamento de informações. A invenção do computador levantou profundas discussões filosóficas sobre consciência, robótica e o futuro da humanidade. O progresso na engenharia genética levou a questões semelhantes. Procuro entender a relação entre esses desenvolvimentos tecnológicos e a expressão artística – tanto como isso afeta nossa conversa, quanto como estamos facilitando essa conversa. Os artistas estão adotando abordagens científicas para a autoexpressão e incorporando ferramentas e tecnologias da ciência aplicada e da engenharia em sua prática. A tecnologia desenvolvida para impulsionar o progresso científico também está transformando as Artes.

Esta dissertação busca compreender a relação dinâmica entre as descobertas científicas, o rápido desenvolvimento tecnológico e a expressão artística. Ao dissecar a relação desse tripartite, um discurso multifacetado envolvendo ideologia, poder, educação e ruptura do sistema é descoberto. Acadêmicos e especialistas do mais alto nível estão expressando sérias preocupações sobre a condição de nossa civilização porque - em paralelo à melhoria dos padrões de vida e acesso à informação por meio de aparelhos eletrônicos avançados - enfrentamos uma miríade de ameaças existenciais, todas remontando ao exatamente os mesmos desenvolvimentos que nos permitiram graduar na civilização moderna. Limites, estruturas e fundações existentes há milênios estão sendo desafiados nesta metamorfose de um século da condição humana. Espero, por meio da arte, como um espelho da psique humana coletiva, compreender melhor essa relação em constante evolução entre nós, humanos, e a tecnologia que inventamos. Compartilho a opinião dos pensadores a serem discutidos nesta dissertação, de que a inovação científica e tecnológica deve fazer parte de uma conversa pública e que os artistas em sua natureza expressiva, investigativa e comunicativa têm um papel a desempenhar nessa discussão.

Os efeitos do desenvolvimento científico e tecnológico nas artes foram amplamente discutidos ao longo do século XX. Apresentarei 4 desses livros abordando este tópico de ângulos muito diferentes. Isso iluminará os pensamentos do início do modernismo, descreverá uma frustração de meados do século e nos deixará com uma visão quase atual

sobre o assunto. A análise apresentará primeiro alguns pontos de vista ideológicos sobre a questão da segregação da sociedade em grupos especializados e as consequências disso. A importância de um sistema de educação poli-matemática e do conhecimento intersetorial geral é discutida com diferentes objetivos e razões. A segunda parte da análise descreve a transformação da escultura ao longo do século XX com foco na separação da tradição e no abraço da ciência. São oferecidos alguns pensamentos sugestivos sobre o significado dessa metamorfose. Em conclusão, uma seção de teoria discutindo o ambiente atual, incluindo uma descrição de estruturas úteis na prática de combinar arte com ciência. Focar a parte analítica de minha dissertação nesses fatores macro ambientais serve ao propósito de colocar meu trabalho na linha do tempo.

Após a análise, há uma seção sobre o estado da arte. Abordo isso cobrindo algumas das ferramentas e técnicas mais recentes no campo da escultura; as práticas intimamente ligadas de modelagem 3D e manufatura aditiva. Esses dois campos, extremamente úteis no processo de fazer esculturas, sofreram um rápido desenvolvimento e melhorias nos últimos 20 anos e foram centrais para o desenvolvimento de meu próprio corpo de trabalho. O estado da arte também inclui uma seção sobre educação. A discussão de minha análise tem a ver com a introdução de novas tecnologias e seu impacto nas artes. Portanto, considero relevante olhar para o panorama atual da educação artística para ver se, e como, essas discussões se manifestaram na academia de hoje.

A última parte da dissertação é dedicada ao meu próprio trabalho - o que chamo de Projeto Sistema. O Projeto Sistema é um termo abrangente que cobre meu trabalho produzido no período entre 2020 e 2021, focando na natureza em constante mudança dos sistemas vivos. Vou descompactar a base sobre a qual a obra está assentada e apresentá-la em relação a artistas que buscam caminhos semelhantes de investigação. Em seguida, ampliarei o processo de modelagem da escultura e explicarei as decisões subjetivas que tomei nessa área. Concluindo o corpo da obra, incluo um conjunto de imagens como documentação para a exposição do corpo da obra prática submetida ao curso de Mestrado em Escultura da FBAUL, realizado no espaço expositivo da Cisterna da faculdade.

Concluo minha investigação sobre a relação entre arte, ciência e tecnologia com a observação de que ao longo do século XX ocorreu uma convergência gradual entre vários parâmetros. Os artistas estão adotando abordagens científicas para a autoexpressão aplicada e

incorporando ferramentas e tecnologias da ciência e da engenharia em sua prática. A tecnologia desenvolvida para impulsionar o progresso científico também está transformando as Artes. Decorre da tecnificação da arte que novos canais de criatividade foram estabelecidos e que isso continuará ainda mais. Os artistas estão engajados em narrativas e explorações que exigem conhecimento técnico e científico. Os artistas contemporâneos são assim encorajados a familiarizar-se com novos meios de comunicação e auto-expressão. Sugere-se ainda nesta dissertação, que a cooperação entre as faculdades entre as artes e as ciências oferece benefícios mútuos, e que essa fusão já está ocorrendo através do estabelecimento de faculdades interdisciplinares em todo o mundo.

Na escultura contemporânea, a adaptação da tecnologia da ciência e da engenharia se manifesta especialmente por meio da manufatura aditiva e da modelagem 3D. Essas ferramentas estão aumentando o processo de escultura e permitindo a fabricação de objetos tão complexos que desafiam nossa abordagem de construir objetos físicos. Computadores e máquinas controladas por computador são, portanto, cada vez mais usados na fabricação de esculturas, deslocando o conjunto de habilidades básicas dos escultores contemporâneos em uma direção digital. Está garantida uma maior tecnificação das Artes, e as próprias ferramentas utilizadas para a expressão artística tornam-se mais inteligentes. Poderíamos supor que toda uma estética da inteligência artificial evoluirá. O provável resultado da influência da tecnologia sobre a arte no século XXI pode ser uma série de formas de arte que manifestam inteligência real e capacidade de relacionamento consciente com os seres humanos.

Palavras-Chave:

CIÊNCIA, TECNOLOGIA, ESCULTURA, MODELAGEM 3D, MANUFATURA ADITIVA.

ABSTRACT

The unprecedented rate of scientific and technological developments in the twentieth century caused a chain reaction of disruption on a global scale. Following the electrification of civilisation came electromechanical appliances and information processing technology. The invention of the computer raised deep philosophical discussions about consciousness, robotics, and the future of humankind. Progress in genetic engineering have prompted similar questions. I seek to understand the relationship between such technological developments and artistic expression – both how it affects our conversation, and how we are having it. Artists are adopting scientific approaches to self-expression and incorporating tools and technologies from applied science and engineering into their practice. The technology developed to drive forward scientific progress are thus also transforming the Arts.

Keywords:

SCIENCE, TECHNOLOGY, SCULPTURE, 3D MODELLING, ADDITIVE MANUFACTURIN

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INTRODUCTION

This dissertation seeks to understand the dynamic relationship between scientific discoveries, rapid technological development, and artistic expression. By dissecting the relationship of this tripartite, a many-faceted discourse involving ideology, power, education, and disruption of the establishment is uncovered. Scholars and experts at the highest level are voicing grave concerns about the condition of our civilization because - in parallel to the improvement of living standards and access to information through advanced electronic appliances - we are faced with a myriad of existential threats all tracing back to the very same developments that enabled us to graduate into modern civilization. Boundaries, frameworks, and foundations in place for millennia are being challenged in this century-long metamorphosis of the human condition. I hope through art, as a mirror of the collective human psyche, to better understand this constantly evolving relationship between us humans and the technology we invent. I share the opinion of the thinkers to be discussed in this dissertation, that scientific and technological innovation must be part of a public conversation and that artists in their expressive, investigative, and communicative nature have a part to play in that discussion.

The effects of scientific and technological innovation on the arts have been thoroughly discussed throughout the twentieth century. I will introduce 4 books approaching that topic from very different angles. The analysis will first introduce some ideological viewpoints on the consequence of segregating society into specialised, enclosed groups. In extension to this, the importance of a poly-math education system and general cross-sector knowledge is argued with different aims and reasons. We will move on to the present-day environment, introducing a methodology for working in the intersection between art and science, and a manifesto from a Dutch art and design academy reinventing itself to accommodate the mounting list of technical and entrepreneurial skills associated with contemporary art and design practices. In conclusion, we analyse the transformation of sculpture more generally throughout the twentieth century, focusing on the parting with tradition and the embrace of science and technology. We are offered some speculative thoughts on the significance of this metamorphosis, and where we might be heading in the future. Focusing the analytical part of my dissertation on these macro-environmental and historical factors helps substantiate my practical body of work in relation to these ongoing discussions and developments.

Following the analysis is a section on the state of the art. I approach this by introducing two impactful exhibitions which embodied the thinking as described in the analysis. I will also include a selection of artists whose work is representative of cross-disciplinary practices. Subsequently I include a section on novel impactful technologies from the field of contemporary sculpture; the closely tied fields of 3D modelling and additive manufacturing. These two technologies, extremely useful in the process of making sculptures, have undergone rapid development and improvements over the past 20 years and have been central to the development of my practical body of work.

The last part of the dissertation is dedicated to my practical body of work - what I call the Sistema Project. The Sistema Project is an umbrella term that covers my work produced in the period between 2020 and 2021 focused on the ever-changing nature of living systems. I will unpack the foundation on top of which the work is constructed and present it in relation to artists pursuing similar paths of inquiry. I will then zoom in on the modelling process of the sculpture system and account for the subjective decisions I made in that area. Lastly, I present a series of pictures as documentation for the exhibition I held in conclusion to the practical body of work submitted for the Masters' degree in sculpture at FBAUL, held in the Cistern exhibition space of the faculty.

1 AREA OF STUDY

1.1 OBJECTIVES

Society is enormously affected by technological developments; it changes the way we communicate, how we work, and in general how we live our lives. Public dialogue on technology-related issues is therefore very relevant. Artists can help us contemplate these developments by asking difficult questions and exposing viewers to thought-provoking scenarios. However, the art world itself is affected by the very same technological transformations - changing the way we express ourselves creatively.

In the following pages I investigate the mechanisms behind the technification of art throughout the twentieth and into the twenty-first century. The motivation behind this analysis comes from a desire to understand how technology enables, expands, or even inhibits, our ability to communicate and express ourselves artistically. The scientific method has succeeded in answering many fundamental questions about the world, leaving lesser room for imagination. I seek to understand how this has impacted the arts, where uncertainty and mystery are intrinsically welcome as fuel for the creative process. Central to the analysis is a question about the technical skillset and capabilities of contemporary artists. Readily available and affordable technologies have completely unlocked new ways of expression and enabled previously unfeasible works of art. Which tools might a well-equipped contemporary artist want to acquire today, and to what technical degree? The objective for this dissertation is to unpack these questions, and to better understand the dynamic relationship between art, science, and technology - how it has played out historically, and what it looks like today.

1.2 ANALYSIS

The analysis will be guided by the following books:

1) C. P. Snow – *The Two Cultures and the Scientific Revolution*, 1959.
2) László Moholy-Nagy – *The new vision: And abstract of an artist,* 1947 (1928).
3) David Edward – *ArtScience: Creativity in the Post-Google Generation*, 2010.
4) Jack Burnham – *Beyond Modern Sculpture*, 1975.

This will provide us with an overview of art-science theory from the beginning of the twentieth century to the near present. I will give each book its own section and account for its content there with subsequent references. The analysis includes mention of historical socio-political factors that impacted the subject matter and will begin by assessing one of the most widely discussed interpretations on the growing distance and mutual ignorance between humanists and scientists.

1.2.1 C. P. Snow

In 1959 Charles Percy Snow (1905 - 1980) gave the annual Rede lecture at the Senate House in Cambridge. Snow was an English novelist and physical chemist who also served in several positions in the British Civil Service and briefly in the UK government. The concerns he raised in his talk would become the basis for much discussion for decades to come - the core of his argument has remained a relevant debate to this day. Snow's talk, titled *The Two Cultures and the Scientific Revolution* broadly diagnosed a problem he believed challenged the future of all western democracies: The growing dissociation between humanists and scientists. What gave Snow a rather unique vantage point on this topic was his professional background, both as a chemist, and a novelist. He had first-hand experience of dining in cafeterias and conversing with scholars on either side. Snow believed that the sciences and the humanities was separated by a wall of complete opposing ignorance. Each side, he claimed, was lacking in knowledge of even the most basic principles about the other (Snow, 1959, p. 15). Being a writer himself, literature came to represent the opposing side of science, but his argument covers all the humanities. For Snow however, this 'we do not know and will not know' scenario was something deeply troubling that threatened the future of us all, and he dramatically refers to the fall of the Republic of Venice in the second part of the eighteenth century as a comparison to the decline of British sovereignty. Both nations, he argued, had become rich and powerful by chance, and failed to keep the essential fire burning until the system collapsed (Snow, 1959, p. 39). For this concern to make a bit more sense, consideration of the atomic tension between USA-UK and the USSR at the time of his lecture must be taken. Both superpowers were mobilizing scientists and engineers as soldiers of modern warfare. Nevertheless, the concern was not just a product of a world in political turmoil, it was rooted in something deeper and went on to question the pillars of western democracy, the philosophy of education and governance.

In his lecture, Snow described Britain's elite humanist scholars as being a closed community of people opposed to new technology and ways of working and held them responsible for Britain's national decline at the time (Snow, 1959, p. 22). In contrast he believed scientists were responsible for progress, prosperity and leading the way towards the future. He argus this by referring to the industrial revolution, which he maintains was driven forward by very little university educated talent, and primarily relied on skilled handymen with deep knowledge about machinery (Snow, 1959, p. 24). The industrial revolution, the gradual use of machines, the change in agricultural labour employment to men and women in factories was a bottom-up evolution of optimization — not an academic project. Snow highlights these hands-on mechanical engineers changing the world with their practical knowledge and building the foundation for the coming scientific revolution. He demonstrations frustration with comfortable scholars writing papers without knowledge about applied science and engineering - the real engine of progress (Snow, 1959, p. 31). He was in essence concerned about a more fundamental question of who, and with which qualifications, is supposed to govern a country? A practical question to ask but not an easy one to answer, especially when a possible answer might not match the status quo. Snow attacks the specialization of the school system and society as the reason for the mutual polar ignorance (Snow, 1959, p. 18). He blames old institutions like Oxford and Cambridge for sticking with old traditions and argues that further specialization seems inevitable.

Reading Snow's arguments 60 years later, you still find the basis for relevant debate today. We are facing different challenges, have seen a shift in the global socio-economic power balance, and technology has gotten more advanced, but fundamentally, we are grappling with issues not too dissimilar from the ones posed by Snow in 1959. Snows main criticism targeted the lack of cross-sector knowledge between the humanities and the hard sciences. The big difference in the picture between then and now seems to be computers, data, and software. The hard sciences - physicists, biologists, engineers, etc - were early to incorporate, apply and further develop emerging technologies. The potential use case of applied computer science can appear boundless and is everywhere to be found in the hard sciences, while social science and the arts have been slower to adapt. The challenge is you need large amounts of data and complicated analytical tools to understand and derive meaning from our collective behaviour. While the hard sciences are studying natural phenomena where few issues with consent forms and property rights arise, studying human behaviour with the same analytical tools is a much more complicated academic pursuit. Large private companies are instead gathering that data through consumer products and services, and they are using it to sell targeted adds for profit. That information could be used by our humanitarian institutions to improve and better understand the human condition. Technology is increasingly becoming embedded into our daily activities, where our behaviour is being tracked and analysed. Snow argued that scientists should read novels and experience art, and that basic scientific principles should be understood by the humanities. Today that would incorporate digital literacy, a knowledge of computer programming and all the potential it unlocks. He described the industrial revolution essentially as a process of optimizing production, and the scientific revolution as the ability to control matter with atomic precision (Snow, 1959, p. 29). We have now for 40 years been living through an information revolution, where information could be considered, along with matter and energy, as the third constituent part of the Universe - information being carried by matter or by energy (Wiener, 1948, p. 155). Snow wanted to stress the importance of understanding the principles of both science and art. If you understand only one, you are unable to fully make sense of what is happening and where things are heading.

C. P. Snow's observations tell a story about a world getting ever more complicated. Compartmentalization and specialization seem like a natural way to handle growing complexity - produce experts to operate in delimited fields. There is a discernible concern in his speech however, coming from the fear of totalitarianism and failure of the free democratic world. The conundrum seems to be that the public at large have little to no technical understanding of the powerful technologies of our time, which largely and at bottom, amounts to applied scientific knowledge and technical engineering capacities. With these tools you can build a thriving economy, a good healthcare system and expand the collective human knowledge of the natural world. Snow's concern is rooted in the scenario where, as was the case with Nazi Germany, the USSR and which is now the case with China, a totalitarian regime utilizes those powerful technologies with little or no regard to the general population. It is difficult for a democratic system with concerns about human rights to compete with an extreme and less regulated system. You can conclude from Snow's lecture, the importance of understanding the existence of that potential threat, and actively work towards mitigating it by utilizing the unbound creative potential of free democratic societies.

1.2.2 László Moholy-Nagy

László Moholy-Nagy (1895 - 1946) was a contemporary of C. P. Snow and in essence, these two thinkers were talking about one and the same thing: the importance of cultivating a polymath education system. They have a slightly different approach, however. Moholy-Nagy is visibly more philosophical and artistic in his reasoning. He sees the global industrial production system and its obsession with optimization and economic gain as a suppressor of a deep-rooted human compulsion to follow its biological instincts. Moholy-Nagy was a professor at the Bauhaus in Weimar and later the director of the Bauhaus school in Chicago. He was an influential thinker on the matter of creative education, and a strong advocate for the integration of technology and industry into the arts.

In *The new Vision* Moholy-Nagy first makes the statement that his group was not interested in the personal quality of expression usually referred to as 'art', but in its primordial basic elements. The ABC of expression itself (Moholy-Nagy, 1947, p. 13). A very scientific approach to the creation of art indeed, and one that resonates well with Snow's criticism of the superficial and at times mythical understanding of science by the arts. Snow observes in his essay how little of twentieth century science has been assimilated into twentieth century art and use examples of poets conscientiously using scientific expressions and getting them wrong (Snow, 1959, p. 19). He argues that this ignorant and almost supernatural representation of science isn't the way that science could be any good to art. It has got to be assimilated along with, as a constituent of, the whole of our mental experience and used as naturally as the rest. Moholy-Nagy reproduces this view, and his way of diagnosing the cause of this cross-sector illiteracy, was by pointing to the deliberate segregation, or 'specialization' of the workforce by governments (Moholy-Nagy, 1947, p. 15). It is a known optimization technique of the industrial revolution to assign a single task to each worker, with the knowledge that repetition, and narrow expertise creates efficient workers. It isolates the persons skillset and limits their opportunities to find work elsewhere, creating a relationship of dependency on the company or state - thus allowing the company to further worsen the conditions of their workers in a parasitic pursuit of profit (Moholy-Nagy, 1947, p. 15). The specialization of the workforce is not only seen in its extreme case of factory workers, but also fundamentally the way society is structured from school to workplace, and it has been in the economic interest of governments and private companies that things remain so.

For Moholy-Nagy, this compartmentalised way of organizing humans goes against our deepest biological nature. Characteristic to him and his group, he uses such fundamental arguments as biological nature, to describe the well-being of humans and their development - go against our biological nature, and you are on the wrong path. He refers to children and pre-modern humans as being especially good at respecting their nature. They sleep when they are tired, don't pretend to be interested or to like someone if they don't, etc. (Moholy-Nagy, 1947, p. 17). Adults are not able to follow their instincts to a similar degree because they are deadlocked in doing the bidding of a large incomprehensible system guarded from their influence. He argues that the system of moneymaking, competition and trade is destroying the inherent values of life and needs to be replaced by one instead focused on human development and well-being. This is backed by the idea that human beings are developed through the crystallization of the whole of their experience, and that our system of education contradicts this by emphasizing single fields of activities. Two initiatives are mentioned as useful in the development of a reformed system (Moholy-Nagy, 1947, p. 18):

1) By purposeful observation and rational safeguarding of organic, biologically conditioned functions - through art, science, technology, education, and politics.
2) By relating the single results to all human activities.

The new vision serves as an extensive roadmap towards this desired outcome and describes in detail the philosophy, structure, and practical content of the Bauhaus school of art and design which laid the ground for many art and design academies for decades following. His thoughts on how to improve the dystopic view of humans as a cog in the wheel of a production machine is rather attractive - if not bordering on utopic in the other direction. It is curious to see two thinkers identify largely the same issue but approaching it from completely different angles. Snow seemed concerned about factuality, competitiveness and improving the overall knowledge of the public - maybe even hoping to increase the throughput of the industrial system as a result. Moholy-Nagy, exhibiting his artistic nature, instead takes a much more sympathetic standpoint and argues for the well-being of humans on this planet. To make technology and all our machines work *for* us, so we can all leisurely spend our time learning about science and make art. Moholy-Nagy's views on the inherent human nature would pair curiously with the current state of the world, our technological society and on the prospect of universal basic income. Our increasingly automated production system could render large parts of the un-educated population unemployable within this century and free, monthly distribution of money to everyone might be the most efficient and way to deal with that issue. If done well, and humans are free to spend their time on leisure, learning and creating, Moholy-Nagy's utopic vision might come to pass.

1.2.3 David Edwards

David Edwards (1961) is a biomedical engineer, writer on art-science and an active member of a global network of initiatives working to advance the field. In his book *ArtScience* (2008) Edwards cites many examples from the worlds of science, art, civil society, and industry that show how transposing ideas or strategies from one field to the other often results in radical innovation. Art-science to him is an intermediate area of creativity where neither art nor science are clearly defined. Stimulating this zone, he considers to be one of the key strategies to foster innovation. The core idea that makes such collaborations and intermediate zones possible is that art and science are both considered as types of research, and that they are thought to be complementary in many ways. Where science maintains an aura of objectivity and detachedness, art favours subjectivity and critical engagement. Where peer review and validation are the norm in the science community, artists are expected to be nonconformist and original. Where science is expressed in formulas and text, art often exists through non-verbal subjective experience (Edwards, 2008, p. 6). Ultimately, however, art and science share the aim to enlarge the scope of our ideas about the world. Edwards argues that if science contributes to revolutions in art, art can also lead to revolutions in science. Much like C. P. Snow, Edwards discovered the benefits of cross-sector interaction between the humanities and the technical sciences by himself making the traversal - from biomedical engineer to teacher and facilitator of art. Through his work with art students, he observed a general trend by those engaged in art-science projects; An idea or curiosity forms which forces the investigator/artist to cross over into unfamiliar territory. Commitment to partial re-education if necessary (or further strengthening of already acquired skills) and serious investment into the subject matter (Edwards, 2008, p. 21). A risk tolerance is required when venturing into unknown territory potentially parting ways with colleagues and making irreversible career decisions. The benefits of an interdisciplinary pursuit often have a positive feedback effect, offering the investigator unique insights from one field to the other and help drive them both forward - he refers to this process as 'idea-translation' (Edwards, 2008, p. 29).

Edwards goes on to describe how the practice of art-science is not just flowing from science into art, but also the other way around. An art-science approach can thrive in research institutions because innovation in both fields relies on the kind of culture-exchange you get by crossing traditional art and science barriers (Edwards, 2008, p. 54). Additionally, he explains how the crossing of disciplines is not bound to only take place between science and art, but just as easily could be bridging theoretical physics and materials science - or as we are seeing today in bioengineering, an exchange between materials science and biology (Edwards, 2008, p. 69). In that sense Edwards is advocating interdisciplinary polymath education beyond what has previously been discussed to encompass all of academia. He describes how research institutions translate their ideas by:

1) Developing an idea or vague concept through serious interdisciplinary study.
2) Testing the idea through experimentation that may involve personal experience.
3) Translating the idea within or by reaching outside their research institutions.
4) Realizing their idea by arriving at an awareness of art-science as a catalyst to their research.

(Edwards, 2008, p. 69).

Through personal experience, he goes on to explain what it means to pursue and validate a novel scientific hypothesis with rigor and passion. Intuition, inspiration, and passion are all components we expect to find at the core of an artist's pursuit, but these words are generally less appreciated in the scientific culture (Edwards, 2008, p. 79). Here, those traits will often be received with scepticism and ridicule - unless the hypothesis is undeniably probable or already proven. Careful analytics and proven (repeatable) experiments lie at the core of the scientific method. You hypothesize, construct careful experiments, collect data, validate, scrutinize. It is reserved for the very few and especially gifted to be guided by intuition, and even then, it only serves as a compass. Once you arrive at the idea, you still must apply the rigor of the scientific method. Blind scientific progress can be extremely dangerous without perspective. This became evident at the beginning of the Industrial Revolution where a collective conversation was sparked about the direction of all this new technology (Edwards, 2008, p. 79). The story of Frankenstein (1818), Dr Jekyll & Mr. Hyde (1886) and H. G. Wells' The Invisible Man (1897) all became legendary books by taking up this subject of misguided, all-powerful, and isolated scientists gone mad. An overdue public conversation had been started, and it was the arts that blew the whistle.

Technological development has since relentlessly powered on. The global flow of information has become noisy, and the conversation is at risk of becoming subdued. An unaware and controlled public on the one side and the status quo establishment on the other. In the turbulence of this, scientific progress is persistently surging forward. It is often left to outsiders to keep up with the latest developments, reading ever more technical research papers, and trying to make sense of it all (Edwards, 2008, p. 107). It takes extra careful and conscientious people to mobilize a public conversation about existential threats like artificial intelligence or the genetic revolution at our doorstep. Both developments will inevitably change the fabric of society to an unrecognizable degree within the century, but it is very hard to find evidence of that in the public discourse. Some of the most important conversations faced by humanity, are competing for attention along cat videos, troll farms and self-promotion. We have been left with bad decisions which later threatened our existence before, and it has never been easier for powerful profit-driven organizations to take control and manipulate the public according to their agenda. Theodore Kaczynski (also known as the 'Unabomber') was a skilled American mathematician protesting technological progress by terrorizing the public and academia through mail-bombs targeted at people he considered responsible for the negative development of modern society. The story of Kaczynski is complicated since he was himself terrorized by the US intelligence service in collaboration with his faculty at Harvard through a series of unethical psychological experiments. However, he is often brought up in conversation about our technological society and the direction we are heading because of his elaborate manifesto on the topic. His writings emanate the psyche of a damaged person, but his utopic references to pre-technological society is not far off from Moholy-Nagy's in *The New Vision*. We are moving fast forward as a species, and there is a very important conversation to be had about that trajectory.

Science and technology-based societies have with their fast-paced progress burdened the planet on many fronts: deforestation, the ozone crisis, desertification, pollution, resource scarcity etc. This is contributing to political instability, extremism, natural disasters, and dire living conditions for billions of civilians. For these and other reasons some of the most relevant art-science projects today aims at these contemporary social issues (Edwards, 2008, p. 111). Multifaceted issues call for interdisciplinary understanding, and this is the role of art-science in society today. Contrary to scientists, artists do not make their reputations by solving practical problems, and you could argue that much of art merely reacts or comments on the development of science and technology - the active driver of societal change. Moreover, artists and scientists face rather different institutional, cultural, and educational obstacles when it comes to confronting society's problems. True of both, however, is that you won't be able to make sense of a complex world if you choose to only operate within a narrow field of interest. There are many societal and planetary issues that needs parsing, and to understand them deeply, you must get out of your faculty and into the world. The fusion of art and science -

art being intuitive, thriving on uncertainty, 'true' meaning a reflection or interpretation of our experiences in life, expressive of nature in its complexity

science being analytical, deductive, conditional on problem definition, 'true' meaning repeatable by experiment and expressive of nature in its simplicity

- may account for most of the significant intellectual engagement of social problems and technical development occurring today (Edwards, 2008, p. 111). Edwards argues that if you don't pair up your artistic practice with some degree of scientific study, you are not taking part in the most important conversations of our time. This is what lies at the core of what art-scientists aim to do. Edwards, being a founder of art-science labs himself, explains how process matters more than results, experiments are never repeated, and results are never bad (Edwards, 2008, p. 178). Investigating a subject without a clearly defined objective removes the fixation on results and allows you to discover unexpected solutions. Failing is a big part of an art-science pursuit, since it is inherently forcing you into unknown territory. Failure is not deserving of much contemplation; it is not important and merely serves as a tool for navigation. Laboratories as described by Edwards are mostly about creating and only secondly about results (Edwards, 2008, p. 184).

As an extension to Edwards's observations on education and institutions, I will here include a section on art institutions focused on the intersection between art and science. I do not intent to analyse art education at large or suggest which framework is right. I will include a recent manifesto by a Dutch art academy re-inventing itself based on a desire to encompass the latest technological developments and prepare its students to function in a dynamic creative economy.

The ArtScience Interfaculty at the Royal Academy or Art, The Hague recently celebrated its 30th anniversary. It is an interdisciplinary art program that teaches aspiring artists to navigate and combine scientific developments with artistic expression and lists Edwards as a key influence on their philosophy and structure. Other schools such as Central Saint Martins, The MIT Centre for Art, Science & Technology (CAST) are offering similar courses specifically designed for artists to build a symbiotic relationship between art and science. The sprouting of these new sub-faculties suggests that we are passing through a wave of focus on art and science. What is different this time - compared to early twentieth century or the late sixties? It is tempting to say everything. Tools once expensive, unintelligible, and out of reach are now accessible to the public, giving birth to the maker-movement; A many faceted open-source community where anyone curious and willing to learn can go to find their like. Where previous waves of art-science curiosity relied heavily on expensive trained engineers and technicians, this time everyone and no one is the expert. The relatively low cost of using relatively complex technologies has not only democratized the production, distribution and consumption of art and design products; it has also democratized aesthetic values. New technologies and methods of communication are no longer the privileged domain of professionals but are increasingly becoming available to amateurs and consumers. We might see art faculties dedicated to curiosity driven science research, but students will likely turn to a community of these makers when they need to acquire new skills. There are very few limits to what you can teach yourself online - which brings me to the second thing that makes this art-science wave different that the other two: the internet. Rivalling even the advent of language itself, few things have enabled the spreading of knowledge more than the internet. Not just written knowledge, also software and the infrastructure to ship goods around the world in a matter of days.

In an essay published by the Willem de Kooning Academy in Rotterdam titled *Re-inventing the art school* (2013) Jeroen Chabot (1957), dean and executive director, discusses this matter in depth and lists 4 points critical to the development of a capable and contemporary artist and/or designer and which therefore will have to be the four pillars on which the academy of the future must rest (Chabot, 2013, p. 18).

1) The idea that art and design are subject to fixed rules is an outdated concept. Yet many of the complex conventions and techniques which have come to define art and design clearly demonstrate the need for comprehensive bachelor and master education programs.
2) Technical expertise and critical engagement are essential requirements of artistic practice, and as such must occupy a prominent place in the education programs.
3) Regardless of the economic sector in which the artist/designer chooses to make a living, all practitioners must develop strong competences in the fields of collaborative strategies as well as networking and entrepreneurial skills.
4) The intense and inspiring relationship among students and between students and teachers within a learning environment is an essential condition for the development of the critically engaged artists which the professional practice requires.

It is challenging for art institutions to keep up with the fast-paced technological developments. Art faculties provide social interaction between its students, but niche technical knowledge is abundantly available through open-source online communities. Professors are being tested on their ability to guide their students through areas where the student might be more technically knowledgeable than the teacher. For this reason, adaptive thinking and modernization of the classic art academies is still a relevant debate. Hesitation or reluctancy on behalf of institutions, could result in artists being handed outdated toolkits, essentially becoming unable to compete with contemporaries trained to navigate the field of technological development. The technical capacity to create artwork with a present (or future) relevance depends on adaptability, exposure, curiosity, and insight - less on legacy techniques.

1.2.4 Jack Burnham

Jack Burnham (1931 - 2019) was an American writer on art and technology and himself a practicing sculptor and trained engineer. He made important contributions on art theory in the sixties, especially on describing the transitory phase from sculpture as an object to sculpture as a system, which Burnham sees as the 'means by which sculpture gradually departs from its object state and assumes some measure of lifelike activity' (Burnham, 1975, p. 10). Few people have put words to this important metamorphosis of sculpture better than Burnham.

One of the first observations he makes is the growing impermanence of sculpture. Historically sculptures were solid, long-lasting, and embodied the very physicality of artistic thought, providing us with a strong record of human cultural history (Burnham, 1975, p. 10). In contrast post industrial revolution sculptures are often perishable and disconnected from the traditional values of sculpted objects. This is caused by a general trend of the industrial age towards a systematized environment altogether. Objects such as furniture, cooking utensils, books and tools used to be passed down through generations and were made to last as non-perishable objects (Burnham, 1975, p. 11). In contrast, the object now is a replaceable component in a system of production and need fulfilment, even with a planned obsolescence build-in. Objects have lost their sovereign status in the technological age, partly because we are capable of manufacturing more objects than ever before. Burnham refers to the realistic portrait after the invention of photography as a comparable debasing through technology (Burnham, 1975, p. 11). The next phase in the transformation of classic to modern sculpture was the vanishing of the base. The base had long served as a physical and psychological barrier between the sculpture and its surroundings helping to construct a sense of dignity and significance. The meaning and symbolism of the base however was dismantled when it was suggested that any object could be mounted on a base and become art. Burnham goes on to describe the lengthy effort of artists to dissociate themselves with the base, seeking to build an environment where observer and object are given equal status. Focus shifted to the naturalness of things, objects, and organisms to be accepted for what they are, not for what they represent (Burnham, 1975, p. 20).

Progress in science trickles down and affects society at large. Scientific consensus is constantly fluctuating however and corrects itself in phases. These phases are characterized by the general acceptance of the same paradigms which produce uniformity between world views and the experimental results. Does our theories and experience of reality match up with what we measure? Periodically large shifts in the scientific consensus occur and changes the collective human perception of the world - Copernican astronomy, Newtonian mechanics, or Darwinian evolution for example. The massive flux of scientific progress in the 20th century enforced a stronger consensus on objective reality than has even been established before. This has, according to Burnham, pushed sculpture and art at large away from their historical territory. Just as science, sculpture has historically also been questioning the nature of reality, but whereas science is built around a rigorous methodology designed to answering those questions, sculpture rarely seeks more than asking and suggesting. For centuries the relationship between art and science was perfectly symbiotic. There were plenty of questions science couldn't answer, and this was nourishment for artists. Every unanswered question and hint of mystery is fuel to the artistic machinery. However, when two bodies - one equipped with an objective, analytic, systematic framework for progress (science), and the other purely focused on contemplating abstract concepts, externalizing emotions, and the mimicry of natural phenomena (art) - are pursuing a similar path of inquiry, science is destined to reach conclusions and art challenged to accept that consensus. The room for imagination gets smaller and smaller. As the scientific world picture is acknowledged, sculpture has become engaged in a trade-off between its strivings toward science-oriented ‘objective’ reality and the necessity for retaining some of the imaginary and artistic characteristics of the past. Burnham uses Karl Marx' (1818 - 1883) concept of reification (or 'thingification') to describe the reinvention of sculpture as challenged by science. For Marx, thingification was a term which described how certain societies transformed all ideas into objects. Burnham explains, "Thus the process of 'thingification' which has given birth to modern sculpture is the constant resynchronization of artistic sensibility with a disclosed form-world of scientific theory". Thingification brings sculpture away from its traditional modes of focus and the changes manifest themselves in the following way (Burnham, 1975, p. 6):

a) The transition of sculpture from craft methodology to a reflection of the modern production of goods.

b) The sporadic passage of sculpture from idealism (as expressed through the traditional hieratic values of the sculpted object) to materialism.

c) The evolution of sculpture from a psychically impregnated totemic object toward a more literal adaptation of scientific reality via the model or technologically inspired artifact.

d) The replacement of inanimate sculpture with life-simulating systems through technology.

The industrialization of the production of goods changed the premise on how quality products are made. Previously (and still today in the production of niche products), quality was obtained through the skills of trained craftsmen, and sculptors were masters of a trade just as blacksmiths and shoemakers were masters of theirs. When industry raised the quantity of their products using novel machinery and materials, craftsmen became unable to compete - if not on quality, then on quantity and price. The methodology of using exquisite handcraft as the main separator between art and object therefore was rendered insufficient. The heavy and expensive machinery and material expertise needed to produce these industrial products also made it inaccessible for relatively small-scale artists used to working with simple tools like brushes, chisels, and plaster moulds. Modern industrially produced objects changed the frame of reference as to what is considered quality and technically difficult to produce. Thus, artists had little choice but to use comparatively simple tools and techniques to comment on the developments and effects of industry. The second point on Burnham's list, ultimately is the result of artists commenting and/or mimicking consumer products to such a degree that nowadays the line between an art object and a consumer product can be very hard to distinguish; oftentimes they purposefully are one and the same thing. The last two points cements the dominating effects of science and industry, and the adaptation of the scientific worldview in the creation of art. Steadily we move toward a 'scientific artistry', one that rejects whatever is inconsistent with contemporary science. Modern artistry has become the ability to apply technology, science, and engineering in a skilful and novel way to reflect and comment on the impact those very things have on the individual human, on society, and on the future of our species. Bio, robotic, multimedia, and other technically demanding and often collaborative art forms, poses a question: has the manifestation of artistic expression changed because of this technification? As alluded to, artists of the future will benefit from having knowledge about complex technologies currently used in engineering, computer science, chemistry, biology, and others. If not possessing the knowledge themselves, they will have to collaborate with those who do.

Burnham describes a persistent desire of artists to produce, not just mimicry and representations, but real natural structures and live subjects (Burnham, 1975, p. 55). The advent of technologies such as high-resolution additive manufacturing and genome editing are now granting us access to this godly domain previously inaccessible. 3D printing represents a direct line between computed structures in digital space, and the physical three-dimensional world. Similarly, genome editing has opened the door to our own source code allowing us to create, for the first time in the history of evolution by natural selection, subjects that have been artificially genetically selected for. Subjects that is not just a representation of imagination or a simulacrum, but real, live 'art', that exists on the same terms as other living beings, and which therefore demands the same responsibility we grant humans and animals. The 'artwork' will increasingly be able to express itself without the need of any artist to direct it. The story of Pinocchio essentially describes this human desire to produce real living systems capable of dancing and thinking for themselves. The making of a 'Pinocchio' might be feasible soon, only delayed by rapidly improving technical abilities. Sculpture has historically been understood as something separate from biology and the technological drive, instead of something closely related. According to Burnham we have now transitioned past this and instead view sculpture and art as an indication of humans changing conception of biology, and a form of biological activity in itself (Burnham, 1975, p. 376). One of the underlying meanings of early abstract sculpture was the concept that life could no longer be characterized or idealized by mimicking it through symbolism, and that a more analytical approach held the key to biological representation (Burnham, 1975, p. 167). Bio-art with its direct application of scientific tools and methods manifests the completion of this decade-long artistic metamorphosis.

Artists has throughout history been competing on quality and technical ability. A master sculptor was largely defined by technical expertise. The distinguishing factor being their ability to contrive thoughtful compositions and communicating insightful truths about the human condition. The past century has brought the end to this way of producing art - technical ability is rarely appreciated as being the main artistic quality of an artwork today (Burnham, 1975, p. 114). The ‘deep and insightful’ compositions of the past - a careful *memento mori* of a human staring into the face of death - would today be considered cliché. Not that we have lost interest in death, but if you remove the religious and mythical aspect of it, death can be understood merely as a process of material decay - the evolution of sculpture from a totemic object toward a more literal adaptation of scientific understanding. A good example of this is the Cloaca ‘poop machine’ (2000) by Wim Delvoye (1965), a Belgian conceptual artist. Cloaca is a machine that mechanically breaks down matter as it happens inside our intestines. Our own bodies will undergo a similar process if put into the ground, becoming food for bacteria and bugs. Another modern artwork that approaches death and decay in this more naturalistic way is Damien Hirst's (1965) *A Thousand Years*, where a cow’s head is being consumed by a swarm of flies, which themselves are being killed by an electric flytrap. A very bleak and un-ceremonial perspective on both life and death, and very different than the mythical grim reaper narrative. We are shifting away from the *ignoramus et ignorabimus* worldview, and no longer turn to imagination when faced with difficult philosophical questions.

Where I find Burnham’s analysis of contemporary sculpture most interesting is towards the end, where he speculates about the future of humankind and the role of art in that development. Exponential developments in technology means that you cannot expect the progress of the past century to simply extend into the next. This century promises the coming of more than the type of technological developments we saw in the twentieth century. We could be experiencing the beginning of a critical transitory phase of the entire human species, which according to Burnham, centres around the development of human-made intelligent lifeforms (Burnham, 1975, p. 371). In 1975, he was very early to make such observations and his view on the role of sculpture in that transition even more distinctive. He asks whether art is a form of biological indicator of what's coming? If art can be considered as a mirror of our collective human psyche, and art icrementally is fusing itself with mechatronics, computers, and biology, could this activity be understood as an indication of a coming automata revolution? Automata, is the term used by Burnham to describe a fully sentient artificially created system or being, generally referred to as artificial general intelligence (AGI).

There is broad consensus that artificially created intelligent lifeforms are technically possible, it is essentially a question of information processing, however, there is much disagreement about the impact of such an invention. Nick Bostrom (1973), the founder of the Future of Humanity Institute at Oxford University – a multidisciplinary research institute that employs the tools of mathematics, philosophy, and social sciences to understand big-picture questions about humanity and its prospects – reflects on the potential outcome of a synthetic super intelligent creation in his paper *Ethical Issues in Advanced Artificial Intelligence* (Bostrom, 2003). The ethical issues related to the possible development of machines with general intellectual capabilities far outperforming those of humans are very different from any ethical problems we have yet had to consider. Such super intelligent systems would not be just another technological development; it would be the most important invention ever made and would lead to explosive progress in all scientific and technological fields, as the superintelligence could conduct research with superhuman efficiency (Bostrom, 2003). The foreseeable technologies that a super intelligence is likely to develop include atomically precise manufacturing, which will allow for advanced space travel and von Neumann probes (self-reproducing interstellar probes), elimination of aging and disease, fine-grained control of human mood, emotion, and motivation, and many other significant and disruptive and dangerous technologies (Bostrom, 2003). The concept of intelligence as a technology that can be developed might benefit us, or it might spiral out of control and begin optimizing for the reproduction of synthetic life over organic life, leaving us for extinction. If you consider the collective behaviour of humankind, you will see a collection of organisms with a mechanism in the brain constructed as a positive feedback-loop for technical innovation. Technical behaviour is rewarded with dopamine and increases intelligence, which leads to more technical behaviour and so on. Burnham argues that art and the whole image-making drive in humans, may be a way of preparing us for physical and mental changes which we in time will make upon ourselves (Burnham, 1975, p. 373). If so, sculpture becomes a kind of psychical radar signal preparing humans thousands, or now perhaps only decades, of years in advance for the coming of the singularity – the point in time at which technological growth becomes uncontrollable and irreversible, resulting in unforeseeable changes to human civilization. A point made by recognized scientists, Max Tegmark (1967) in *Life 3.0,* Nick Bostrom in *Superintelligence,* and Susan Schneider (1964) in her paper *Alien Minds* - is that biological intelligence is only a transitory phenomenon and that if we ever encounter extra-terrestrial intelligence, it very likely will be post-biological in nature. Whether this inevitable transition from biologic to synthetic intelligence implies a gradual phasing out of all natural organic life or a symbiotic coexistence, is unknown for the moment.

2 STATE OF THE ART

In this section I will introduce two impactful exhibitions which embodied the thinking as described in the analysis: *Cybernetic Serendipity*, 1968, by Jasia Reichardt (1933) and *Software*, 1970, by Jack Burnham. This is followed by a portrayal of a selection of artists whose work is relevant to the topic of discussion and my own body of work. I include mention of these artists for the purpose of understanding how my work relates to other artists following a similar path of inquiry, and to establish that I am subscribing to a pursuit whose cohort include an array of established artists.

2.1 CYBERNETIC SERENDIPITY & SOFTWARE

Cybernetic Serendipity was curated by Jasia Reichardt, an art critic, teacher, and writer, interested in the relationship between art and other areas of human activity such as architecture, science, technology. The aim of the exhibition was to discuss artist's involvement with science and the scientist's involvement with the arts (Reichardt, 1968, p. 5). Cybernetic Serendipity contained much basic information on the historical development of digital computers. It included scientific experiments and works by artists which utilized the principle of feedback in machines designed to respond to external and/ or internal stimuli. Other exhibits featured printouts (visual diagrams) from computers as used in music analysis and music synthesis, computer graphics and movies, computer-designed choreography, and computer poems and text analysis. At the time of the exhibition, computers and electronic equipment were scientific tools used for calculations and experiments and had not yet been incorporated by the arts. Reichardt was interested in discussing how technology could revolutionize the arts, as it had already done with science. This was achieved using computers and electronic equipment to output things beyond their normal use case and without a practical purpose. While Reichardt was interested in the impact of technology on the arts, she also wanted to make a point come across that resonates with the observations from our analysis – that the technification of the arts extends the range of expression of the exercising creatives and involves a new type of skillset (Reichardt, 1968, p. 5). She recognised that the tools of science and engineering could be used for artistic self-expression, and that physicists, mathematicians and engineers already were exploring their equipment in a creative fashion. This point was underlined by not distinguishing between works made by an artist, an engineer, or a mathematician – for her, in the future, they would all be using a shared toolbox.

Burnham approached the discussion of technology and its impact on art from a slightly different angle. Central to his investigation into the transformation of art throughout the twentieth century is the suggestion that the technification of art and self-expression denotes an evolutionary technification of the human species itself. Part of this evolutionary metamorphosis includes the invention of an artificial super intelligence resulting from continuous advances in computer technologies. He understood information technology as the first step in that direction and makes a comparison between human mind/body dualism and the software/hardware construct of electromechanical systems (Burnham, 1970, p. 11). A human brain can be understood an organic control system transmitting small electrical signals. Information processing in computers works in a similar way and is only temporarily held back by its premature developmental phase. It follows from advances in transistor density as described by Moore's law and improvements of software systems that computers could eventually become as sentient as human beings (Burnham, 1970, p. 14).

As our dependency on information technology increase, we are forced to confront the computer as a tool central to further development of our civilisation. This scenario includes a paradox: we cannot survive without technologies potentially just as dangerous as the challenges they are designed to solve (Burnham, 1970, p. 14). It was based on these premises Burnham assembled the Software exhibition. He was, however, questioning the application of technology to merely reproduce or mimic styles of existing human artistry (Burnham, 1980, p. 6). Seeming focused on the intension, or lack thereof, behind a machine programmed to carry out an arbitrary task, he instead directed attention towards the concept of information technology itself. He sought out to make an educational exhibition with interactive works showcasing information processing in all its forms (Burnham, 1980, p. 7). The Software exhibition thus became a very technically difficult endeavour and suffered severely from malfunctioning equipment. A New York times article about the exhibitions describes it as a confusing, capricious, and sometimes fascinating educational display (Glueck, 1970). The critic explains that the exhibition was lacking a consistent intension – showing witty exhibits alongside serious ones and items that by and large could be understood as product placement, thus failing to present a working point of view about its subject (Glueck, 1970). Ironically, central to Burnham's proposed discussion, was a concern about the effects of novel information technologies on our ability to navigate reality informedly and consistently. In that sense, an incoherent and confusing exhibition with powerful, malfunctioning technologies, complements his intensions in a very real way. Cybernetic Serendipity and Software, along with other similar exhibitions at the time, introduced us to a new type of art experience and drew attention to the artistic possibilities and possible dangers of modern information technology.

2.2 H. R. GIGER

H. R. Giger (1940 - 2014) is known for contriving the xenomorph creatures from the Alien film franchise in 1979 by Ridley Scott (1937). Giger was a world-builder, and he was imagining alternate lifeforms in the universe and the potential dystopic encounters between species. His date of birth, 1940, offers some explanation to his alien escapism and dystopic worldview. He was born into a world in with war. As overserved by David

***Figure 1 - H. R. Giger**, Alien III, 1990.*
Source: https://news.artnet.com/art-world/h-r-giger-2039120

Edwards, the disruptive technologies of the Industrial Revolution prompted a concern about misguided and all-powerful scientists – resulting in a series of novels portraying dystopic futures. Similarly, Giger seems influenced by the brute force mechanics of war machines and the eugenic ideology that was coupled to much of the political agenda at the time. His work depicts parasitic biomechanical entities devoid of human emotion and moral, possibly as an exaggerated extrapolation of continued technological developments and eugenic engineering. His creatures, while appearing alien, hostile, and bizarre, share many anatomic similarities to humans and are even depicted engaging in sexual reproduction. Giger might have been envisaging the future of human beings, rather than an alien civilization, when constructing his xenomorph creatures.

2.3 BRUNO GIRONCOLI

Bruno Gironcoli (1936 - 2010), an Austrian sculptor, gained public recognition with his monumental sculptures in the mid 1980s. Akin to Giger, he seems to have taken fragments of reality and used it to construct an alternate version. Parallel to the

Figure 2 - Bruno Gironcoli*, Donaucity, 1980.*
Source: https://commons.wikimedia.org/wiki/File:Gironcoli_sculpture_3.JPG

development of Gironcoli's sculptures, important discoveries in genetic engineering were made. Opening the door, for the first time in history, to targeted genome editing. Gironcoli seems to ponder the effects of such technologies through his sculptures, which together suggest hybrid forms and organically inspired machines. Prototypes of new species. Detached from real sizes and dimensions, as well as from the laws of physics and the limits of bodies, his sculptures are abstract and suggestive rather than concrete. They merge to form surreal constellations and scenes.

2.4 MARGUERITE HUMEAU

Marguerite Humeau (1986) is a French artist and designer. In recent years she has become especially known for her keen interest in de-extinction, the science of reviving extinct species. The research conducted within this field is relevant at a time of accelerated loss of biodiversity. Her work is created in an ongoing dialogue with experts in biology, palaeontology, sound design, and 3D modelling. Since de-extinction requires qualified guesses about the appearance of something that no longer exists, Humeau regards this endeavour as sculptural and artistic in scope. For her most recent project

***Figure 3 - Marguerite Humeau**, waste, 2019.*
Source: https://flash-art.com/wp-content/uploads/2019/11/Marguerite-Humeau_Flash-Art_03.jpg

Humeau was interested in creating a conceivable animal that never existed. Taking her starting point in the scientific hypothesis that the real difference between human beings and chimpanzees is articulated speech, a difference that arose due to a random mutation of the gene known as FOXP2 some 100,000 years ago, Humeau imagined this mutation taking place in elephants instead of in human beings. The result is a world where elephants are the dominant species. Humeau has long been interested in elephants, partly because they are ascribed to experience complex emotions – such as grief, expressed through funeral rituals. Humeau's practice reflects a renewed scientific interest in artificial intelligence, immortality, and reverse aging.

2.5 Olafur Eliasson

Olafur Eliasson (1957) is driven by a fascination for basic elements, the forces of nature, and the emerging dynamic environment. He has worked extensively with water in all its states, electromagnetism, light fracture and lensing, and many other areas. His studio employs engineers, specialized technicians, architects, and designers. Together they build sculptures, installations, buildings, and immersive experiences. Famous for his

***Figure 4 - Olafur Eliasson**, your natural denudation inverted, 1999.*
Source: https://olafureliasson.net/archive/artwork/WEK101405/your-natural-denudation-inverted

work on light, he explores principles of lensing, refraction, and other types of manipulations that affects the viewer's perception system. Eliasson uses scientific and technical knowledge of natural phenomena to submerge spectators in scenographies of altered states of reality. Light can be used to incite emotional responses or to isolate groups of color from being perceived, as explored in *the weather Project* (2003) and *Room for one color* (1997). To manipulate such natural phenomena, you need a scientific understanding of the underlying mechanisms. Olafur Eliasson has been able to do this successfully and stands out as an artist who does not merely interpret scientific principles but applies it with artistic consideration.

3 TOOLS AND TECHNIQUES

This section, on tools and techniques, will concentrate on two technologies central to the development of my sculptural practice: additive manufacturing and 3D modelling. These two closely tied technologies allows you to maneuver between digital and physical spaces and are used across industries where boundless and detailed object-modelling is needed. Both fields are subject to ongoing innovation and their full potential and use case have yet to be revealed. I assert the use of such technologies to be very applicable in contemporary sculpture and therefore relevant to our examination of sculpture and its linkage to science and technology.

I draw on learnings from the course *Digital Sculpture* facilitated by Professor José Revez, as well as frequent engagement with João Costa and João Rocha from the product & interior design lab (Projectlabb) during the development of my practical body of work. I rely further on Francis Bitonti (1983) and his book *3D Printing Design: Additive Manufacturing and the Materials Revolution* and publications by the Danish Technological Institute (DTI), for reference and insight. Bitonti is a New York based designer, author, and pioneer of algorithmic design and computer aided manufacturing. DTI is an independent and non-profit research and development institute in Denmark. Engineering.com is an online publisher on science and technology. To maintain relevance, both to our analysis and the coming section on my practical body of work, I deliberately exclude other contemporary and emerging art fields such as bio-art, robotics, NFT's (Non-Fungible Tokens), etc., in the section on the state of the art.

3.1 ADDITIVE MANUFACTURING

3D printing is more accurately called additive manufacturing (AM), but the terms are used interchangeably. It is covered by the broader category of 'computer-aided manufacturing' (CAM) and describes different mechatronic technologies that can be used in combination with a wide range of materials to produce (i.e., print) objects directly from a digital 3D file. The additive process stands in contrast to subtractive manufacturing - where objects are produced by incrementally removing material from a block - and the casting process of formative manufacturing. AM was gradually developed in the second half of the twentieth century and is therefore a relatively modern approach to fabrication.

The process relies heavily on mechatronic hardware components and software which only recently have become readily available and cost-effective - illuminating why it has not been developed earlier in history. AM essentially generates physical objects by replicating the volume of a digital mesh - a process that allows for designs with enormous structural complexity. The variety of available materials, the scale and level of detail of the output, are all increasing and improving. It follows from the improving accuracy of AM that the space between the digital and physical dimension is getting smaller, allowing digital objects to be exported with little to no loss of detail.

AM systems can fabricate extremely complex shapes, so the technical limitations of the output often lie in the capacity to construct the digital object itself. The sculpting process can be supplemented by 3D scanners, which essentially does the opposite – digitize physical objects into 3D mesh. 3D scanners can be very accurate and help you omit large parts of the laborious hand sculpting process. While the accuracy of 3D scanners might be high, it is still not a 1:1 representation of the target object and therefore mostly serves as a rough starting point or for direct modelling purposes (see section 2.3). Much innovation is going into the materials science of AM. PLA and PETG plastics are the most widespread – they are rigid, durable, beginner friendly and inexpensive. The range of filaments spans much further however, encompassing an array of materials with distinct properties and requirements. Compared with conventional manufacturing techniques, AM is still in its developing phase with its full potential and use case yet to be understood. I find two phenomena arising from AM to be particularly impactful: The concept of materials as a linguistic phenomenon, and distributed manufacturing.

3.2 MATERIALS AS INFORMATION

Bitonti describes how the digitisation of object modelling and manufacturing presents sculptors and designers with the opportunity to redefine, not only aesthetics, form, and function, but the notion of materiality and structural composition itself (Bitonti, 2019, p. 10). Analogue processes of material and object development are being replaced by digital models and procedures. Digital systems are contingent on following logically derived instructions as defined by a variety of programming languages. The fabrication of objects is therefore increasingly becoming a codified process allowing matter and structure to evolve through language – materials as a linguistic phenomenon (Bitonti, 2019, p. 11). The next generation of AM systems will have even fewer formal constraints allowing for greater capacity and variation between materials and composites. This prospect aligns with the physical understanding that objects are comprised of fundamental building blocks called elements held together by energy. The ability to generate objects and manipulate matter in this way has not been part of human technology long. It will introduce new categories of materials and enable us to fabricate shapes previously constrained to exist as digital representations (Bitonti, 2019, p. 32). AM machines are increasingly capable of printing with more than one material at the time – enabling a new type of composite fusion-object where the transition between materials is fluid. It would further open the possibility of making enclosed pockets of distinct materials and integrated mechanical features. Multi-material AM combined with computational modelling (see section 2.3.2) will change the way we understand and produce objects. No longer will the composition and function of an AM produced object be apparent through visual inspection. A solid, single-piece object could be comprised of several different materials layered in intricate patterns with integrated channels and functional mechanisms. Such an object is not accurately described by its material composition, but by the digital information that guided the fabrication.

3.3 3D MODELLING

3D modelling is also referred to as 'computer-aided design' (CAD) and describes a process that allows computer operators to design a variety of objects and geometric shapes digitally rather than building them physically. Some terms are necessary to introduce when talking about 3D modelling and computational design. A computer is working by methodically executing a set of instructions called algorithms. We interact with the computer through a graphical user interface (GUI), which is the interface projected on the screen attached to the computer. 3D modelling software can then be understood as program designed to receive input through the GUI by the user and render 3D objects on the screen (Bitonti, 2019, p. 23). 3D modelling software consists of a GUI through which you can define and manipulate digital representations of shapes. Many programs share the commonality of having buttons, dials, and tables of input for you to interact with the scene. While the distinction has been made between parametric, direct, and computational modelling, you are increasingly offered the opportunity to switch between modes in one and the same program or through plugins. There is further terminology attached to CAD modelling: (Bitonti, 2019, p. 24): *Polygon:* A Polygon is a plane figure that is described by a collection of straight segments connected to form a closed polygonal chain. The bounded plane region, the bounding circuit, or the two together is called a polygon. *Point/Vertex:* A point/vertex is where two or more edges of a polygon meet. *Edge:* The edge of a polygon is the straight line between two points/vertices. *Face:* The face refers to the closed plane created from vertices and edges of the same polygon. *Polyhedron:* Bounding polygons together in three dimensions forms a polyhedron – a higher dimensional object. Its most basic geometric shapes are the cube, a sphere, or a pyramid.

3.4 COMPUTATIONAL MODELLING

Direct and parametric modelling have many more commonalities between them than with computational modelling. Computational modelling is less constricted by conventions and userbases and thus exists in greater varieties. Essentially, you use algorithms and/or mathematical functions to generate objects instead of sculpting yourself. Basic knowledge about computer programming is therefore an advantage. This approach springs out of scientific research fields like computational chemistry, complex data representation, machine learning, and cellular automata. Where computational modelling is offering something difficult to achieve through direct and parametric modelling, is in volumetric design (Bitonti, 2019, p. 33). So far, most CAD software assumes that materials are consistent all the way through the cross section. This is effective for subtractive methods of production – if you are carving a block of stock material, you are not able to shape the internal composition of the part. This is not the case with AM, however, where you can print microstructures in alternating materials. The additive approach to manufacturing allows for control of geometry with high resolution, and volumetric design is a tool that enables the making of objects with a non-uniform kernel (Bitonti, 2019, p. 34). Computational modelling is gradually becoming more accessible for the non-technically trained through integration into conventional 3D modelling software packages with user-friendly interfaces. These services come in many different packages depending on the task it performs. Increasingly complex algorithms are making their way into more and more appliances, and for a while now engineers have been using the analytic power of computer algorithms to optimize their design. ‘Generative design’ or ‘topology optimization’ it is called, and it is a very powerful tool used to discover, in unison with the engineer, the most efficient shape for a specific purpose. An example of a computational modelling tool that operates in the space between programming and hand-sculpting, is 'Grasshopper'. Grasshopper, a plugin for the Rhinoceros 3D modelling package, is a graphical algorithm editor that takes advantage of the software’s existing tools. This plugin requires no programming or scripting knowledge, but it allows designers a high degree of flexibility in creating both simple and complex forms. Most of these algorithmically created shapes are then buildable in combination with CAM technologies.

4 BODY OF WORK

4.1 SISTEMA PROJECT

My body of work centres around the evolving nature of living matter and the improving accuracy with which we can analyse and manipulate it. We use instruments to extend our senses and understand the things we cannot see with our eyes alone. The lenses in these instruments are essentially gateways into other dimensions. My work is influenced by cellular automata, computational biology, gene editing and atomically precise manufacturing, which will be accounted for in the following section. Here, I will present a selection of books which introduced me to a world of components, mechanisms, building blocks and basic principles. Whether it being the structure of DNA, atoms or molecules, *small things with distinct properties come together to form larger structures with emerging features*. This might be a rather self-evident characteristic of any kind of system, be it natural or constructed, but the very universality of the principle evoked a curiosity about a sculpture based on a similar set of principles. A building block sculpture system, assembling into endlessly large structures with emergent qualities.

I will unfold the developing of this objective, which I came to label as 'The Sistema Project'. The desire is to construct a multitude of sculpture systems each relating to their own phenomena – technology, humans, organism, etc. – conveying both abstract and concrete observations. A three-dimensional universal sculpture-language parsing natural and technological phenomena. I consider my sculpture systems as a very literary translation of a Danish word called 'formsprog'. It means form-language, and we use it to describe the means of expression that characterize a work of art, an artist, or a style. I take it however to mean shape-language, a three-dimensional alphabet. Like an alphabet has letters that form words which then form sentences; my sculptures have components that assemble into shapes which can grow into endlessly large structures. The expression and meaning decided in tandem between the assembler/author and the audience/reader. The Sistema Project as a system can be updated, enhanced, and expanded just like software. I imagine fine-tuning the structures with alterations and additions, allowing for mutations and improvements just like natural organisms. The entirety of my future body of work could potentially be able to interact with each other through converters, thus exhibiting the progress and mutations taking place over time.

4.2 Influence

In science there is no such thing as eternal ideal proportions. Living organisms are constantly in flux – mutating and evolving. Selecting for the most efficient shape within its environment. Ideals are temporary and relative. The age of Earth is around 4.5 billion (4.500.000.000) years old, and Homo Sapiens have existed for about 0,006% of that time (300.000 years). What exists now will be gone or have changed in the future, humans included. Francis Bacon (1561-1626) was an important figure in this realization. He is regarded as a pioneer of the scientific method, and his approach to learning changed the course of history. We started to understand the big picture. 150 years ago, Charles Darwin (1809 - 1882) introduced the idea of evolution by natural selection. The tree of life was slowly being revealed to us, and the understanding that biotic life had sprung from abiotic components. We have only had this knowledge for 0,05% of our existence as humans. That we are part of a large network of life and that snails and trees are distant cousins of ours. Due to mechanisms governed by the laws of physics, matter organized itself into ever more complex systems and eventually began competing for resources. Over time, being able to make a distinction between hot/cold, light/dark, left/right, up/down, became an advantage over the competitors who couldn't. We are essentially the outcome of this competition.

These are some of the conditions my sculptural practice rests upon. It can be considered my base layer on top of which I can construct independent ideas. These ideas, different from each other as they might be, will always hold the same base conditions to be true. To initiate a new project, I include topic-specific insights until a direction starts to materialize. The Sistema Project was strongly influenced by Richard Dawkins (1941) and his book *The Blind Watchmaker* from 1986. Dawkins is a British evolutionary biologist, ethologist, and popular-science writer who emphasized the gene as the driving force of evolution. The book introduces the basic principle of evolution by natural selection, genetics, adaptation, and other things biology related. What really inspired me, however, was the wonderful experiment he developed for mimicking these evolutionary processes with a simple computer program. Dawkins' main idea was to illustrate the

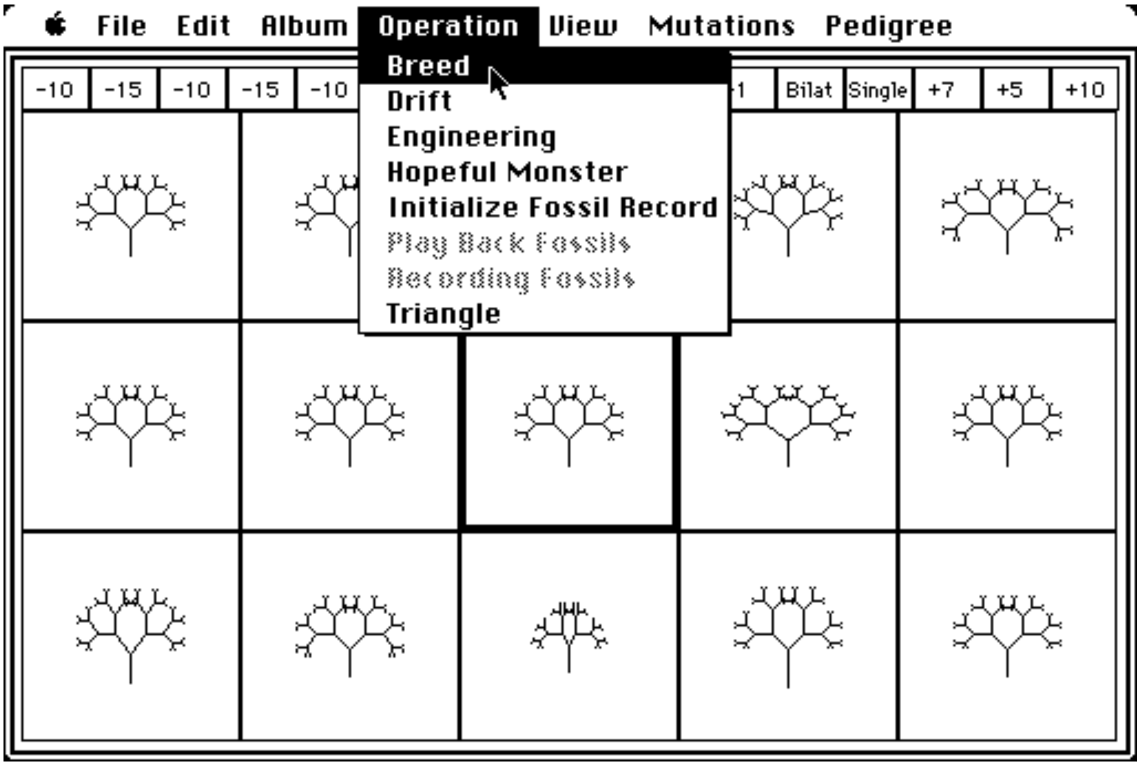

Figure 5 *- Richard Dawkins Biomorph program.*
Source: http://www.ittybittycomputers.com/Essays/BreedMenu.gif

difference between the potential development of complexity resulting from pure randomness, as opposed to that of randomness coupled with cumulative selection (learning/memory). The program displayed a two-dimensional shape - a 'biomorph' - made up of straight black lines (see figure 5). The length, position, and angle of which were defined by a simple set of rules and instructions. Once you click on one of the options, the program will 'breed' x-number of new options with a slight variation from the one you chose. This process represents one generation of genes being passed on to the next. The complexity and diversity of shapes arising even after a few 'generations' is astounding. Dawkins describes how he sat for hours 'breeding' little digital animals and organic shapes, and how difficult it was to breed the same shape twice. If you have 14 choices at each turn, and you 'breed' for 100 generations, the possible outcomes are difficult to comprehend. A very powerful and endlessly complex natural phenomenon illustrated in the simplest and most basic form. This experiment seeded the idea of building a modular physical system capable of adjusting, reshaping, growing, and shrinking.

An additional source of inspiration in the making of the Sistema Project, came from a book by Jamie Metzl (1968) called *Hacking Darwin*. Metzl is an American geopolitical expert who served as a national security counsellor under the Clinton administration. The reason why he had an impact on my work however is his mission to educate the public about the ongoing genetic revolution. His latest book describes in detail the current developments in genetics and gene editing tools, and the insights are truly mind-bending. The world is about to change, and most people don't even know it. Gene editing tools such as CRISPR-Cas9 allows for cheap and easy alteration of the natural code we are made of. The implications of these developments can be hard to wrap your head around. They include:

Stem cell treatment: Insertion of stem cells into your body that regenerate various functions and fend off a long list of deceases. Embryonic stem cells can be turned into anything inside the body and could therefore also be used to replace any organ or limb.

Embryo selection: Screening of fertilized eggs with the purpose of choosing the one least likely to contain heritable genetic disease, or to choose desirable traits such as IQ, athletic ability, eye colour, the list of things to select for is growing every day.

*Growing embryos from stem cell*s: A mixture of the previous two. Growing eggs and sperm using stem cells. This technique allows for the creation of thousands of embryos to select from, increasing the variables to choose from when selecting your baby. This technology also allows for the creation of same sex offspring, since stem cells from a man also can be used to grow an egg. This egg can then be fertilized with sperm cells from another man (or even the very same person). It also allows for much higher 'resolution' when choosing which embryo to take to term, since you can have tens of thousands of choices rather than just 5-10. This means you can even start selecting for personality traits, hobbies, intro- or extroversion etc., these things are all determined or greatly affected by your genes.

Alteration of DNA: Tools like CRISPR-Cas9 acts like a scissor with a delivery package. It can cut open the DNA strain and insert/replace a targeted gene sequence with an artificially prepared one. This again, means that you can take control over your genes and decide which ones will be allowed to procreate.

Gene drives: A gene drive is a tool that forces certain genes to be in a species' population. Gene drives do this by greatly increasing the chance a certain gene is passed on to an organism's offspring. By inserting a gene drive to an organism and releasing it, you can therefore change the course of that entire species forever.

The genes and genomes that underpin organic life are based on a code written in four letters – C (for cytosine), G (guanine), A (adenine) and T (thymine). Organisms are basically biological machines built by executing programs written in these letters. Just like computers, in other words, which are just machines that execute programs written in ones and zeroes. The implications of this analogy are mind-blowing. Once you have figured out the sequence that programs an organism, then, in theory, you could replicate it. And if you can write biological code then you can edit it to change the organism or even create an entirely new one. You can, in other words, become a biological programmer and play God. Metzl includes an analogy that draws on our experience with platforms constructed using various programming languages, running on various devices. 'Biology will be the next platform, DNA will be the code that runs it, and CRISPR will be the programming language used to edit it' (Metzl, 2020, p. 165). Many analogies are being made between computer programming and our genetic biological code, and that raises concern for some people, since computer programming are notoriously based on a trial-and-error approach. An error tampering with our genetics could have disastrous unfixable implications.

The desire to figure out the workings of nature is a very old human intellectual pursuit. With the advent of computer systems, a new approach to answer difficult questions presented itself, the juggernaut power of computation. You can attribute the rapid developments of the second half of the 20th century to many factors, but few were more impactful than the computer in its many shapes and forms. Without its analytical and predictive assistance, breakthrough technologies such as the genetic revolution mentioned above simply would not have been possible. Simulating natural phenomena

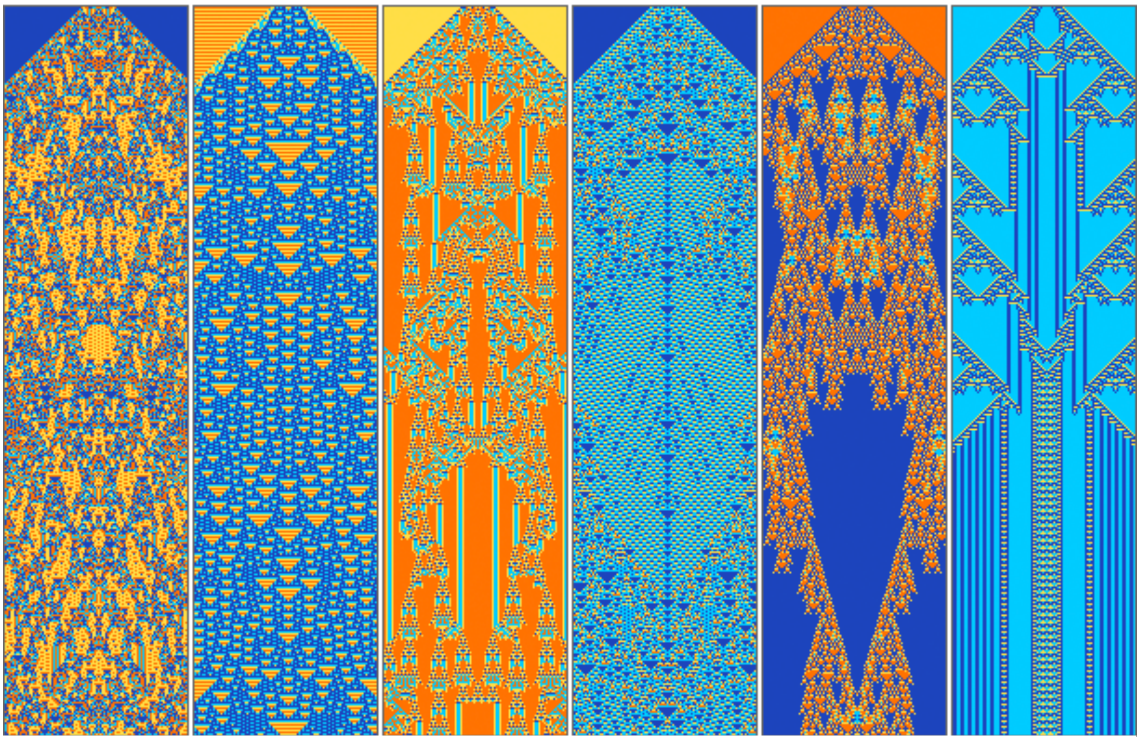

Figure 6 *- Stephen Wolfram, cellular automata.*
Source: https://writings.stephenwolfram.com/data/uploads/2017/05/conditions.png

gives us further insights to the mechanics of nature, and while it is difficult to include all the parameters of a multifaceted natural system, drastically simplified models is often enough to mimic the behaviour of much more complex systems. Stephen Wolfram (1959) put this to principle to the test when he started to work on Cellular Automata in the 1980s. Cellular automata is one of the best visual examples of complexity arising out of a set of simple rules. Wolfram is not an artist; he is among many things a computer scientist and a computer language designer. His book *A New Kind of Science* is a testament to his extensive work on understanding complexity arising from simple principles. His tools are computation, and his canvas is a screen, so these systems are far less restricted than any physical structure. In figure 6 you can see different rules computed.

The initial condition of the system determines the behaviour of the computation and altering any of the parameters will change the outcome. The space in which the computation takes place is a pixelated grid (see figure 7). One generation/round of computation happens with every step on the y-axis, and what determines whether the pixel will be black or white is described by the 8 rule parameters under the computation. The colour of the square at the bottom is determined by the 3 squares above. If the 3

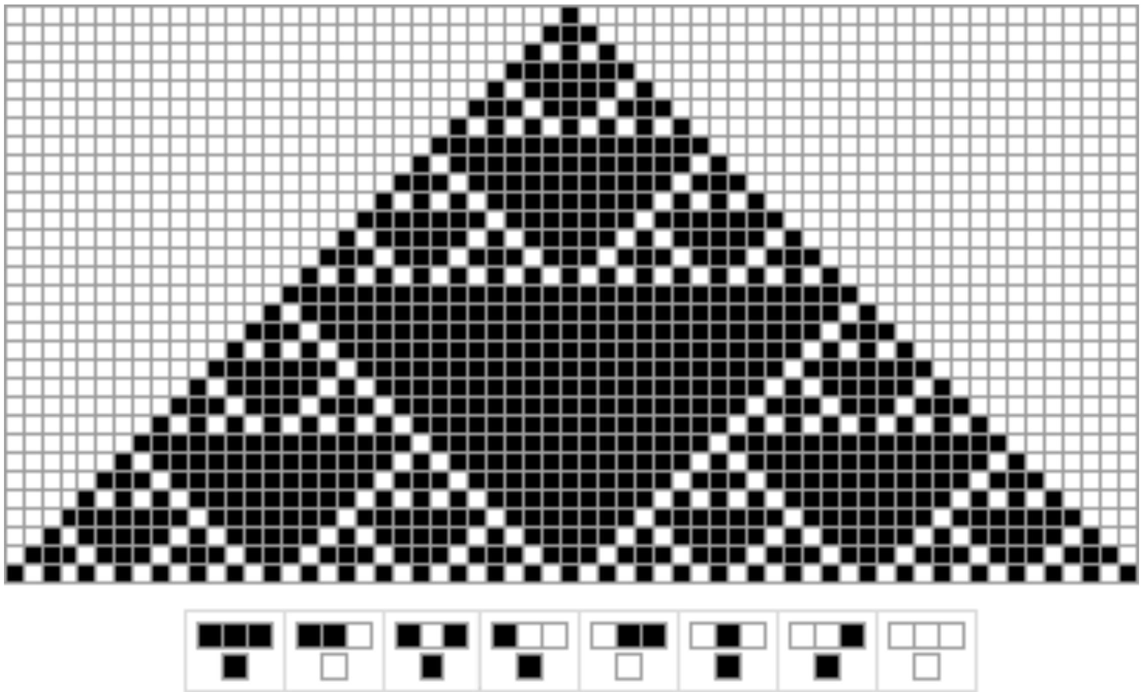

***Figure** 7 - Stephen Wolfram, Rule 30*
Source: https://writings.stephenwolfram.com/data/uploads/2017/05/conditions.png

squares on top are all black for example, the square on the bottom will also be black, if the first 2 squares are black and the last one white, the bottom square will be white etc. Some of these rules give rise to such complexity that it becomes impossible to predict the outcome given enough steps. The only way to find out how the pattern will materialize, is to run the computation itself. Wolfram calls this computational irreducibility. The principle of computational irreducibility says that the only way to determine the answer to a computationally irreducible question is to perform, or simulate, the computation itself.

4.3 SCULPTURE

The Sistema Project embodies a desire to pass through gateways into different dimensions. To traverse scale and represent the mutating and metamorphic nature of life. In materializing these intentions into a sculpture, I let myself be guided by mechanisms and principles from evolutionary biology, genetics, and computer programming. This section will describe the modelling process of the sculpture.

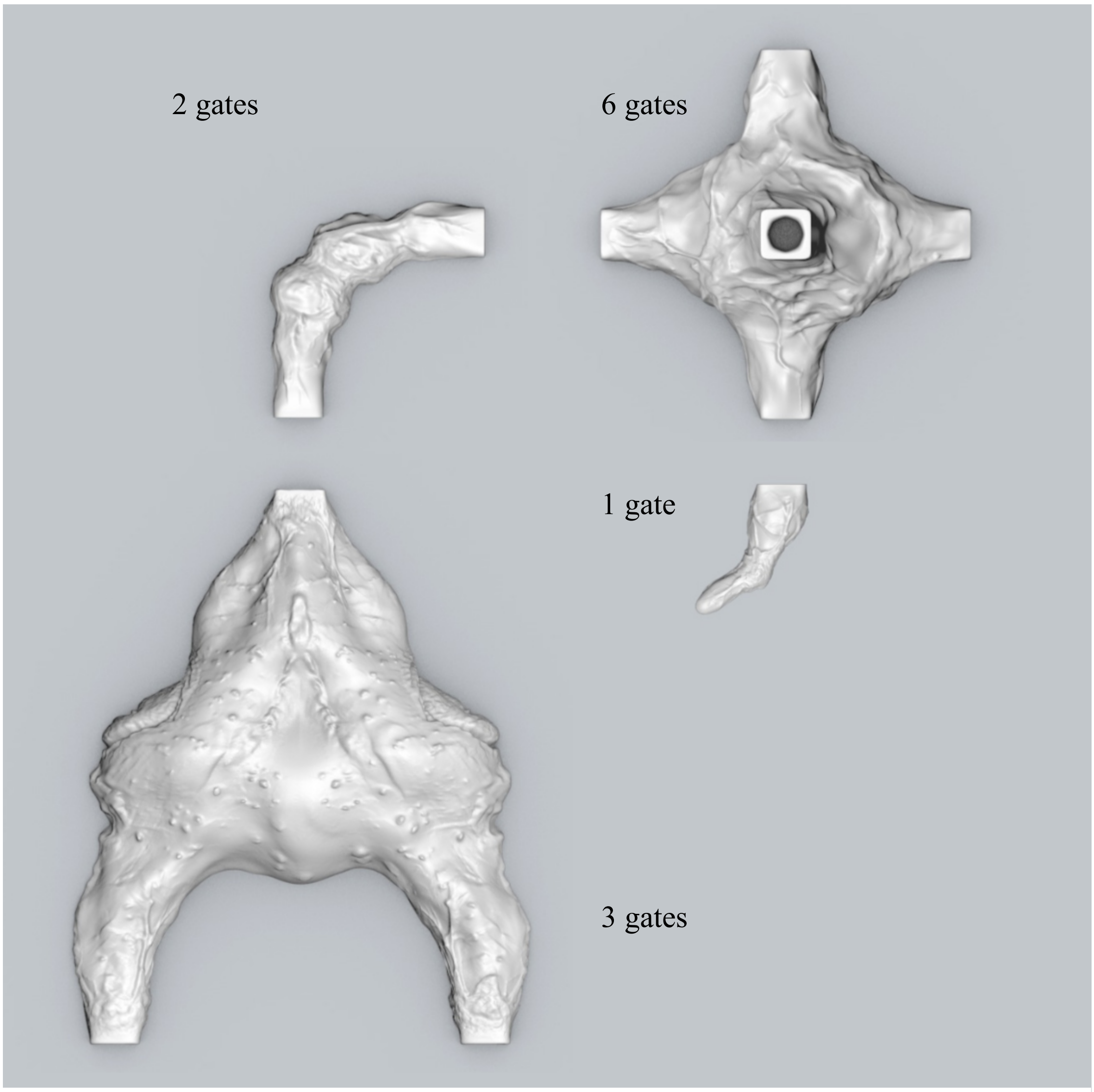

Figure 8 *- Sistema sculpture system 1.0*

The first sculpture system is built around a quadratic grid and allows for the size of any components that multiplies or divides within that matrix. 4 components make up the sculpture system and they differ in size and number of connections/gates they have (see figure 8). The most fundamental is the 6-gate piece — it has connections up, down and in all 4 directions on the other plane. The 2-gate piece is useful as glue in binding together other components. The 3-gate component with an added half dimension to its length offers a lot of potential variation to the system because of its forking ability to jump into the parallel and otherwise inaccessible space. The last component in the system only has 1 gate and therefore serves as a filler for unused openings. It plays the role of external receptor and maintains homeostasis by keeping any opening of the system sealed.

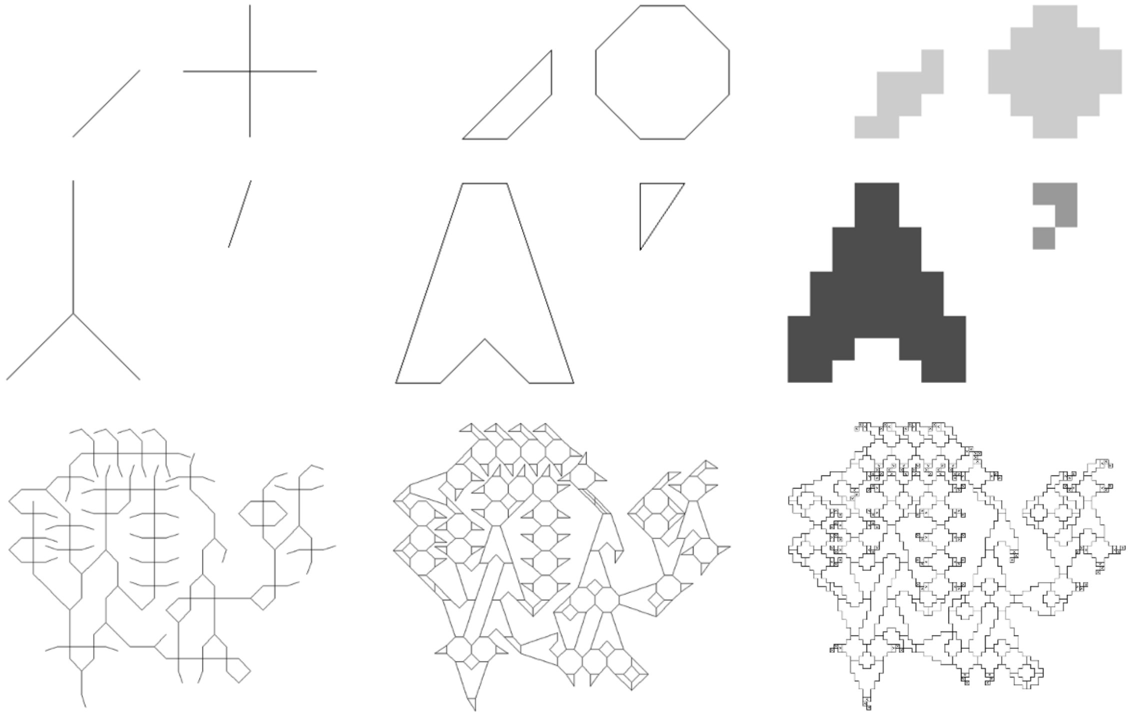

Figure 9 *- Sistema sculpture system 2D versions*

As Figure 9 demonstrates, the underlying geometry of the sculpture can be translated into a 2D space and within that space be represented to a varying degree of detail. The geometry of these 2D representations matches its 3D digital and physical counterparts. This is a reference to fields like digital chemistry, self-assembly systems, and cellular automata. Part of the Sistema Project will be to develop a self-assembly script for these 2D systems to build structures based on a set of initial conditions. In principle these structures would be buildable 1:1 with the physical 3D system.

The basic framework of the sculpture is a foundation on top of which many different structures can be built. Shaping the surface of the system is where the sculpting starts and where vast amount of variation is offered. In sculpting the surface, you decide the subject matter of that system. As described earlier I intend to build various systems each relating to their own subject — still interlock-able with each other however. In the making of the first system this was less clear to me, so the sculpture ended up as a mixture of all things living. I used textures from amoebas, cuttlefish, salamander eyes and pictures of neurons from brain imaging. The technique I used is very similar to copying a textured surface by putting a piece of paper on top and running a pencil over it. In much the same way digital images can be used to texturize a 3D mesh. Each module is made using 3D sculpting software (Cinema 4D in this case, Maya is an alternative), taking symmetry and interconnectability into account. The 3D mesh is then exported to a .stl file, which can be read by a 3D printer. Following the 3D printing, each part is glued together (depending on the shape of the object and the capability of the printer it is sometimes better to split each object into 2 parts when printing, allowing for better layering of the filament) and coated with a formulated epoxy resin to smooth out the 3D print striations. This is important as I will make a silicone mould of the printed part which will capture every detail of the object, and I don’t want the layers of filament to show on the final piece. A silicone mould of the objects is made, and then a process of reproduction through casting.

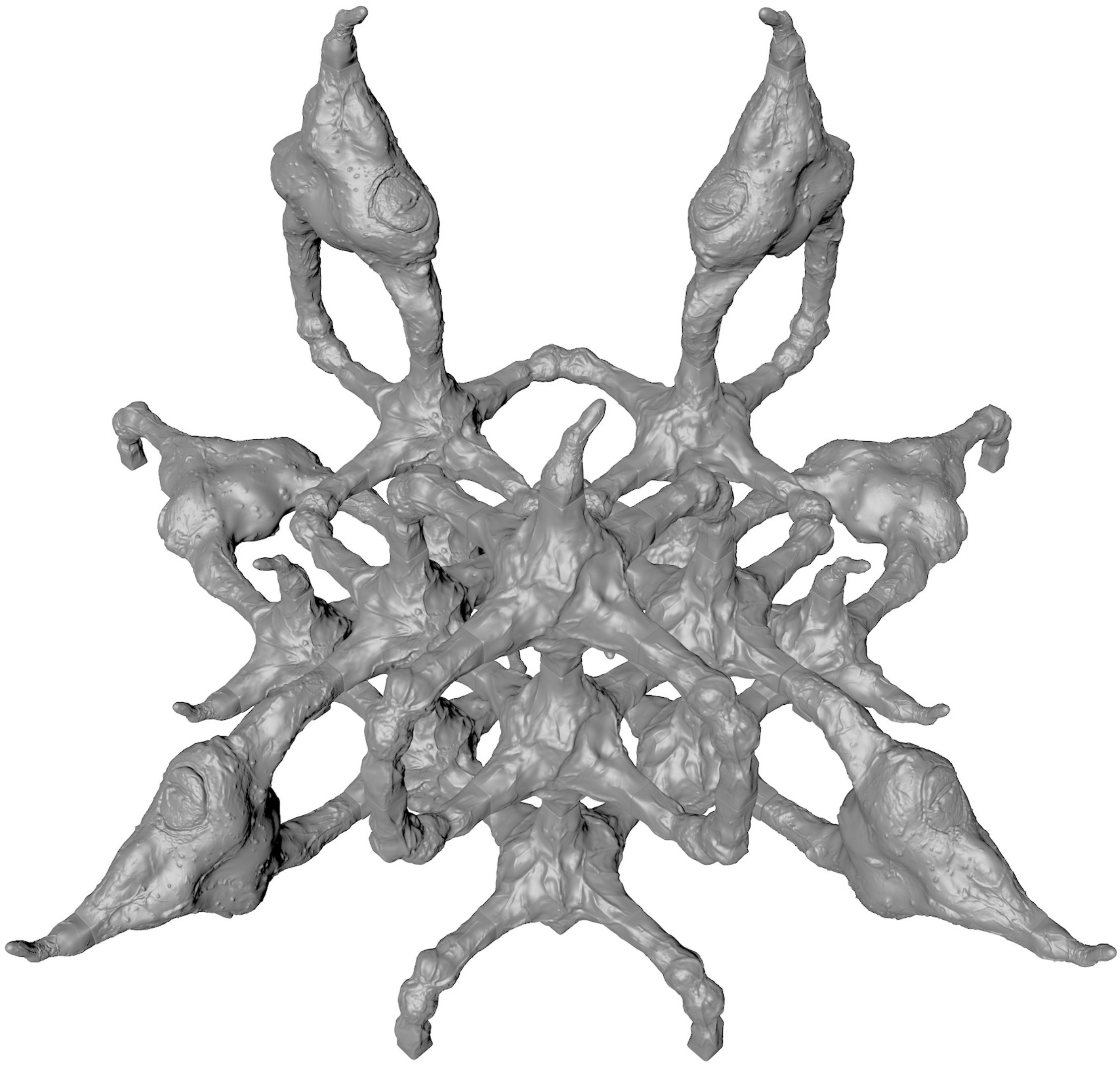

Figure 10 - *Sistema sculpture system 1.0 assembly*

I used a special type of urethane resin that allows for hollow/roto-casting, however I will not describe this process further since mould-making and casting is a big field.

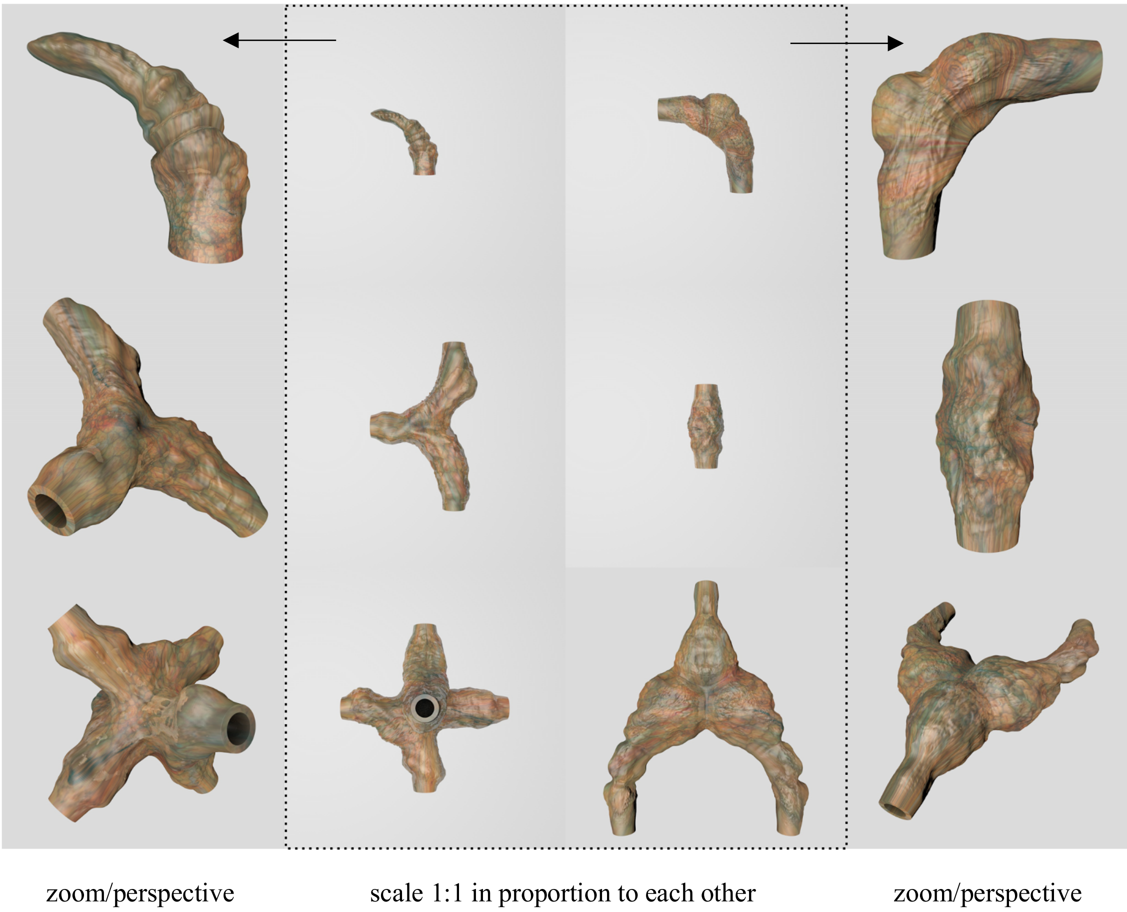

***Figure 11 - Sistema** sculpture system 2.0*

I sculpted other systems to explore different techniques and geometry. The sculpture system above for example has 6 components instead of 4. The two additions can be seen in the middle section of the figure; 3-axon part that connects up/down and to the side, and a 2-axon half dimension part useful in combination with the larger, 1-and-a-half-dimension part directly below it. The skin of this sculptures is made in reference to subterranean fauna, worms, bugs and beetles, roots, and mycelium networks. In addition to developing different types of sculpture systems using the same sculpting approach, I also wanted to explore different ways of generating that surface layer/skin of the sculpture, as well as looking into other export formats — CNC instead of 3D printing for example. For this purpose, I explored the field of generative design, a state-of-the-art software tool used by engineers to optimize strength and minimize weight on various

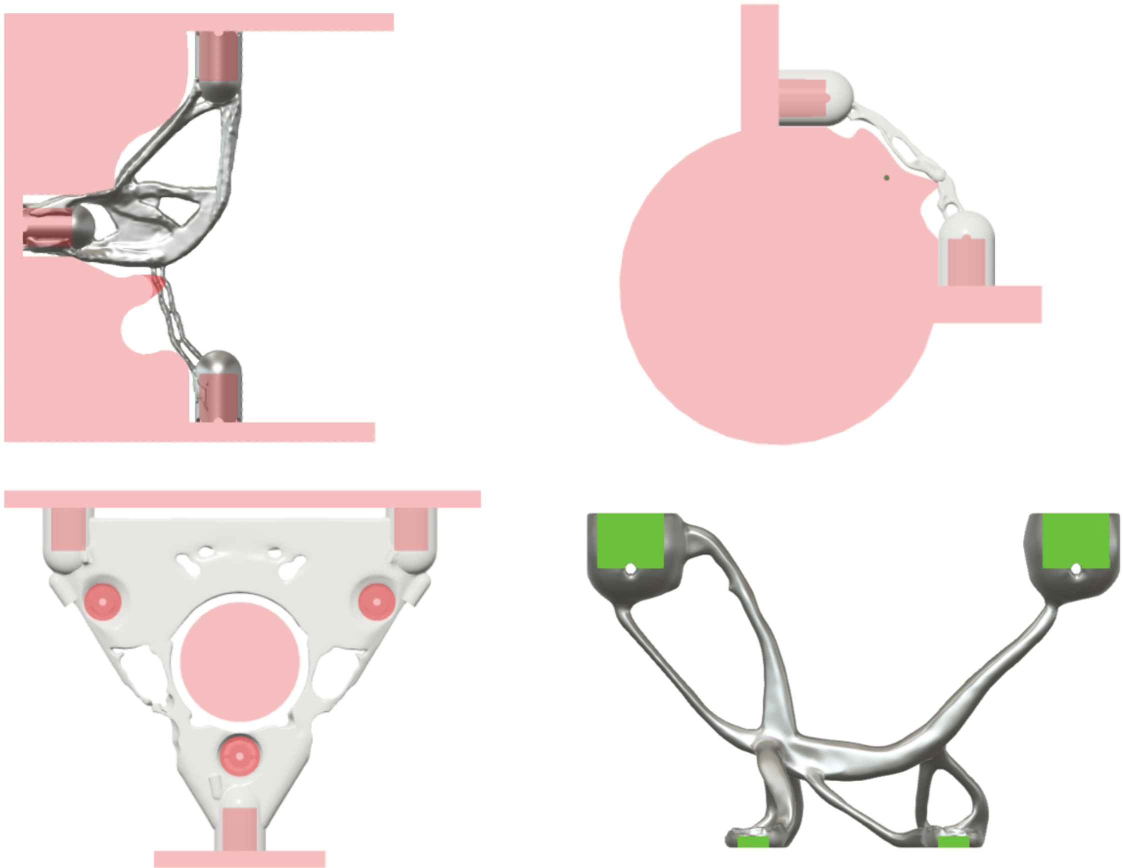

Figure 12 - Sistema *sculpture system, generative design algorithms*

parts and brackets. Before generating the shapes, you must set parameters defining the use case and materiality of the object as well as the forces that will act on it in use. The software will then use those parameters to search for the most efficient shape. It was through these parameters my conversation with the software was enabled. Since the shapes I intended to generate were without mechanical function, I constructed misleading parameters for the software to accomplish. In figure 12 you can see an example of some these manipulations - the pink parts represent areas of the environment where the algorithm is not allowed to go, and the green parts are areas it must include. Building these constraints and obstacles to challenge the software offered a great sculptural exchange between me and the program. It truly felt like an exchange of ideas I have otherwise only experienced in conversations with my design teacher or fellow students. Whereas the earlier two sculpture systems were referring to life, living matter and processes, the sculpture system generated using these methods represents instead our technology. The line between biology and technology are getting blurry. Both internal

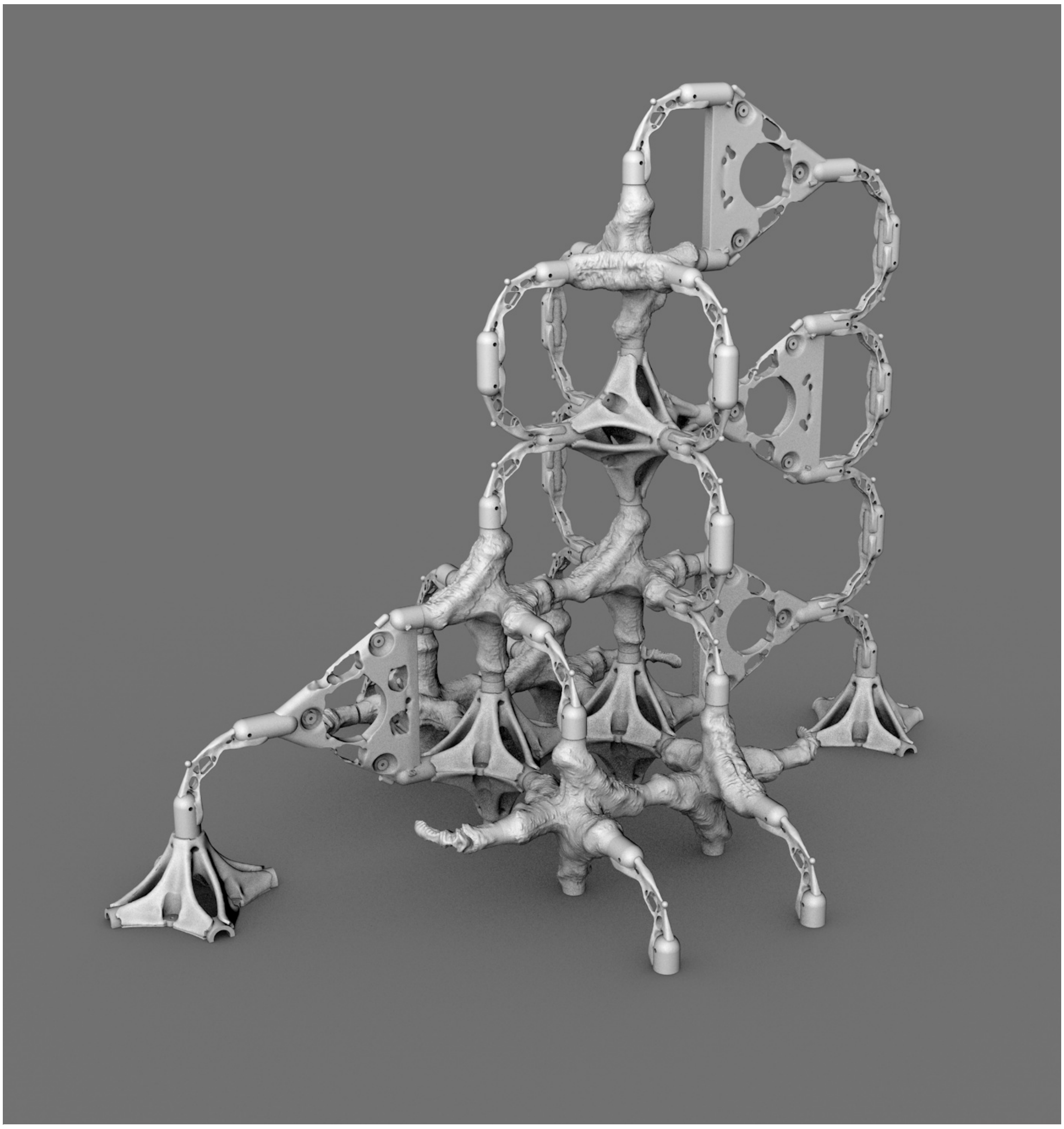

***Figure 13 -** Sistema sculpture system juxtaposed*

and external to the human body, technology is assisting us in ever more advanced ways. The shared basic geometry of the sculpture system allows for the interlocking of the different sculptures. In figure 13 the technology system has been interposed with the organic system, visualizing through very simple and abstract means this fusing of the two worlds into the bionic. The juxtaposing abilities of the systems was not understood by me in the beginning, but I see it as a powerful way to tell stories in an abstract physical language.

4.4 DOCUMENTATION

The pictures in this section are documentation for exhibiting the body of practical work submitted for the Masters' degree in sculpture at FBAUL.

***Figure 14 - Sistema 1.0**, practical body of work exhibition.*

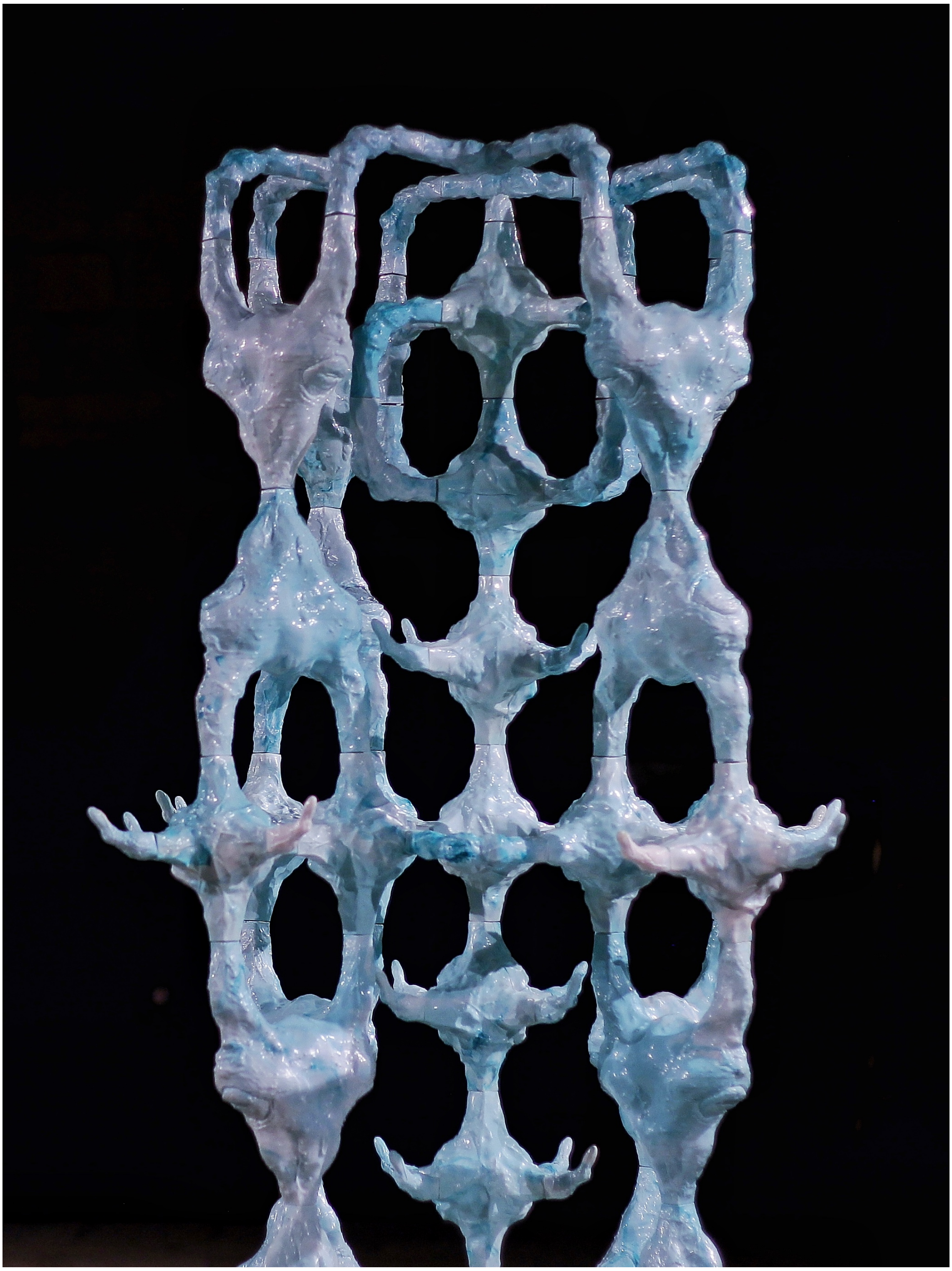

***Figure 15 - Sistema 1.0 detail**, practical body of work exhibition*

Figure 16 - Sistema Generative Design, *practical body of work exhibition*

Figure 17 - Sistema Generative Design *(2), practical body of work exhibition*

***Figure 18 - Wall installation**, practical body of work exhibition*

***Figure 19 - Tollund man**, practical body of work exhibition*

CONCLUSION

I conclude my investigation into the relationship between art, science, and technology with the observation that a gradual convergence across several parameters has taken place throughout the twentieth century. Artists are adopting scientific approaches to self-expression and incorporating tools and technologies from applied science and engineering into their practice. The technology developed to drive forward scientific progress are thus also transforming the Arts. It follows from the technification of art that new channels of creativity have been established and that this will continue further. Artists are engaging in narratives and explorations that require technical and scientific knowledge. Contemporary artists are thus incentivised to familiarize themselves with novel outlets of communication and self-expression. It is further suggested in this dissertation, that cross-faculty cooperation between the arts and sciences offers mutual benefits, and that this fusion already is taking place through the establishment of interdisciplinary faculties around the world.

In contemporary sculpture, the adaptation of technology from science and engineering manifests itself especially through additive manufacturing and 3D modelling. These tools are augmenting the sculpting process and enabling the fabrication of such complex objects that it challenges our approach to constructing physical objects. Computers and computer-controlled machines are thus increasingly used in the fabrication of sculptures, shifting the basic skillset of contemporary sculptors in a digital direction. Further technification of the Arts is guaranteed, and the tools used for artistic expression themselves to become more intelligent. We might suppose that an entire aesthetics of artificial intelligence will evolve. A likely outcome of technology's influence on art in the twenty-first century could be a series of art forms that manifest real intelligence and with a capacity for sentient relationships with human beings.

The twenty-first century promises further development of currently unimaginable technologies, as was the case in the 1920's. The tools of modern technology can be used for many different applications. Public awareness and debate are crucial for integrating these tools ethically into society. Art, by adopting and incorporating these novel technologies, has the potential to take the lead in such difficult conversations.

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