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GROW: EXPERIENCING NATURE IN THE FIFTH DIMENSION

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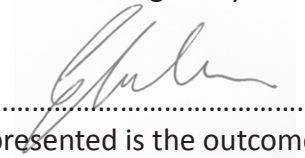
Declaration of Originality



I, ... [sign and date] hereby declare that the thesis here presented is the outcome of the research project undertaken during my candidacy, that I am the sole author unless otherwise indicated, and that I have fully documented the source of ideas, references, quotations and paraphrases attributable to other authors.

Acknowledgments

I would like to acknowledge and offer sincere thanks to the following people for their generous support of my practice-led research *Grow*;

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Finally, I had always wanted to dedicate this Exegesis to the memory of my dear friend Ken Shahaf, who had inspired me with his passion for stereoscopic photography during our undergraduate days. I would now like to share this dedication in loving memory of Jacqueline Beresford, mother of Georgia and Nick, who died on 2 January 2016.

Abstract

Grow: Experiencing Nature in the Fifth Dimension, is an interdisciplinary practice-led research project traversing the realms of art, science and technology through the exploration of germinating seeds. Through my investigation of the aesthetic possibilities of the computational extension of vision with time-resolved (4D) micro-X-ray Computed Tomography, I have tested the potential for visualising virtual germinating seeds in an immersive stereoscopic installation. Using this technology I have set out to create a work of art where an audience can experience seed growth from a very different perspective. However, the rationale to propagate seeds in this way began not just to test the limitations and possibilities of this technology. As an artistic inquiry, my premise for focusing on plant life also began as a way to examine this work from an ecological perspective. By considering the third and fourth dimensional elements in this project I am proposing that an individual's experience of nature in my work can be considered as an additional 'fifth dimension'. My research is placed within a range of disciplines from contemporary art and new media practices to scientific technological research and the natural sciences. The works of art developed through this research have been viewed in relation to ideas of the fourth dimension in modern art, to microscopy in both historical and contemporary art practice, to contemporary installation practices, and in relation to ideas of time and wonder. My experience of meeting the Seed Morphologist Dr Wolfgang Stuppy and staying at the Millennium Seed Bank, Royal Botanic Gardens, West Sussex in the UK has also been a point of reflection. The seed becomes a visual analogy for ideas of time, growth and renewal in the context of issues of creating art in the time of the Anthropocene. This exegesis explores the multi-dimensional properties of my research in the wider context of art, science and philosophy.

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…So the Citizens of that Celestial Region May aspire yet higher and higher To the Secrets of FOUR FIVE OR EVEN SIX Dimensions, Thereby contributing To the Enlargement of THE IMAGINATION…

Edwin A. Abbot, (1828 - 1936)
Flatland: A Romance of Many Dimensions [by a Square], 1884.

INTRODUCTION

Grow: Experiencing Nature in the Fifth Dimension.

Aims, focus and context

Grow is an interdisciplinary practice-led research project traversing the realms of art and science through the exploration of germinating seeds. Through my investigation of the aesthetic possibilities of the computational extension of vision with time-resolved micro-X-ray Computed Tomography, I have tested the potential for visualising virtual germinating seeds in an immersive stereoscopic installation. Using this technology I have set out to create a work of art where an audience can experience seed propagation from a very different perspective beyond the original process. By considering the third and fourth (time) dimensional elements in this project I am proposing that an individual's stereoscopic experience of virtual nature through my work can be considered as an additional 'fifth dimension'.

This exegesis explores the multi-dimensional properties of the research in the wider context of art, science and philosophy. My research is placed within a range of disciplines from contemporary art and new media practices to scientific technological research and the natural sciences. The works of art developed through this research have been viewed in relation to ideas of the fourth dimension in modern art, microscopy in both historical and contemporary art practice, contemporary installation practices, and in relation to ideas of time and wonder. The seed has become a visual analogy for ideas of time, growth and renewal in the context of environmental issues.

My research candidature is experimental and cross-disciplinary. Situated in Photography and Media Arts at the ANU School of Art, my acquisition and visualization of 4D micro-X-ray Computed Tomography (4D micro-CT) is facilitated by the ANU Department of Applied Mathematics through CT Lab, and Vizlab in the ANU Supercomputer Facility and National Computational Infrastructure (NCI). An area of research in the Department of Applied Mathematics focuses on the complexity of dynamic microscopic systems. This requires researchers to resolve the properties of volumetric (3D) data with the

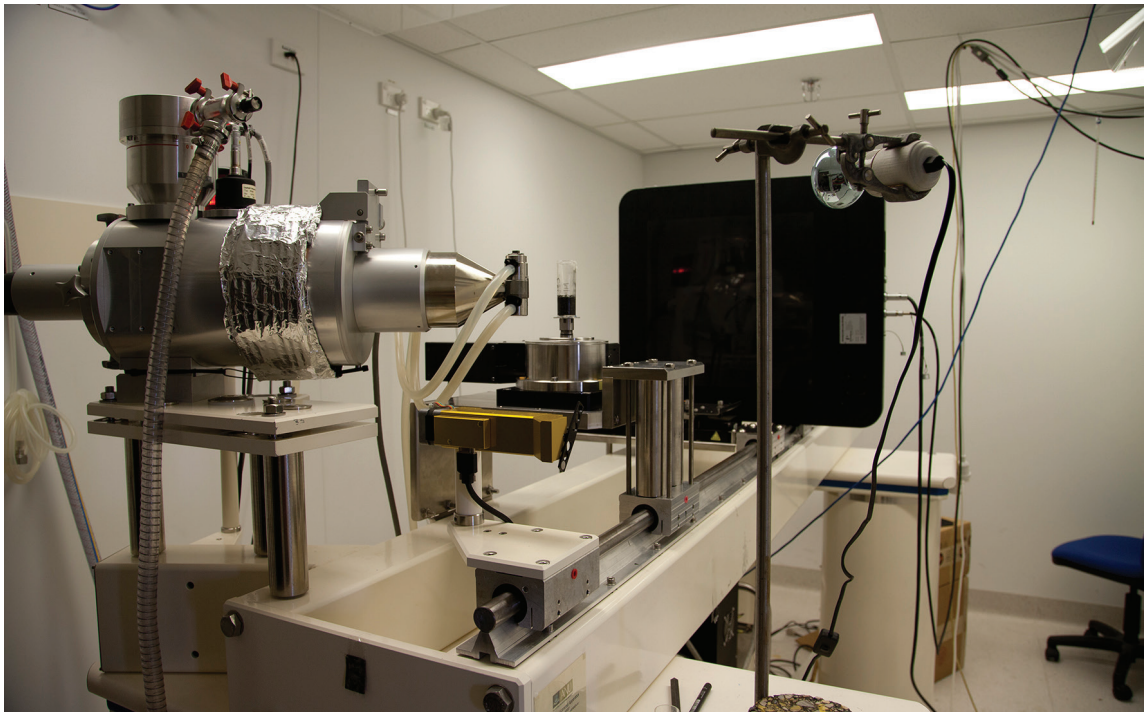


Fig. 0:1. (left) A close-up view of the germinating seeds in a test tube during the scanning process, (2011).

Fig. 0:2. (above) A view of an experiment to germinate seeds in the CT Lab: a test tube containing seeds is placed in the centre on a rotating axis. The X-ray source is directed from the front to capture the information on the detector at the back, (2011).

additional dimension of time, hence 4D micro CT. My proposal to germinate seeds with this technology was initiated through my own interests relating to my artistic practice. It also follows my exploration of *Drishti*, the open source volumetric exploration software developed in Vizlab alongside the CT Lab. I explain further in Chapter one.

The datasets I am visualising of germinating seeds are not derived from fragmentary evidence or rendered through mesh framing techniques used in conventional computer generated imagery (CGI). In contrast to conventional CGI imaging in which the object is simply bounded by a representation of the enclosing surface, 3D micro-X-ray Computed Tomography (3D micro-CT) records a fully three dimensional map of X-ray opacity throughout the entire volume of the object, with microscopic resolution. The system developed at ANU delivers a resolution of two microns, which is approximately 100 times the resolution of a medical CT instrument. The volumetric datasets are acquired by placing the seeds in front of a finely focused but divergent X-ray source. [See Fig. 0.1] By illuminating them in this way the expanding cone of X-rays projects a scalable radiographic image on an X-ray detector. In moving the detector along the optical axis the magnification of the projected radiograph can be varied from about x1 to almost x200. A single radiograph is insufficient to recover 3D structure and in practice several thousand radiographs are taken from different angles through a full 360 degree revolution.

Fig. 0:3. Mung beans sprouting in a dish, (2011).

For this research I have attempted to use this technology to capture the most precise virtual model which records the processes of germination, simulating the texture and material density of both the internal and exterior structure as the seed begins to sprout. Using the word 'virtual' to describe volumetric data is to distinguish it from the 'actual' or original sample it was taken from. It follows the derivation from the Latin *virtus*, or *virtue*, as in displaying the ideal or true qualities of what is real. Static 3D micro-CT creates 'virtual' data-sets that are the algorithmic recreation of a real-life object. Each volumetric pixel represents its real-life counterpart at five microns. It is not mesh-framed or texture mapped. 4D micro-CT includes the additional movements of the data over a period of time. The difference between conventional micro time-lapse photography and 4D micro-CT, is that, with the latter, when visualized in the program *Drishti,* both the interior and exterior of the virtual germinating seed can be observed simultaneously and from any angle. I discuss the outcomes of my investigations in the CT Lab in more detail in Chapter three.

Using this technology I have set out to create works of art where an audience can experience seed propagation from a very different perspective beyond the original process. However, the rationale to propagate seeds with 4D micro-CT began not just to test the limitations and possibilities for this technology as an artistic inquiry. Importantly my premise for focusing on plant life also began as a way to examine this work from an ecological perspective.

I wanted to determine the capacity for these works of art to affect deeper meanings and sensations, such as the experience of wonder when watching the phenomena of plant life

coming into being. The seeds I have therefore chosen for this experiment are ordinary edible varieties that we might grow in the garden or sprout on our windowsills. I used these domestic species in order to make connections with ideas around agriculture, and as a way to reflect on human relationships with nature such as our dependence on natural systems for survival. This directed me to further investigate issues to do with the future of biodiversity and the impact of global extinction of plant species. The subject of seeds has led me to also consider the concept of the Anthropocene, the next geological epoch, influenced by human activity. My experience of meeting the renowned Seed Morphologist, Dr Wolfgang Stuppy, and staying at the Millennium Seed Bank, Royal Botanic Gardens, Kew, West Sussex in the UK has also been an important point of reflection in my research.

In proposing that an individual's experience of nature in my work can be considered as an additional 'fifth dimension', I have tested how my stereoscopic projections of germinating seeds might create the opportunities to explore new meanings and interpretations of this seminal event. My understanding of the 'fifth dimension' in this context is based on the artist Ólafur Elíasson's concept of the sensory properties in his own installations, which are often about the transposition of 'nature' into a constructed environment. He describes the dimension of subjective experience as an additional 'fifth dimension', "because it allows for a greater relativity in our understanding of the other three or four dimensions."[1]

Elíasson's practice is based on the principle that sensation as a quality is as important as the object itself and as an artist he employs phenomenological methodologies in order to position experience as one of the key concepts underpinning his work. Elíasson's view is that 'the greatest potential of phenomenology lies in the idea that subjectivity is always susceptible to change.'[2] He views the third dimension as being the object/subject, the fourth time or temporality, wirh the 'fifth dimension' being a necessary component of the perceptual process which works to destabilise the truth, or objectivity of the work, and transform it into an individual experience.

I found Elíasson's concept of subjective experience as the 'fifth dimension' relevant in relation my own practice, particularly as I am encompassing the third and fourth dimensions in virtual datasets of nature, with the view to creating immersive stereoscopic projection installations. This connection led me to consider recent research which proposes that phenomenological practices of artists like Elíasson might be an effective way to engage people with scientific concepts such as environmental crisis. I expand further on this in Chapter two. This has been useful in order to position my own practice-led research within the field of contemporary ecocritism. By bringing the virtual data

[1] Madelaine Grynsztejn, "Take your time: in conversation, with Ólafur Elíasson and Robert Irwin," *Take Your Time: Ólafur Elíasson*, San Francisco Museum of Modern Art, 2007, 53.

[2] *Ibid*., 55.

out of the computer and into the gallery space, I have sought to examine and test the potential for new experiences and new meanings in relation to nature and the future of the environment in my own work.

By bringing together all of these ideas, subjects, methodologies and processes my research is situated within a range of disciplines from contemporary art and new media practices to scientific technological research and the natural sciences. By employing micro-CT as the instrument of my research, in conjunction with *Drishti*, one of the most powerful visualization software tools currently available, my works of art are firmly located at the apex of scientific visualisation and modeling. These inventions, singular or combined, have extended human vision so that we may observe phenomena and details in nature that were previously invisible. I have examined the potential for this advanced science of 4D micro-CT to create additional experiences of wonder and awe, further contributing to the potential for subjective experiences as the 'fifth dimension' in *Grow*.

Through this research I have created works of art in order to reveal new critical perspectives on scientific technology, its processes and relationships to society, with the aim of extending the field of knowledge in the area of interdisciplinary or art/science practice. This approach to an interdisciplinary practice has been identified by Stephen Wilson, Director, Conceptual Information Arts Program, San Francisco State University. In his publication *Art + Science Now* (2010) Wilson discusses artists whose practices are firmly located, 'with scientific or technological research at the conceptual and artistic core of their work.'[3] Wilson notes that artists engaged in such interdisciplinary practice recognise questions or problems that are unlikely to be pursued by other scientific researchers, as they might not share the same priorities. He emphasizes that such artists are inventive in the ways they share their research results for an audience, tending to add a critical dimension or introducing totally new agendas with broader cultural questions.[4] These may include a critique or reflection on the kinds of science and technology artists are utilising as a way of questioning progress as the dominant paradigm of a technological society.[5]

In interdisciplinary fields such as biological art, robotics or generative programming, artists push the boundaries of traditional aesthetic frameworks as a way of exploring possible transdisciplinary outcomes. Recognised hybrid-artists in this field include Marta de Menezes, George Gessart, Eduardo Kac and Oron Catts, whose practices involve simulating or appropriating life-systems such as plants and animals to address themes of post-humanism, robotics, artificial intelligence, genetic engineering and bio-technology. In my research I am not proposing any theoretical premise about cellular modification or

3 Stephen Wilson, Art + Science Now, Thames & Hudson, New York, 2010, 13.

4 *Ibid*.,11.

5 *Ibid*.,12.

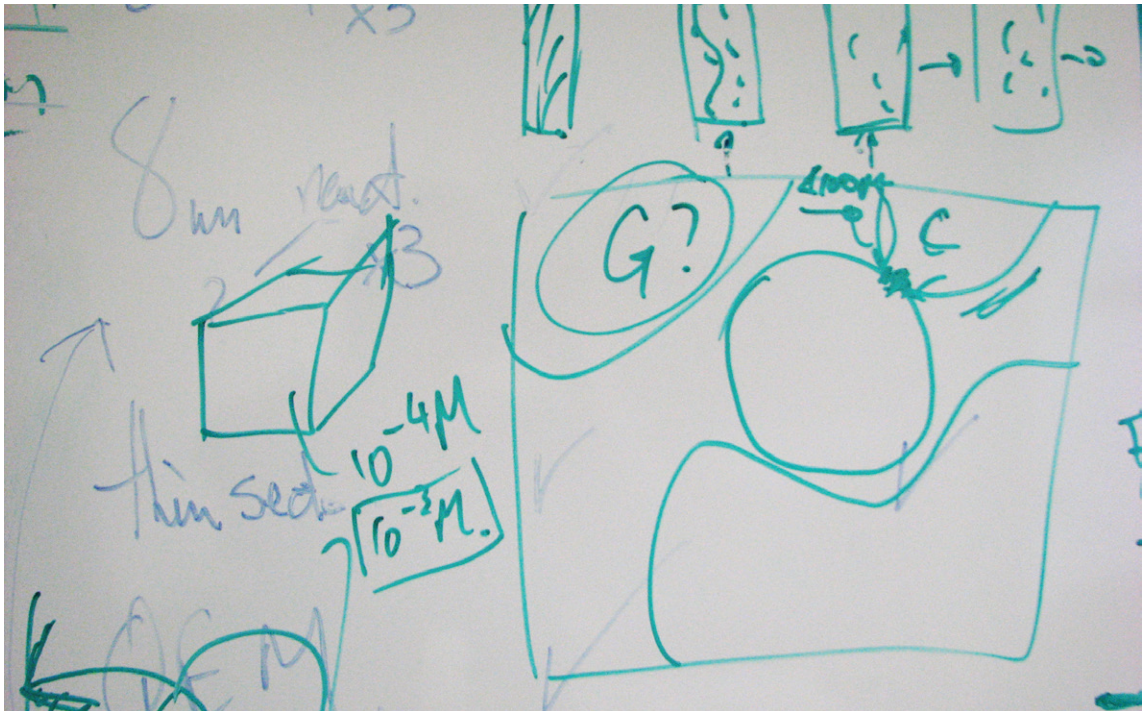


Fig. 0:4. Whiteboard diagrams: working out how to germinate a seed, CT-Lab, (2011).

evolutionary biology in the seeds I am germinating. However, like these artists my art purposefully extends the use of scientific technology to test our perceptions of the limits of nature as a way to explore questions about ourselves and our experience of the world.

I have supported my practice through an analysis of the work of contemporary artists. In Chapter two I discuss Ólafur Elíasson's installation *The Weather Project* to explore how he responds to concepts of nature and creates self-reflective experiences through phenomenological methodologies. I discuss specific works by Stephanie Valentin and Maria Fernanda Cardoso in Chapter three. Both artists employ microscopy visualization to reflect on concepts of scale and human vision. In Chapter six, I show how my consideration of Paul Klee's 1921 painting *Pflanzenwachstum*, [*Growth of plants*] has led me to reflect further on the depiction of time, nature and the future in my own practice.

In addition to considering these artists, my research has been informed by key contemporary readings in the fields of art theory, social, scientific and natural history and environmental philosophy. My ideas have been informed by the contributions of academic writers such as Susan Best, Lesley Duxbury, Will Steffen, Jonathon Crary, Dipesh Chakrabarty and Michael Marder. This enquiry has been important as a means of addressing issues around art and nature, scientific imaging and knowledge, phenomenology and the experience of awe and wonder. It has also helped me to position my work in my own time, in an era of environmental crisis and uncertainty.

Research questions and chapter synopsis

In order to contain the many interconnected and tangential ideas in my research I have identified and explored four main threads of inquiry. The first is the process of acquisition and visualization of volumetric data of germinating seeds with 4D micro-X-ray Computed Tomography and Drishti. Second is an analysis of the concept of germinating seeds in relation to the Anthropocene via field research of seed conservation at the Millennium Seedbank in the UK. The third examines time in the context of the use of time-lapse, temporality and subjectivity in my practice. Finally, a study of specific works by contemporary artists has informed my studio research in relation to immersive installation practices and the use of scientific imaging.

My research is framed by three main questions:

1. How will I create engaging works of art using the science of 4D micro-CT?
2. How can the resulting work connect to underlying environmental concerns?
3. How is my work positioned in the context of contemporary artistic practice?

Chapter one: Seeding the idea

In the introductory chapter I establish how I came to germinate seeds with 4D micro-CT, providing a background to the science and technology, and the software *Drishti* in context of my practice-led research. I discuss aspects of the employment of micro-CT through research at the ANU Department of Applied Mathematics and how I first began to consider the potential for this science in my creative practice. I also explain how my own involvement in the development of *Drishti* has inspired me to further explore this software through *Grow*.

Chapter two: Exploring New Dimensions

In the first year of my research I followed several lines of inquiry that helped me relate the subject of seeds in my studio practice to questions concerning agriculture and the environment. This chapter establishes how I began to consider the concept of the Anthropocene, and I demonstrate how these ideas are further informed through key readings on contemporary installation practices, which have enabled me to situate phenomenology as a useful way to engage viewers more deeply with environmental issues. I explore these concepts by considering Ólafur Elíasson's *The Weather Project*, as a way to situate my own practice-led research in the context of the 'fifth dimension'. I conclude this chapter by reflecting on how the concept of the fourth dimension in modern art inspired my own imaginative use of the science of 4D micro-CT.

Fig.0:5. My experiments with different saturation levels to test the germination speed for 4D micro-CT, (2011).

Chapter three: In the laboratory

This chapter begins with a focus on the processes and methods I explored in the CT Lab and addresses the question of whether volumetric data of germinating seeds can actually be captured with 4D micro-X-ray Computed Tomography, and what the results reveal. Examining the virtual data rendered in Drishti, I consider the meaning of verisimilitude in the context of scientific imaging. To situate my practice within an interdisciplinary enquiry, I consider how the artists Stephanie Valentin and Maria Fernanda Cardoso explore scientific visualisation as both a means and a metaphor and create works of art that reveal what exists beyond the reach of normal vision. I then explore my research questions through the contemporary scientific visualization of seeds produced by Dr Wolfgang Stuppy, and in relation to the 19th century glass objects made by Leopold and Rudolf Blaschka.

Chapter four: Lived experiences

As my research progressed I began to question the agency of wonder in the process of discovery as it is understood in science, and how this might relate to subjective experiences of the 'fifth dimension' as proposed in my practice. In this chapter I consider the function of wonder in the visual world and, in particular, events that are not ordinarily experienced in the every-day. In relation to these ideas I describe my experience of meeting Dr Wolfgang Stuppy on a 2012 field trip to the Millennium Seed Bank in the UK,

and how this extended my understanding of the Anthropocene in relation to my virtual seeds. Inspired by this experience I developed a work-in-progress, *Constructed Landscape*, to test how the idea of an uncertain future might be expressed through the growth of plants. In addition to this I show how I explored the materiality of virtual data through 3D printing.

Chapter five: Optical Experiments

Further developing my work, I consider historical and contemporary uses of time-lapse photography in order to explore how the results of my 4D animations of virtual germinating seeds in Drishti depart from these conventions. I then follow this line of research by considering the optical effect of projecting this work in stereoscopic installations, thereby further enhancing the possibility of experiencing nature in the 'fifth dimension'. I describe how I extend and test these ideas by exhibiting a new stereoscopic projection *Grow,* at the Powerhouse Museum, (The Museum of Applied Sciences) in 2013, Sydney.

Chapter six: Experiencing nature in the fifth dimension

In the later stages of my candidacy I created a new work, *Monster* for a key exhibition *Science Fiction*, at Canberra Contemporary Art Space, 2013, and presented my research at several public events. Chapter six demonstrates how these opportunities helped me to resolve the format of my final exhibition for examination, and determine how I might consolidate the ideas underpinning my research. I show how Michael Marder's paper, 'The sense of seeds, or seminal events', led me to draw my ideas together, and bring new meanings to my germinating seeds in my final work of art. I conclude by describing how Klee's *Pflanzenwachstum* is useful in considering seasonal time as pertaining to my own time and environmental concerns of the 21st century.

Conclusion

I conclude the Exegesis by describing my findings through practice-led research in creating of a new work of art for examination. I then summarise my experiences of undertaking this interdisciplinary enquiry by addressing how I have approached answering my three main research questions.

Fig.0:6. Planting seeds in a test tube in the CT Lab, (2011).

Chapter One

Seeding the idea

From the beginning

I have begun with this introductory chapter in order to establish how I came to germinate seeds with 4D micro-CT and provide a background to the science and technology of 4D micro-CT, and the software Drishti in context of my practice-led research *Grow*.

In investigating the potential for using 4D micro CT my first challenge was to record a kinetic system normally imperceptible to the human eye, but one that would also translate visually and conceptually as a work of art. I initially considered capturing the metamorphosis of a caterpillar to butterfly, a classic cliché for transformative experiences. For me this was the also perfect example of one of life's mysteries that can only be revealed by scientific means. Finding prohibitive practical issues regarding breeding live specimens for X-ray, I turned instead to the potential of germinating seeds. This idea came to me while thinking about the metamorphosis of the butterfly pupa to *imago*, the *imaginal* or mature state. Seeds and germination are also symbolic metaphors for the mystery of life and transformation; therefore I envisaged recording this phenomenon through the medium of 4D micro-CT to create new, imaginative meanings.

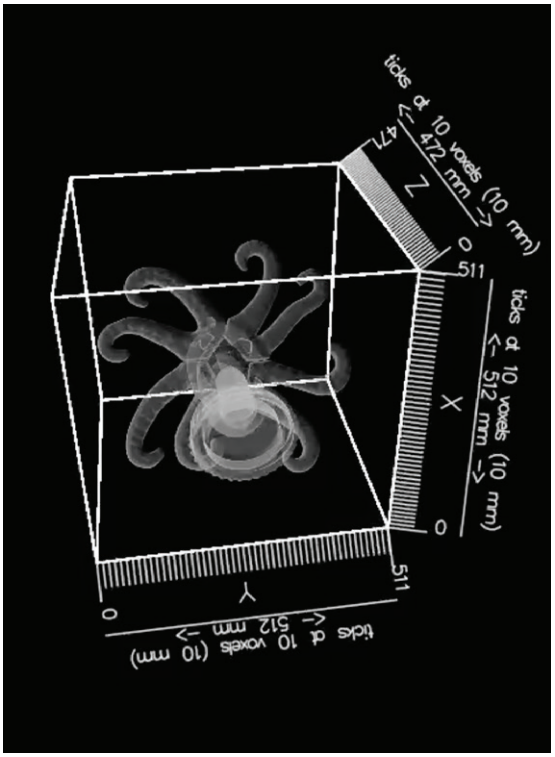
I first came to employ the science of 3D micro-CT for artistic purposes in 2006 when I was awarded an artsACT Project grant to fund a three-month residency at the Department of Applied Mathematics, Research School of Physics and Engineering, ANU. Prior to this I had been exploring scientific imagery of X-ray and microscopy through my practice of printmedia and digital photography. I approached the Department because I was curious about what it might mean to X-ray objects and use microscopes in my practice. I had no idea what 3D micro-CT was or where this investigation might lead me. Professor Senden viewed my proposed residency as an opportunity to further investigate this science through a multi-disciplinary perspective. Ten years ago 3D micro-CT was in an early experimental stage and was yet to be applied more broadly in other scientific fields of research.

Fig. 1:1. [Previous page] Preparing and testing varieties of seeds, (2011).

Fig. 2:2. [Above] A plastic toy octopus on the monitor of the CT Lab in position to be scanned, (2006).

Fig. 1:3. [Below left] A selection of miniature plastic toys from a commercial brand of novelty chocolate, (2006).

Fig. 1:4. [Below right] The volumetric data of the plastic octopus in *Drishti*, before rendering. (2006).



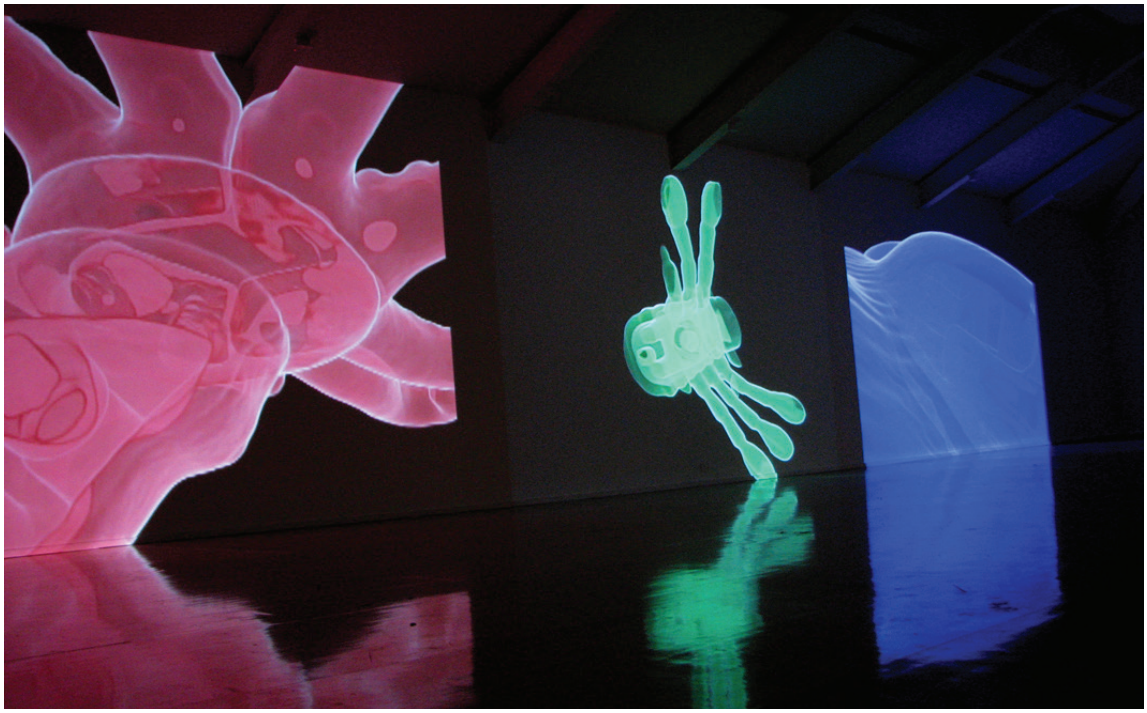


Fig. 1:5. An installation view of *Nanoplastica*, (2008) Three channel projection installation, duration 15 min looped, installation view, Canberra Contemporary Art Space, (2008)

My investigations began by scanning and visualizing a collection of miniature plastic toy animals collected from a commercial brand of novelty chocolate. [See Figs. 1:1-1:3] This was my first introduction to using *Drishti* when the visualisation of 3D micro-CT was in its very early stages of development. Of the small group of people using *Drishti* at the time I was the only non-scientist. I learned how to render volumetric data by adjusting histograms, and to navigate and control the 'camera' eye through and around objects in a 'virtual' space. This resulted in a major body of work entitled *Nanoplastica*, (2008), a three-channel projection installed at Canberra Contemporary Art Space (CCAS). [See Fig. 1:4] Persevering with mastering the required skills for acquisition and visualization, I also began to develop a range of research questions about the representation of nature in science and art that led to my premise for *Grow*, resulting in my PhD candidacy.

When high-energy wavelengths of X-rays is employed to penetrate objects that are normally opaque to visible light, it produces a two dimensional image called a 'shadow-gram' or radiograph. In Computed Tomography, (CT), multiple radiographs are taken from different perspectives. When combined, it reconstructs a three dimensional image representing the internal structure of complex object. CT scans are more commonly associated with medical images, and in the past decade have found their way back into the research laboratory. Contemporary supercomputers make it possible to reconstruct and simulate high-resolution volumetric data accurately, as well as store and retrieve vast volumes of information. This enables the massive acquisition, analysis and

Fig. 1:6. The team of reseachers at the CT Lab, Department of Applied Mathematics, Research School of Physics and Engineering, ANU. From left to right: Dr Michael Turner, Dr Glenn Myers, Dr Andrew Kingston, Mr Ben Young and Dr Trond Varslot, (2011).

modelling of data for 3D and 4D micro-CT as well as for fields of other research including astrophysics, meteorology, oceanography and climate science. The reconstruction of my virtual germinating seeds is supported by the *Raijin* supercomputer at the National Computational Infrastructure, NCI. This facility includes 160 terabytes of memory, over 57,000 interconnected processors with an additional 10 petabytes of disk storage.

The Department includes physicists, chemists and mathematicians engaged in research of an experimental and theoretical nature. Research subjects include porous and granular physics, microscopic crystalline structures, petroleum geology, soft tissue, bone and fossil analysis. The breadth of this research led the team to re-develop modern micro-CT technology over the past decade, and it is their proprietary instrument that has been used in this Exegesis. Results from the department's own research using their micro-CT have also challenged theoretical knowledge of complex materials, including biological structures. A good example is the research into a 380 million year old *Gogonasus* fish fossil found in 2005 by Tim Senden while taking part in an expedition in the West Australian Kimberley region, with a group of leading Australian paleontologists. This was an extremely rare find because the fossil represents the most complete specimen of this species ever recorded. Not only does this fossil provide scientists with a better understanding of the exterior anatomy of the fish, when scanned with micro-CT it reveals an extraordinary amount of detailed information preserved inside.

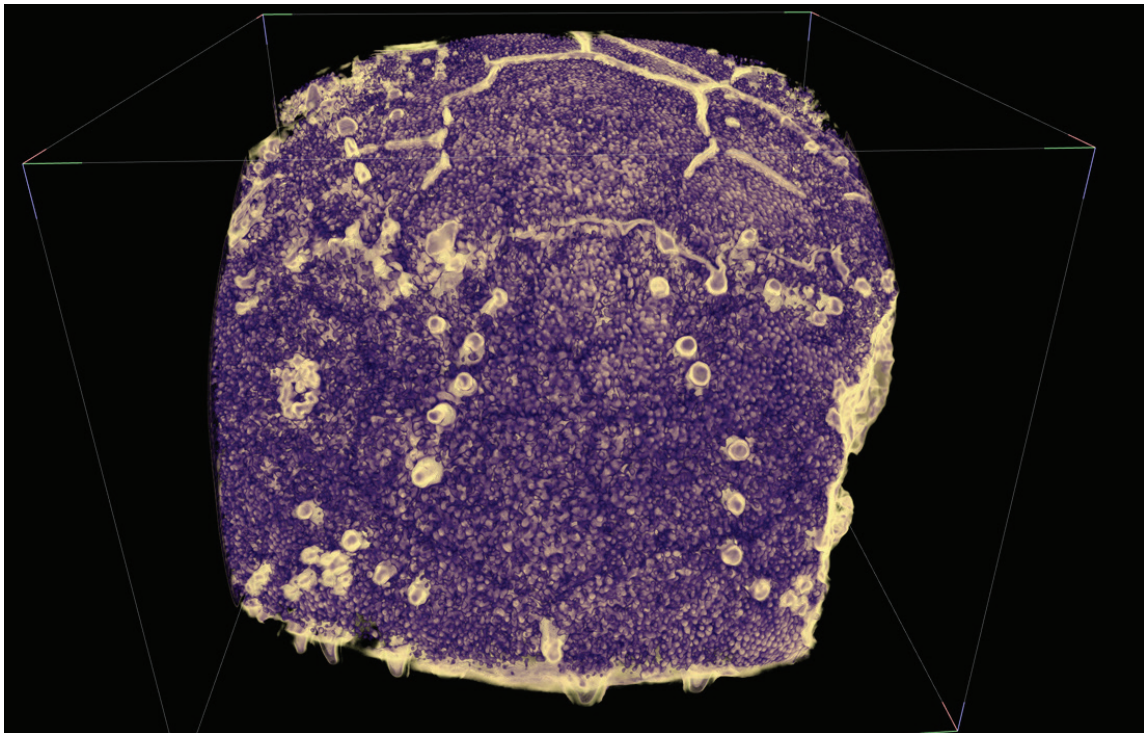


Fig. 1:7. Detail from the *Gogonasus* fossil specimen voluntric dataset imaged in Drishti. Professor Tim Senden (ANU) and Dr John Long, (Museum Victoria), (2006).

Traditionally, paleontologists have been highly reluctant to carve into, shave away or dissolve fossils in order to see cross sections, as this is clearly a destructive process. With the non-invasive nature of micro-CT, Senden's volumetric scan of the fossil enabled researchers to observe the interior structure without damaging the original specimen. The virtual model of the ancient fish skull is replicated in microscopic detail and reveals hidden fossilised sensory systems within the cranial cavity and snout. [See Fig. 2:7] The information recorded in this fossil has paved the way for new insights into the evolutionary link between fish and tetrapods, as animals left the water to walk, smell and breathe air.[6] Another important fossil is the extinct prehistoric placoderm. Imaged with 3D micro-CT this specimen reveals definite evidence of live birth in the late Devonian period. This discovery proved that internal vertebrate copulation began some 200 million years earlier than previously estimated.[7]

The process of synthesizing, or reconstructing dynamic volumetric data of germinating seeds from 3D micro-CT relies on complex algorithms developed in the Department. The time ordered and spatially aligned tomograms comprises of billions of voxels, each with unique x, y and z coordinates, as well as a time stamp. A voxel (volume 'x' element) represents a point or single unit in a 3D grid in the same way a pixel (picture 'x' element)

[6] John Long et al., "An exceptional Devonian fish from Australia sheds light on tetrapod origins," *Nature* 444 (7116): 2006, 199–202.

[7] *Ibid*., 2006.

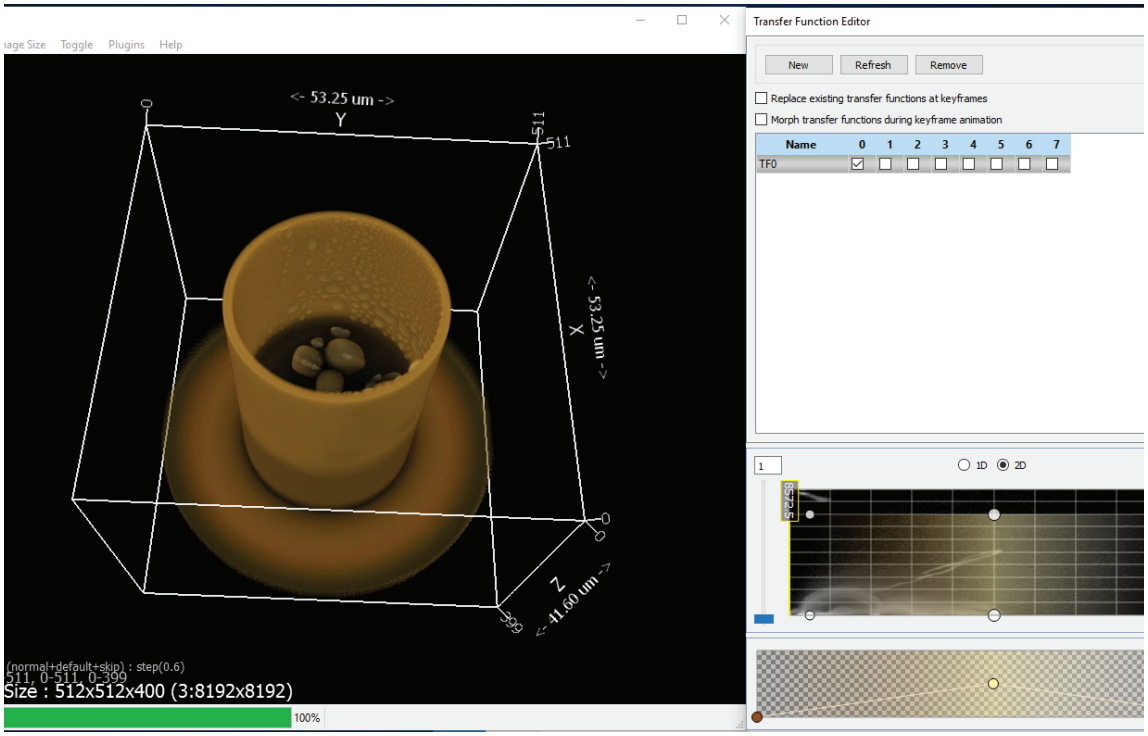


Fig. 1:8. A screen shot of *Drishti*'s interface: The left panel contains the volunetric data set within the x, y, z coordinates of a 3D bounding box. On the right the transfer function shows the histogram which informs the user where the information lies within the bounding box, (2011).

represents a unit within 2D image, or picture. It is important to note that voxels are not the same as texels, which are texture mapping elements used more commonly in CGI.

As 3D micro-CT data is unlike video, digital photography or CGI, the need to visualise volumetric datasets also challenges conventional methods of visualisation. For this reason I have used the software *Drishti* to visualise my volumetric data of germinating seeds. This is a custom-designed, multi-platform open-source software that was specifically developed to explore and visualise volumetric data. The developing author, Dr Ajay Limaye, is a computational scientist and visualisation programmer based at Vizlab at the ANU Supercomputer facility, NCI. Dr Limaye named *Drishti* using a Sanskrit word that refers to a different kind of visual experience as an outcome of enlightenment or illumination. This meaning is also indicative of the kind of perceptual knowledge I hoped to further explore through the subjective experience of the 'fifth dimension'.

Drishti was developed alongside the research program in the Department. While analysis of material data is a primary focus for researchers, the fundamental premise behind the development of *Drishti* as a visualisation tool is an acknowledgment that it is as important to convey an understanding of the acquired data to non-scientists as it is to a research community. *Drishti's* flexibility to evolve, according to its user requirements, is the ultimate power behind open source software. It will be relevant for as long as its application remains accessible to emerging digital environments and new scientific research. An ever-

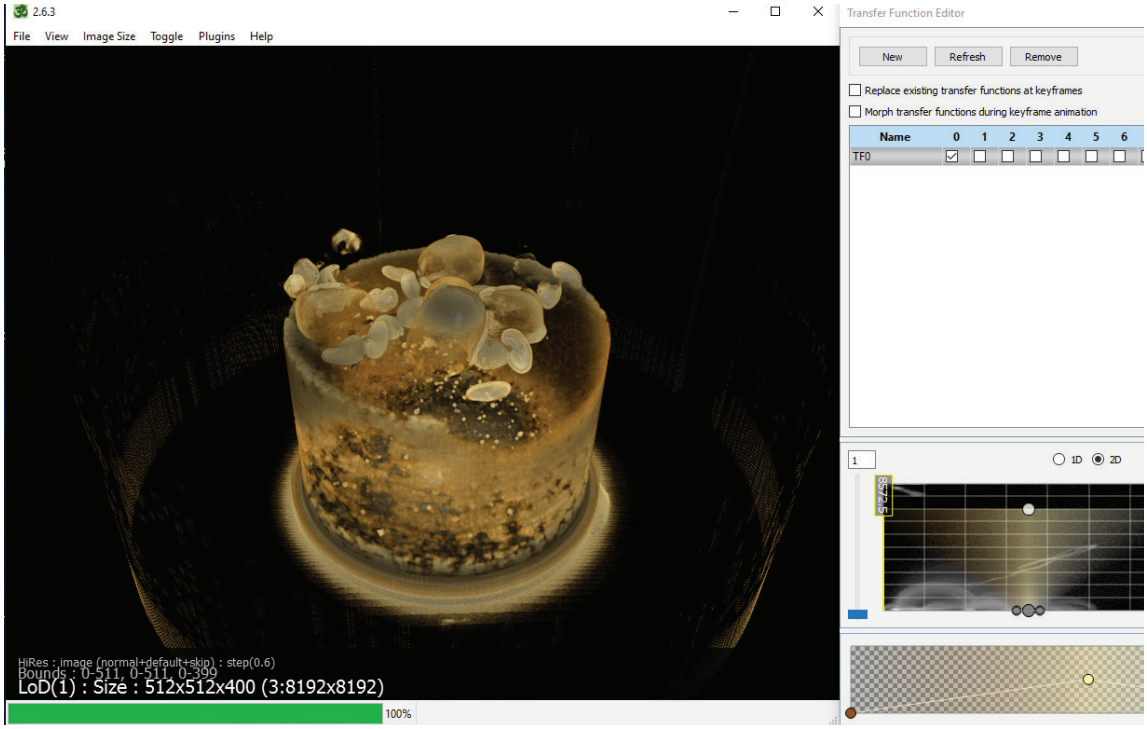


Fig. 1:9. A screen shot of *Drishti*'s interface: The left panel contains the same volumetric data as illustrated in Fig.1:8. This image demonstrates by comparison how specific areas of information can be distinguished by adjusting the transfer function, (2011).

increasing network of international users who contribute to its development and use through diverse research demands, from paleontology, biology to physics and including museum exhibits, now supports the software. An important example of the artistic use of *Drishti* is by the Australian visualisation artists Peter Morse and Paul Bourke, in their holographic installation of the *Pausiris Mummy*, (2011), installed at the Museum of Old and New Art, (MONA), Tasmania.

Importantly, the aesthetic look of volumetric, or 'virtual' data is completely unlike conventional CGI. As the data has no tessellated surface renders or underlying structural mesh armature, the contrast between material densities in the volume can be determined by using the program's transfer functions and histogram panel. This enables features to be distinguished from one another by controlling the transparency and opacity. [See Fig. 2:7-2:8] To further enhance the object or prepare it for particular observation and analysis, the software has a wide range of choice in manipulating the data through colour, cropping, filters, clipping, lighting and contrast. The level of technicality depends entirely on the requirements of the project and complexity of the dataset. Aesthetic choices, such as colour or a definition of realism in relation to the original object, relies entirely on the user. In *Drishti*, the level of visual complexity also depends on the user's research or image requirements as each dataset will demand a range of different skills in problem solving.

Fig. 1:10. Professor Tim Senden working with me to prepare seeds in the CT-Lab, (2011).

3D micro-CT studies static objects, whereas 4D microscopic systems can include water wicking through fibre, oil forced through porous rock, or material such as bone or bead packs compressed under pressure. When researchers in the Department of Applied Mathematics began working on a patent for the acquisition of dynamic data I became interested in how I might incorporate the property of time with 4D micro-CT into my own practice. Discarding the idea of the metamorphosis of caterpillars I decided instead to germinate seeds, hoping to capture this process in its entirety from seed to first leaf. Originally I had considered sprouting native species such as conifers and nuts because of the various interesting structures. The issue with the actual seeds contained within these forms is that they are often too small to be captured in great detail with micro-CT. Germinating these types of seeds also requires a specialist knowledge as many varieties have prolonged germination periods, or only germinate under certain conditions such as bush fire. Therefore the logical alternative for me was to choose faster growing seeds, and in Chapter three, I discuss how I further tested these varieties in the CT Lab.

In 2010, prior the commencement of my PhD, I had an opportunity evaluate this idea as a Visiting Fellow in the Department supported by an artsACT project grant and a Synapse residency through the Australian Network for Art and Technology, (ANAT). I attempted one scan in which I was only able to acquire the data of a radish seed developing with a root length of about two millimetres. This was a long way from capturing a seed germinating to leaf stage, but it revealed that this idea might actually be achievable. The initial test also proved to me that this inquiry would necessitate a much more involved

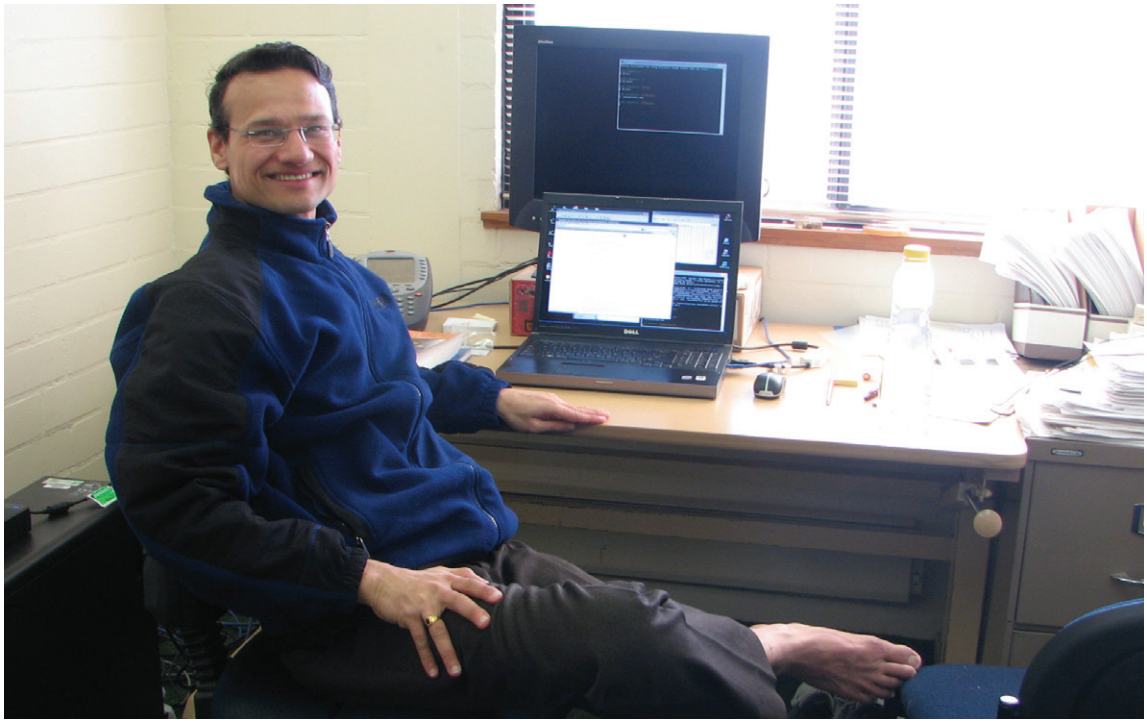
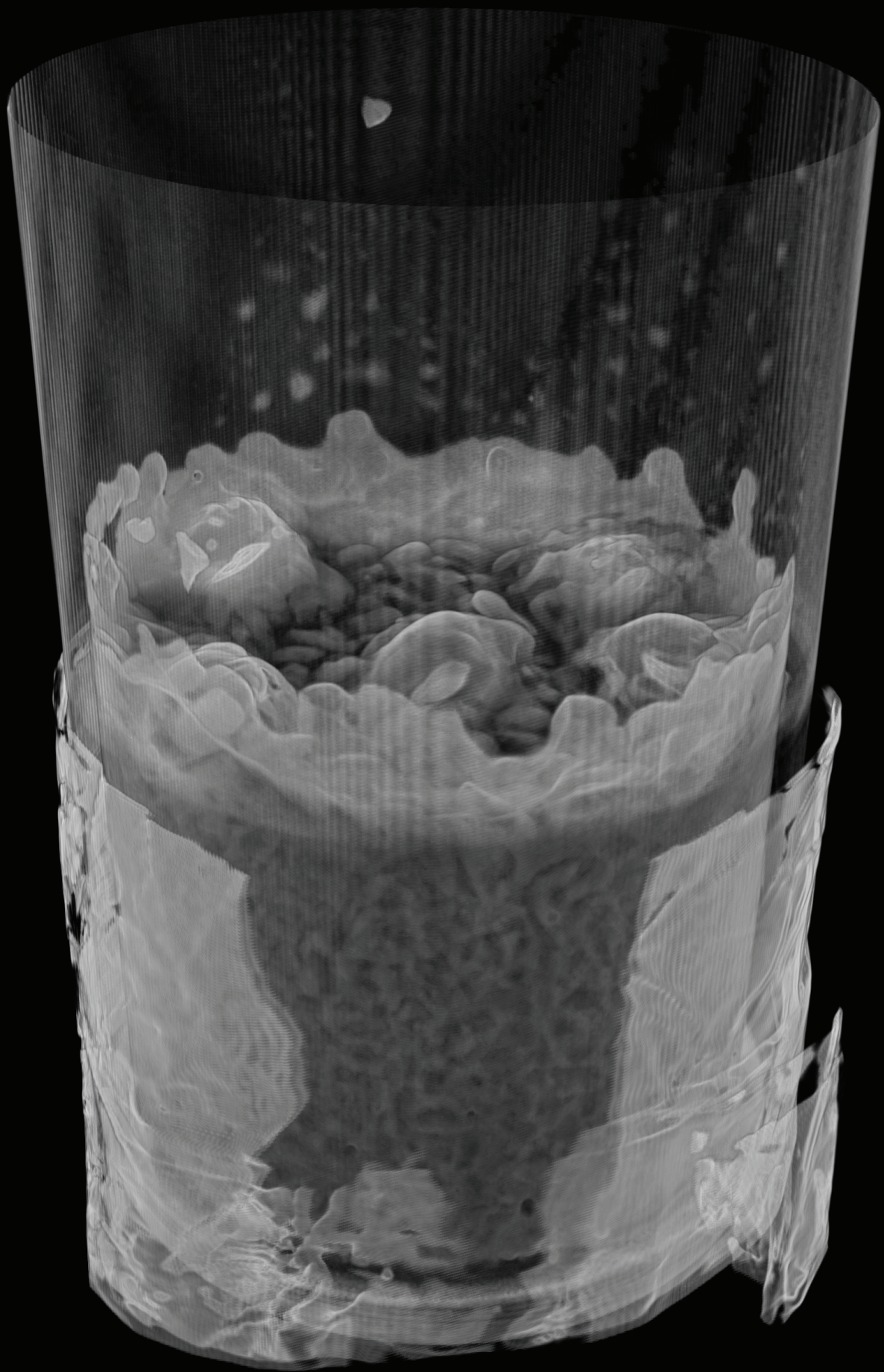


Fig. 1:11.Dr Ajay Limaye, creator of *Drishti,* (2012).

and experimental research approach. In addition *Drishti* would have to be further developed in order for me to visualise and animate sequences of volumetric datasets. Recognising the potential for the creation of new works of art through research led me to apply for the PhD candidacy to enable further investigation of the possibilities of this science, and my premise for germinating seeds as artistic practice-led research.

As there are no precedents for acquiring or visualising dynamic volumetric datasets of germinating seeds, this research has required me to be inventive and collaborative. Crucially, I found my artistic exploration embedded contemporaneously with an original scientific endeavor unfolding in novel algorithms, and innovative experimental methodologies. There is no doubt that in this collision the two explorations have influenced each other. At the same time that Professor Tim Senden guided my experiments in the CT Lab, Dr Ajay Limaye worked closely with me to develop *Drishti* for my research purposes. Happily this has resulted in a two-way exchange. As a constant user of *Drishti*, my input through experimentation has directly contributed and influenced many aspects of the development and improvement of the software's tools and interfaces. I am usually the first person to test new features and upgrades once they are developed by Dr Limaye. He has developed code for tools and applications to animate and interpolate dynamic datasets in *Drishti* based on my experiments undertaken for *Grow*. This collaborative sharing and developing of a visual language to grapple with complex datasets has been a rewarding aspects of my research throughout my candidacy.



Chapter Two:
Exploring New Dimensions

Art for a new epoch

In 2011, the first year of my candidacy, in parallel to working in the micro-CT laboratory, I began by searching for useful associations with seeds and germination in relation to my practice. To test germinating edible seeds for 4D micro-CT, I chose domestic varieties that one might sprout on a windowsill or grow in a garden. Reflecting on these small and personal seed plantings, then tending to them as they develop with the view of harvesting the produce, caused me to wonder if I could find any interesting connections between my work and large-scale agricultural practices. Considering industrial agriculture directed me to discover a broader range of issues around the relationship between humans and agriculture, such as concepts of future sustainability and food security in a rapidly changing world, and subjects of seed conservation in the face of extinction.

In the earliest stages of my research I found it useful to consider the historical significance of seeds which is founded on the agricultural revolution estimated to have begun around 12,000 years ago. In Seeds, Sex and Civilization (2010), Peter Thompson, Founder of the Millennium Seed Bank, discusses how the cultivation or propagation of staple food crops such as grain, pulses, root vegetables and fruit encouraged specialisation and cooperation, and fostered the development of social organisation of communities from the Neolithic era onwards. As Thompson observes, 'humans have exploited the natural characteristics of seeds to ensure that plants are passed from generation to generation, migrate with human populations and, potentially, provide resilience to environmental change.'[8]

The historical relationship between humans and agriculture led me to consider how the subject of germinating seeds might be interpreted in the current era beset by environmental

[8] Peter Thompson, *Seeds, Sex and Civilization: How the Hidden Life of Plants has Shaped Our World*, Thames & Hudson, 2010, 254.

Fig. 2:1. Grey scale rendering in *Drishti* of volumetric dataset resulting from the first stages of scanning seeds with 4D micro-CT, (2012).

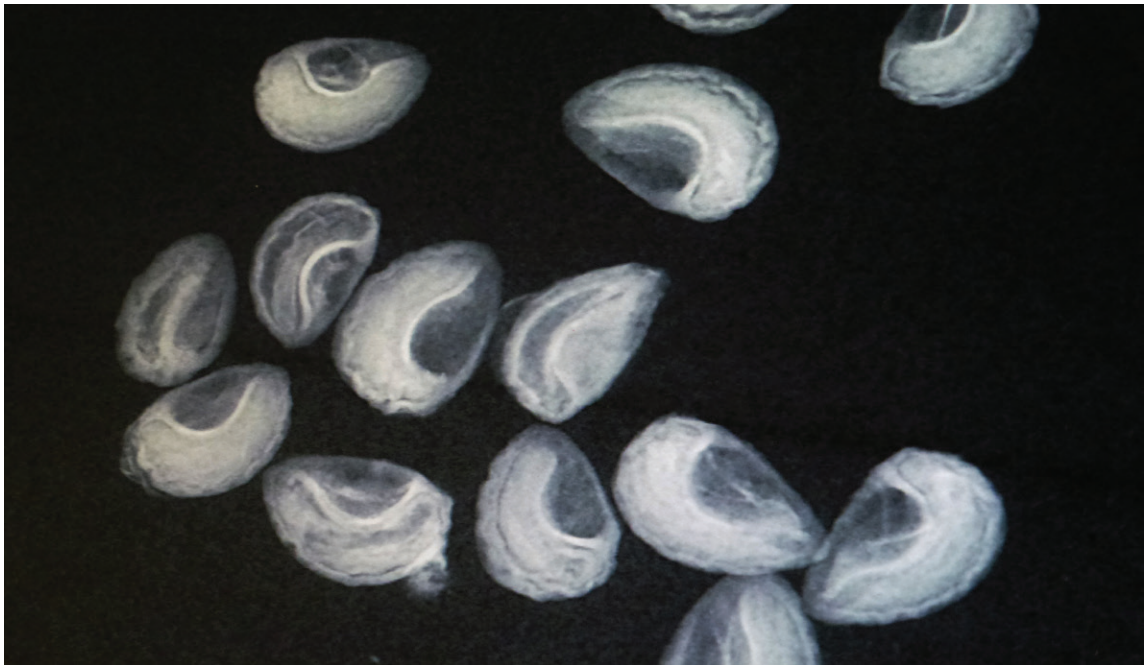


Fig. 2:2. Seeds being tested for viablity through X-ray, Millennium Seed Bank (MSB), Royal Botanic Gardens, Kew, West Sussex, UK. This process can determine if a seed kernel is alive, empty or infested, and is used to determine what percentage of the species in this collection are likely to propagate. Documentation image taken during my field research at the MSB (2012).

concerns. Reading journal articles on food security and global warming, I gathered information on how human-created environmental changes are contributing to a swift decline in the biodiversity of plant species. It is believed that in the next century human civilization will experience circumstances where, 'plants will be driven to extinction and the natural variation of crop plants and their close relatives will continue inexorably to be eroded.'[9] Reports indicate that the sixth major mass extinction of life on Earth is well underway and unlike the previous five, this one is predominantly due to the impact of human population. It is happening faster than any other mass extinction in our planet's history. My reading of this subject has left me agreeing with the natural historian Caspar Henderson who notes in regards to the mounting scientific evidence that, 'the extinction crisis is so vast and complex that it almost repels thought.'[10]

As a consequence, investigating the impact of plant extinction has directed me to address the concept of the Anthropocene in relation to my practice. The Anthropocene is considered by scientists to be the new geological epoch encapsulating the quantitative shift in the relationship between humans and the global environment, and the role human activity has had on re-shaping the Earth's geology and ecology.[11] The serious implication of the Anthropocene is that humans are creating a new kind of environment that is not

9 Thompson, *Seeds, Sex and Civilization*, 229.

10 Casper Henderson, *The Sixth Extinction, Elizabeth Kolbert – Review* http://www.theguardian.com/books/2014/feb/14/sixth-extinction-unnatural-history-kolbert-review, accessed, Friday 14 February, 2014

11 Will Steffen *et al, "*The Anthropocene: conceptual and historical perspectives*" The Royal Society*, vol.369, no.1938, March 13, 2011, 843.

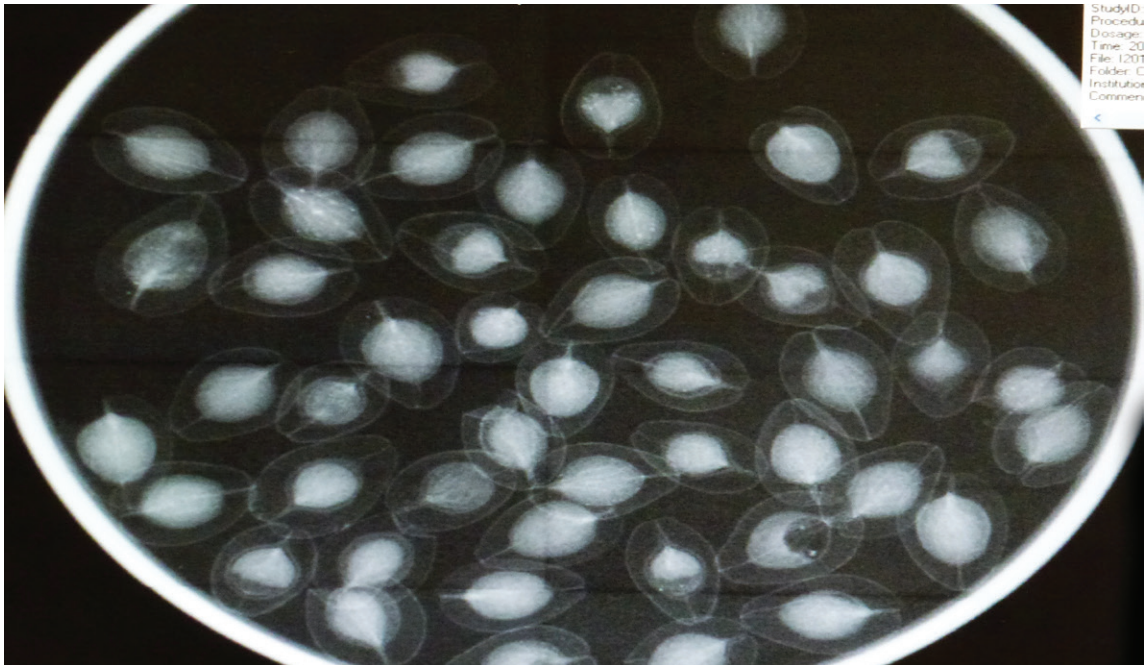


Fig. 2:2. This X-ray reveals that a percentage of this species of seeds in this collection is unviable. Documentation image taken during my field research at the MSB (2012).

conducive to the support of life, not even our own.[12] The proposed Anthropocenic period is understood to have begun in the early 19th century with the onset of industrialization and an increasing reliance on fossil fuels.[13] Only 200 years later, our carbon footprint is now so extensive it is considered to be the main cause of global warming.

The term which combines the Greek word for human, 'anthropos,' with the suffix 'cene', meaning new, was first published as a concept by Nobel Laureate Professor Paul Crutzen in 2000.[14] Professor Will Steffen from the ANU Climate Change Institute also writes extensively on the subject of the age of the Anthropocene, 'a geological age of our own making.' He discusses the now irrefutable scientific consensus around the proposition that the significant environmental challenges we face today have been induced by globalised human activity, and that the human impulse to dominate and exploit the Earth purely for our own purposes, is central to anthropocentric behaviour.

A revealing example is the Costa del Polythene, The Plastic Coast, [See Fig.2:4) in the Spanish province of Almería. There over 200 square kilometres of arid land is tightly packed with plastic greenhouses for intensive farming of tomatoes in order to meet the

12 Will Steffen, "Environmental Climates," lecture as keynote address at the conference, *Affective Habitus: New Environmental Histories of Botany, Zoology and Emotions*. Sir Roland Wilson Building, 9-21 June 2014.

13 Will Steffan et al, "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature," *A Journal of the Human Environment*, Vol.36(8): 2007, 614-21.

14 Paul. J. Crutzen, "Geology of mankind." *Nature, 415*(6867), 2002, 23.

Fig. 2:4. *Costa del Polythene,* a sea of plastic, Almería, Spain.
Over 200 square km of greenhouses, (February 2004). Photo by NASA

European consumer demand for ripened tomatoes all year round.[15] The scale of this crop industry has so remarkably transformed the dry desert landscape under a sea of plastic that it can be seen from space. Inside their artificial environments the tomato plants never directly see the sunlight nor touch soil as they are grown in plastic bags full of perlite stone enriched with chemical and mineral fertilisers. Serious environmental concerns surround this large-scale enterprise including the over-use of pesticides and the depletion of the local water table.

These kinds of human activities have become so predominant that our impact on the Earth's systems is rivalling the forces of nature and we are experiencing the end of the Holocene. Dating from the last glacial period 11,700 calendar years ago to the present, the Holocene is officially understood as our current geological epoch – a series of stable atmospheric periods which have been ideal for supporting human life. Professor Steffen is a leader in a growing group of researchers who are arguing for the Anthropocene to be officially recognised.[16] While yet to be formally defined, the term Anthropocene has already entered the lexicon of the sciences and the humanities. It signifies a revolution, or paradigm shift in how we must urgently rethink our societal impact on planetary life, or face the possible end of civilization alongside the end of nature.

[15] Giles Tremlett, "Spain's Greenhouse effect: the shimmering sea of polythene consuming the land," *The Guardian*, Wednesday 21 September, 2005,

[16] This new geological era is currently being assessed by a panel of experts convened by the Subcommission on Quaternary Stratigraphy, which is a constituent body of the International Commission on Stratigraphy (ICS).

Professor Jill Bennett, Founding Director of the National Institute for Experimental Arts, (NIEA), University of New South Wales, critically examines what it means for artists to think ecologically in an era where the effect of 'the Anthropocene is actually addressing us.'[17] In her essay for *Documenta (13)*, 'Living in the Anthropocene,' Bennett writes that;

> *Ecological thought is changing the way in which our practices might operate in the future. Thinking ecologically means attuning, perceiving and doing what we know how to do differently, in different spaces, dimensions, relationships. This is what it is to be in the midst of a paradigm shift, to be actively living in the Anthropocene.*[18]

In this context, the unique premise of my research to use the frontier science of 4D micro-CT with germinating seeds opens up the opportunity for my art to address ideas about living in this present era of uncertainty. I feel personally affected by the thought of a dystopian future where the natural environment will be damaged or changed beyond repair. My personal anxiety and sadness surrounding this subject has inspired my enquiry to explore through my practice what it is like to live at a time when the Anthropocene is rapidly becoming a reality. By harnessing the multi-dimensional and imaginative potential in my practice and by creating new ways of experiencing the phenomena of germinating seeds as a work of art, this research has led me on an unconventional path of enquiry. In this and in the following chapters, I discuss how the various directions of exploration unfolded, and how I brought together many elements within a resolved work of art for examination. As discussed in Chapter three and four, this line of enquiry also led me to undertake field research at the Millennium Seed Bank (MSB) at Wakehurst Place, West Sussex, UK in May 2012.

Conceptual Perspectives

Throughout my candidature the topic of the Anthropocene has become increasingly prevalent in scholarly inquiry in the humanities. Researchers are exploring this theme through art, literature (fiction and non-fiction) and philosophy as a way to understand the emotional impact of living with the knowledge of this potentially devastating epoch of our own making. Academic writers are now proposing that phenomenological practices in immersive installation art can also be used as models for effectively and emotionally engaging audiences with urgent environmental concerns such as mass extinction, global warming and ocean acidification.

Writers exploring this potential include Professor Lesley Duxbury, Deputy Head of Research and Innovation at RMIT University. Duxbury's essays on art and climate

[17] Jill Bennett, "Living in the Anthropocene'," *Documenta 13: The Book of Books: catalogue 1/3,"* Hatje Cantz Verlaag, Germany, 2012, 347.

[18] *Ibid*., 347.

change have provided context for my research. She highlights the social complexity in understanding potentially cataclysmic events in context of artistic practice. Duxbury examines how the mounting scientific evidence which proves the effect of climate change can be so overwhealming, so as to 'repel thought,' it disengages individuals from the problem. Duxbury puts foward the argument that conceptual art, which transcends didactic clarification, has the potential to create new opportunities for individuals to make meaningful connections with nature, therefore motivating them to seek change;

> *… engaging populations on a personal level to address the ways we perceive our surroundings opens up the possibility that individuals are capable of contributing to the changes required to stem the rapid deterioration of the climate.*[19]

Duxbury discusses an example of this methodology in the artist Ólafur Elíasson's 2003 installation *The Weather Project*[20] as not just an imaginative or aesthetic activity but 'integral to meaningful communication between humans and the changing world.'[21] Exhibited in the great Turbine Hall of Tate Modern in London, this massive atmospheric installation immersed the audience in an all-encompassing aesthetic and sensory experience. The work used a huge semi-circular panel of lights erected midway up the vast back wall of the hall. Reflected in a mirror, the lights became in imposing artificial sun that neither rose nor set but lit the dark, cavernous space in a yellow haze of sugar smoke. Visual records of the installation show viewers lingering in the ominous perpetual twilight, lying on the cold concrete floor observing themselves in the mirrored ceiling above. [See Figs. 2:5-2:6] Duxbury explains that the artist's intention for *The Weather Project* was, 'to encourage his viewers to reflect upon their understanding and perception of the physical world around them through works that capture fleeting aspects of the natural world, evoking the spiritual and emotional.'[22]

German-based researcher Sasha Engelmann also sees potential in Elíasson's methodology to inform modern environmental protest, proposing that this phenomenological approach to engage the individual in immersive installation art can set new 'global paradigms, leaning toward sustainability and long-term interaction between society and ecosystems.'[23] As the rhetoric of eco-activism is often embedded in the same rationalistic view that

[19] Lesley Duxbury, "A Change in the Climate: New Interpretations and Perceptions of Climate Change through Artistic Interventions and Representations," *Weather, Climate & Society*, Volume 2, 2010, 295.

[20] Ólafur Elíasson, *The Weather Project*, 2003,

[21] Duxbury, "A Change in the Climate," 294.

[22] *Ibid*., 297.

[23] Sasha Engelmann, "Breaking the frame: Ólafur Elíasson's art, Merleau-Ponty's phenomenology and the rhetoric of eco-activism," *Stanford Undergraduate Journal for Excellence in Writing*, 2008.

Fig. 2:5. Olafur Eliasson, *The Weather Project*, (2003), monofrequency lights, projection foil, haze machines, mirror foil, aluminium, and scaffolding, 26.7 m x 22.3 m x 155.4 m, installation in Turbine Hall, Tate Modern, London Photo: Studio Olafur Eliasson © Olafur Eliasson 2003.

nature and culture are separate, activism also works against itself by perpetuating these social hierarchies. For Engelmann, in order to reconnect with nature we need to find new ways of shifting our perception of this divided relationship. She proposes that Elíasson's work breaks down traditionalist views and provides a multitude of perspectives from which to reflect on our relationship with the physical world, reminding us that we are bound to nature as we are bound to life. In doing so Engelmann highlights the importance of understanding Elíasson's oeuvre as 'more than just a body of aesthetic phenomena,'[24] urging us to recognize the artist's ability to combine spectacle, phenomena and individual perception as an interface between humans and nature.

Considering this interface in relation to the 'fifth dimension', I thought about the potential of my practice to also offer a departure from a traditional aesthetic idealisation of nature, therefore creating a self-reflective space in which to think about the present era of environmental uncertainty. By creating an immersive stereoscopic installation in a gallery space, I am setting out to test a different kind of temporal aesthetic from that experienced in Elíasson's *The Weather Project*. By using virtual data of germinating seeds I am combining historical and contemporary scientific perspectives through computational vision. Yet, as I discuss in Chapter five, my use of stereoscopy draws upon the historical relationship between the location of the body and image, and breaks down historical notions of perspective and vision. Therefore in thinking about the relationship between the body and the temporal experience of my virtual data, I realised I needed to consider an approach to phenomenology, such as Elíasson's, with the view to creating a self reflective space in my own work.

Phenomenology is the study of structures of perception through, 'a conscious experience as experienced from the subjective or first person point of view,'[25] around an object or temporal event. The word derives from the Greek word for 'appearance', and is a mode of becoming through the disclosure of phenomena by examining an individual's experience of it. Experiences that we live through can be both passive and active, including sensory perception, imagination, thoughts, emotions, desires and actions. While we might observe and engage with experiences in the surrounding life-world, what makes the experience logical, is a self-critical and self-conscious awareness of the present as, 'these make up the meaning or content of a given experience, and are distinct from the things they present or mean.'[26]

In art historian Susan Best's essay, 'What is Affect? Considering The Affective dimension of Installation Art,' she discusses the affect and meaning in postmodern practices of contemporary installation art at the turn of the 21st century. Best considers where the

[24] Engelmann, "Breaking the frame," 2008.

[25] Smith, David Woodruff, "Phenomenology", The Stanford Encyclopedia of Philosophy (Winter 2013 Edition), Edward N. Zalta (ed.), URL: http://plato.stanford.edu/archives/win2013/entries/phenomenology/.

[26] *Ibid*.

Fig. 2:6. Olafur Eliasson, *The Weather Project*, (2003), monofrequency lights, projection foil, haze machines, mirror foil, aluminium, and scaffolding, 26.7 m x 22.3 m x 155.4 m, installation in Turbine Hall, Tate Modern, London
Photo: Studio Olafur Eliasson
© Olafur Eliasson 2000.

experience of the work is, 'a pleasurable entwinement of intellectual, motor and perceptual activity.'[27] She explains that earlier minimalist approaches to art sought to reduce the engagement of the viewer as a way of creating a controlled self-conscious experience through alienation, and that 'affect' was considered a mode of distraction or disorganization. However, Best shows how contemporary installation art of the 1990s, 'tended to go the other way.'[28] Artists had begun to adopt a more phenomenological approach which purposely engaged the viewer by expanding the sensory properties and the affect of installation art as a means to, 'amplify, intensify and motivate aesthetic experience.'[29]

Best proposes that the phenomenological approach to contemporary installation art follows the philosophy of Maurice Merleau-Ponty's, 'notion of the flesh of the world, which is continuous with and yet makes possible sensation and the sensate body.'[30] Best explains that the concept of the 'flesh' is about the gaining of true meaning through an individual's sensory experience of an object – an experience that cannot be 'reducible to

27 Sue Best, "What is Affect? Considering the Affective Dimension of Contemporary Installation Art," *AAANZ Journal of Art*, vol.3, no.1, 2001, 222.

28 Best, "What is Affect?" 222.

29 *Ibid*.

30 *Ibid*., 219.

Fig. 2:7. Ólafur Elíasson, *Beauty*, (1993), spotlight, water, nozzles and hose, dimensions variable. Collection of the Museum of Contemporary Art, Los Angeles, Installation view at Museum of Contemporary Art (MCA), Sydney, documented during my visit to the exhibition *Take Your Time: Ólafur Elíasson,* (2010).

a narrowly conceived linguistic account.'[31] Merleau-Ponty believed that sensation as a quality is as complex as the object itself and that, 'the quality is as rich and mysterious as the object, or indeed the whole spectacle, perceived.'[32]

My understanding of the philosophy of phenomenology has led me to consider how it has been a major source of inspiration to Ólafur Elíasson. He first became interested in the subject as an art student in the 1980s as it offered him a means for understanding subjectivity and ways of engaging with his surroundings. Elíasson notes that for previous generations, phenomenology was used more as a formula for categorizing experience. He warns that phenomenology should not be justified as a kind of truth, but should be considered, 'as a tool for negotiating and re-evaluating the environment – and this can pave the way for a more causal relationship with our surroundings.'[33] Elíasson has stated numerous times that his work is concerned with the concept of seeing yourself seeing, or perceiving yourself perceiving.[34] In *The Weather Project,* his viewers can observe themselves experiencing the perpetual light in the mirrored ceiling above. This additional dimension of personal engagement with is what Elíasson describes as the 'fifth dimension'.

31 *Ibid*.

32 Engelmann, "Breaking the frame," 2008.

33 Madelaine Grynsztejn, Ed., "Take your time: in conversation, with Ólafur Elíasson and Robert Irwin," *Take Your Time: Ólafur Elíasson*, San Francisco Museum of Modern Art, 2007, 52.

34 Madelaine Grynsztejn, Ed., "Take your time: in conversation, with Ólafur Elíasson and Robert Irwin," *Take Your Time: Ólafur Elíasson*, San Francisco Museum of Modern Art, 2007, 55.

Fig. 2:8. Ólafur Elíasson, *Fog assembly*, (2016) Palace of Versailles, 2016, photo, Anders Sune Berg.

The sensory properties of Ólafur Elíasson's installations such as *The Weather Project* are focused around the transposition of 'nature' into a constructed environment. Born in Copenhagen, Denmark, Elíasson spent a childhood experiencing the dynamic volcanic, geothermal and glacial landscapes of Iceland. His work is correspondingly temporal and atmospheric, and many of his installations are accessible and engaging. The audience is invited to become part of the work, as part of the experience. His work evokes phenomena derived from what are referred to as classical elements and forces of nature; light, space, rivers, ice, steam, fog, waves, erosion, atmosphere, solidified lava, moss, mountains, gravity, rainbows, waterfalls, ripples and reflections. [See Figs. 2:6-2:8] However, Elíasson believes that 'nature is a product of civilization,'[35] and that our experiences of life, socialization and civilization are embodied within each of us. Therefore regardless of what circumstance we happen to find ourselves in, our view of nature is changed the moment we look at it, because we look at every environment through the lens of our social conditioning.

In Miriam Schaub's essay on Elíasson's practice, 'The logic of light, technology and Humean turn,' she stresses the noun 'conjunction' as being perfectly descriptive of his ability to create relationships between things, objects, elements and people. Schaub illuminates Elíasson's simple technique of isolating these singular natural components, decoupling them from their usual commingled environment, and repositioning them within an artistic context. Through this process he is conjoining or forcibly linking nature

[35] "Cultural History, Not Natural History," Ólafur Elíasson in interview with Maria Morais, Oliver Koerner von Gustorf, (translation: Andrea Scrima), *Deutsche Bank magazine*, 2002.

with culture, so that the two are inseparable, one always referring to the other. As Schaub notes, Elíasson's phenomenological methodology is strategic, as he is, 'not interested in a new mastery over nature.'[36] instead, his primary preoccupation is with the process of creating new perspectives of observation, sensation and experience.

In 'Mapping Virtual Reality,' [37] Marianne Krogh Jensen discusses the potential for visualising virtual realities in physical locations. She states that the notion of a 'virtual reality' is a concept that most people still find highly abstract, 'in part because it implies total intangibility, and in part because it is most often associated with computers and cyberspace.'[38] For Jensen, the potential for relocating the real through imaginative process is inextricably linked with the location of the body and that, 'the virtual is not limited to cyberspace or to what is not real.'[39] Just as Susan Best proposes Merleau-Ponty's 'notion of the flesh of the world,'[40] as the body being grounded in a continuous reflective sensation of experience, so too does Jensen suggest that physically locating your own body within the imaginative and sensory state can 'become something highly material.' [41]

In my own practice, these ideas have led me to reflect on the intentions I set out to explore in with germinating seeds. This consideration of an additional 'fifth dimension' as a subjective experience of my art has also helped me to ask different kinds of questions that reach beyond just the visualisation of volumetric data. By creating an experience that is grounded in the present, through the viewing of seeds germinating stereoscopically in 4D micro-CT, I wanted to discover whether I could create any useful sensations, meanings and affects in order to create new questions about our environment in the age of the Anthropocene.

Imaginative spaces

Proposing that the experience of my virtual germinating seeds be understood as the 'fifth dimension' is a neat way of tipping my hat to the modernist interpretation of the fourth dimension. It is also a way of drawing on the fact that my practice-research is based on scientific and technological advancements that are relevant to my own life-time. I feel it is important to explain in this context that my interest in the modernist engagement with the fourth dimension is one of the reasons I was drawn to the idea of investigating 4D micro-CT in the first place. Prior to my research candidacy I had been researching the

[36] Miriam Schaub, "The Logic of Light: Technology and the Humean Turn," Thyssen-Bornemisza Art Contemporary: The Collection Book. Cologne: Walther König Verlag, 2009. 139.

[37] Marion Krogh Jensen, "Mapping virtual materiality," *Ólafur Elíasson, Surrounds Surrounded*, Neue Gallerie, Graz and MIT Press, Cambridge, 2000, 302.

[38] *Ibid.*

[39] *Ibid.*, 303.

[40] Best, "What is Affect?" 219.

[41] Krogh Jensen, "Mapping virtual materiality," 302.

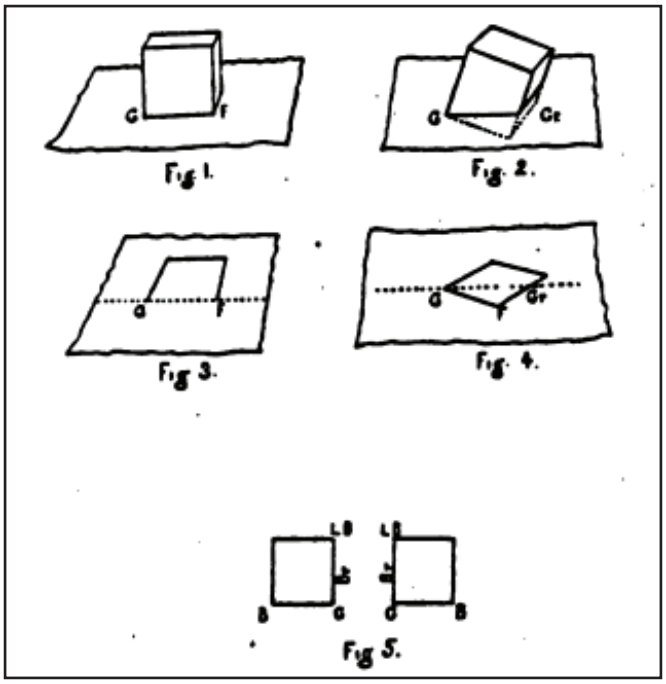


Fig. 2:9. Charles Howard Hinton "The genesis of a cube," *A new era of thought* published London, S. Sonnenschein & co.1888, 110. Digitised by Google.

impact of non-Euclidean geometry and four dimensional space on modern art in the late 19th and early 20th centuries. My reading of this subject has been informed by the key text, *The Fourth Dimension and non-Euclidean Geometry in Modern Art*, by art historian, Linda Dalrymple Henderson.

Henderson has written extensively on the relationship of non-Euclidean mathematical discoveries in late 19th century modernism, as well as the on-going influence of these ideas in 20th century art. Her book is a critical analysis of how emergent theories and innovations in science and maths at this time can be seen as the most important themes that have subsequently unified modern art and theory. Henderson's research in this field does not underpin my practice-led research, but it has been fundamental in shaping my understanding of how my artistic practice and use of science and technology is situated historically. As an artist my use of X-ray, tomography, microscopy, computational visualisation and time-lapse ultimately refer to the role played by scientific invention and discovery on our understanding in the natural world. This leads back through the past century of ideas, and further back still, to the period of the Enlightenment.

The late 19th century saw the beginnings of the popularisation of these scientific and mathematical advancements, and it signified a departure from conventional thought. For example, in the British mathematician Charles Howard Hinton's, *A New Era of Thought*, (1888), his treatise on the genesis of the cube and the higher fourth dimension is introduced with a creative consideration of Immanuel Kant's doctrine of space, 'it is important to develop a space sense, for it is the means by which we think about real things.'[42] [See Fig. 2:9].

[42] Charles Howard Hinton, *A New Era of Thought*, published London, S. Sonnenschein & co.1888, 3.

Henderson looks at concurrent developments in the arts where 'artists, writers and musicians believed they could express higher spatial dimensions.'[43] Concepts such as the fourth dimension and Einstein's Theory of Relativity, and discoveries such as atomic particles and X-ray, not only reflected artists' dissatisfaction with materialism and positivism, but signified a transcendence into a higher consciousness.[44] Discussing how the emergent theories of hyperbolic and elliptic geometry including the spatial dimensions of the fourth dimension were influential in modern thought, Henderson explains,

> *It was the "philosophical and imaginative" implications of four-dimensional space – primarily as an invisible, higher reality – that had caught the attention of the general public by the turn of the twentieth century*[45]

This idea of a new imaginative dimension piqued my interest and allowed me make a connection between the 'fifth dimension' and the three and four dimensions of micro-CT. I saw the additional fifth as a creative way to explore the human engagement with 4D germinating seeds in my practice, but also to position my art firmly in the 21st century.[46]

Henderson's research focuses only on artists and writers who kept personal records, such as journal entries, or public documents which state their understanding and interest in this subject. This allowed her to make direct links between the development of an individual's art practice and theory of art with their knowledge new scientific and mathematical concepts at the time they were first publicly disseminated, either through published articles or lectures. Artists such as Marcel Duchamp, Kasimir Malevich, Max Weber, Francis Picabia and László Moholy-Nagy drew upon these scientific developments as a way of challenging the established laws of representation – of life or reality in art.

Their ideas contributed to the movements, Cubism, Futurism, Surrealism, Abstraction and Russian Suprematism. For example, Henderson attributes Malevich's development of his seminal painting, *Black Square* (1915) [See Fig. 2:10], which depicts a black square within a white square, to his interest in mathematical models of hypercubes demonstrating four dimensional space. As Henderson writes, this painting was an attempt, 'to shake its viewers out of their complacent perception of the world,'[47] as Malevich recognised the artistic potential for this innovative geometry as a means to create new abstract representations of reality and to transcend rationality.

[43] Lynda Dalrymple Henderson, *The Fourth Dimension and non-Euclidean geometry in modern Art*, Princeton University Press, 1983, xxiii.

[44] *Ibid*., 286.

[45] *Ibid*., 2.

[46] In the early stages of my candidacy I developed these ideas in relation to my work-in-progress in a paper *Grow: visualising nature at nanoscale* presented at *Animating Time-space Symposium*, Raglan, New Zealand, The University of Waikato, 30 Sept - 2 October, 2011

[47] Henderson, *The Fourth Dimension,* 412.

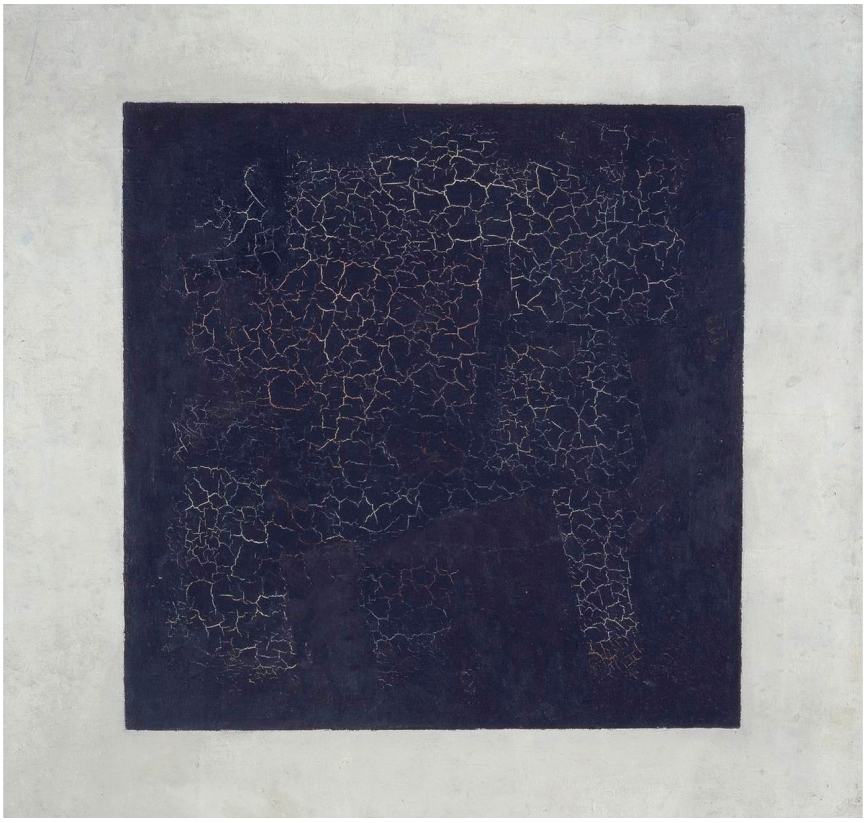


Fig. 2:10. Kazimir Malevich *Black Square* 1915, oil on linen, 79.5 x 75.9 cm,
© State Tretyakov Gallery, Moscow,

While Malevich's *Black Square* painting is a geometric abstraction on a 2D plane, my understanding of it has allowed me to think about the kind of spatial forms I am attempting to create with 4D micro-CT. Further, it t has led me to consider how scientific imaging also creates new kinds of abstract representations of reality, and how in my own practice I am also asking an audience to transcend scientific rationality by experiencing a temporal event of germinating seeds as virtual data projected in 3D.

Early on in my research I came upon a different example of the Modernist approach to time and space in Paul Klee's *Pflanzenwachstum {Growth of plants}* (1921). [See Fig. 2:12] I was curious to find what useful associations I could make between this painting and my own practice of germinating seeds with 4D micro-CT. Klee's painting does not refer directly to the subject of seeds, but his expression of time, space and dynamism is realised through the incremental growth of plants as a study of the fourth dimension. The paintings reductive geometric forms can be attributed to Klee's cubist practice and its aims to find new ways to describe spatial systems beyond classical perspective. As Henderson writes, the cubist rationale and interpretation of non-Euclidean geometry was a, 'practice of deforming objects according to a higher four-dimensional truth.'[48]

[48] Henderson, *The Fourth Dimension,* 205.

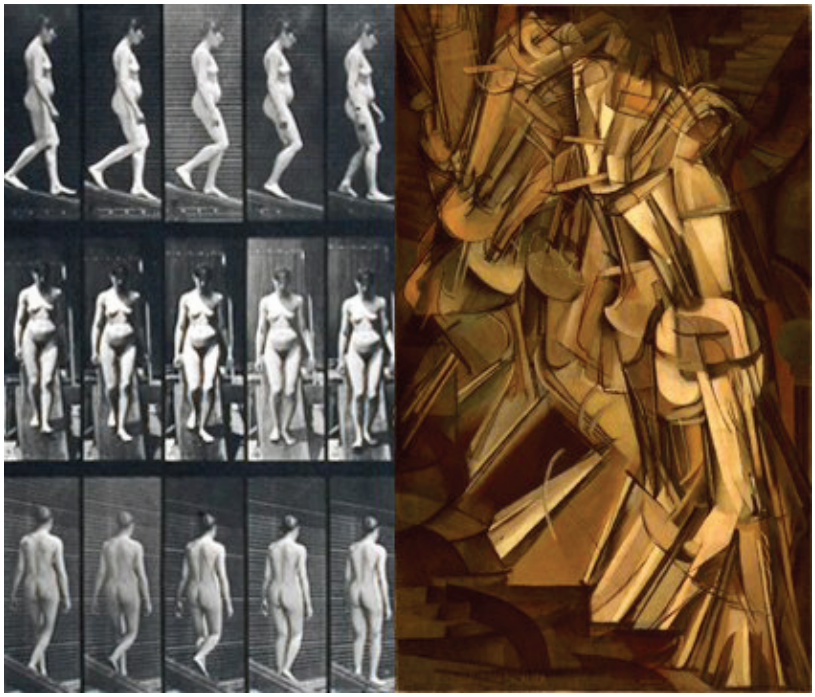


Fig. 2:11. From left, Eadweard Muybridge *Untitled (Woman Walking Down a Plank*) (detail), 1887, and Marcel Duchamp *Nude Descending a Staircase (No. 2),* 1912, Philidelphia Museum of Art.

In Klee's work the pure geometry of rectangles, circles and triangles in various tonal gradations symbolises the energy of plant growth.[49] I first viewed this painting as a possible means of drawing out early influences of chronophotography which captures movement over time in sequences of single frames. This early photographic technique, beginning in the late 1860s, is more commonly associated with the experiments of Eadweard Muybridge and Etienne-Jules Marey in the 1880s. Pre-dating cinematography, these popular photographs of objects in motion were influential in the depiction of kinetic movement in modern art. Marcel Duchamp's, *Nude Descending a Staircase, No. 2*, (1912), is often used as a visual example of the relationship between ideas in art and the stop-motion photography of Muybridge. [See Fig 2:11] As my research progressed I realised I would need to abandon my discussion in order to make way for new discoveries. However, in Chapter six I return to *Pflanzenwachstum* because it led me in a different direction where I began to consider concepts around depiction of the natural world and a representation of seasonal time in relation to my own enquiry.

Considering the 'fifth dimension' as an active element of human engagement in my work has been helpful to situate this experimental research within a creative practice. This dimension of subjective experience, a conceptual addition to the space and time encapsulated in the dynamic volumetric data of germinating seeds, has allowed me to combine the imaginative process of linking ideas, meanings and metaphors in order to write about underlying influences and concerns that I hope to express through *Grow*, in the final work of art.

[49] Klee's studies of forms in nature, which also formed the basis of his teaching in the Bauhaus, was inspired by Goethe's pre-evolutionary theory as published in *Metamorphosis of Plants* 1788.

Fig. 2:12. Paul Klee, *Pflanzenwachstum*, (1921) Oil on Canvas, 54 x 40 cm, Centre Pompidou.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Chapter three

In the laboratory

Testing the hypothesis

The early stages of my practice-led research required me to resolve how to set up seeds to germinate successfully while in the CT Lab. As there were no existing precedents to show how I might germinate seeds in this manner, an experimental approach in the laboratory was required. Ultimately I was aiming for a smooth visual transition in the data to achieve a sense of incremental growth equivalent to what you might experience with conventional time-lapse animation. At the same time I was exploring the aesthetic potential of the data to translate meaningfully as works of art in immersive installations.

Capturing the dynamic data of the germination process involved acquiring a series of sequential volumetric datasets. It differs from stop-motion because one dataset captures a rotation of 360 over a set period of time. Rather than recording motion in sequences of single frames, the rate of growth was recorded across separate datasets. Each dataset was taken between half-hour intervals to give the plants a rest from the radiation. For the time-lapse to work required maintaining an identical registration; the seeds had to be left in position in the CT for the full duration of the sprouting process. Therefore the experiments required a block of four or five continuous days without interruption, and such opportunities in the busy CT Lab are extremely rare.

As I needed to reduce the amount of time required in the CT Lab I looked at optimising the germination process by first testing seeds that take the least amount of time to sprout. In preparation I tested different species of seeds and the methods I could use to accelerate a germination event. To estimate sprouting time I spent several weeks trialling a range of garden-variety seeds: broad and climbing beans, peas, corn, alfalfa, mung beans, sunflowers, pumpkins, beetroot and a variety of other legumes. [See Fig. 3:2]

Fig. 3:1. Testing the growth of seeds in the CT-Lab. In this experiment I recorded the growth rate to see at what stage the seeds developed in particular ways, (2011).

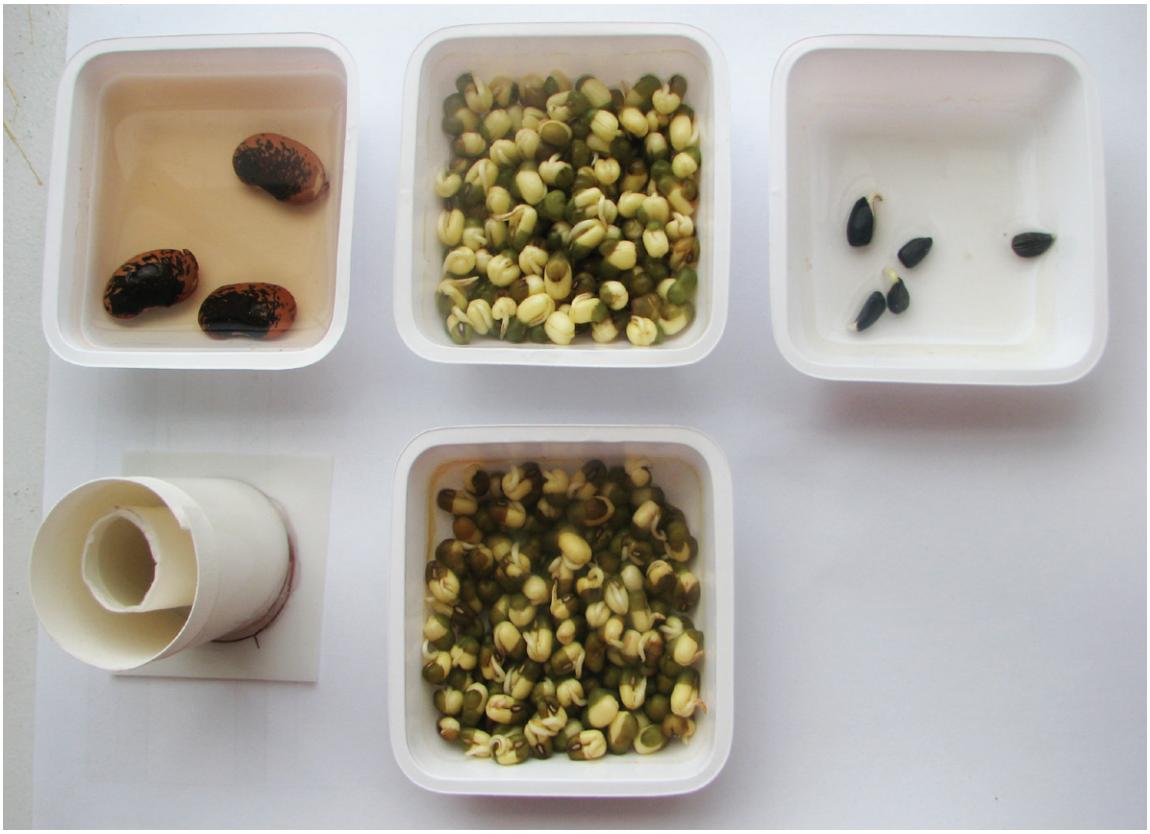
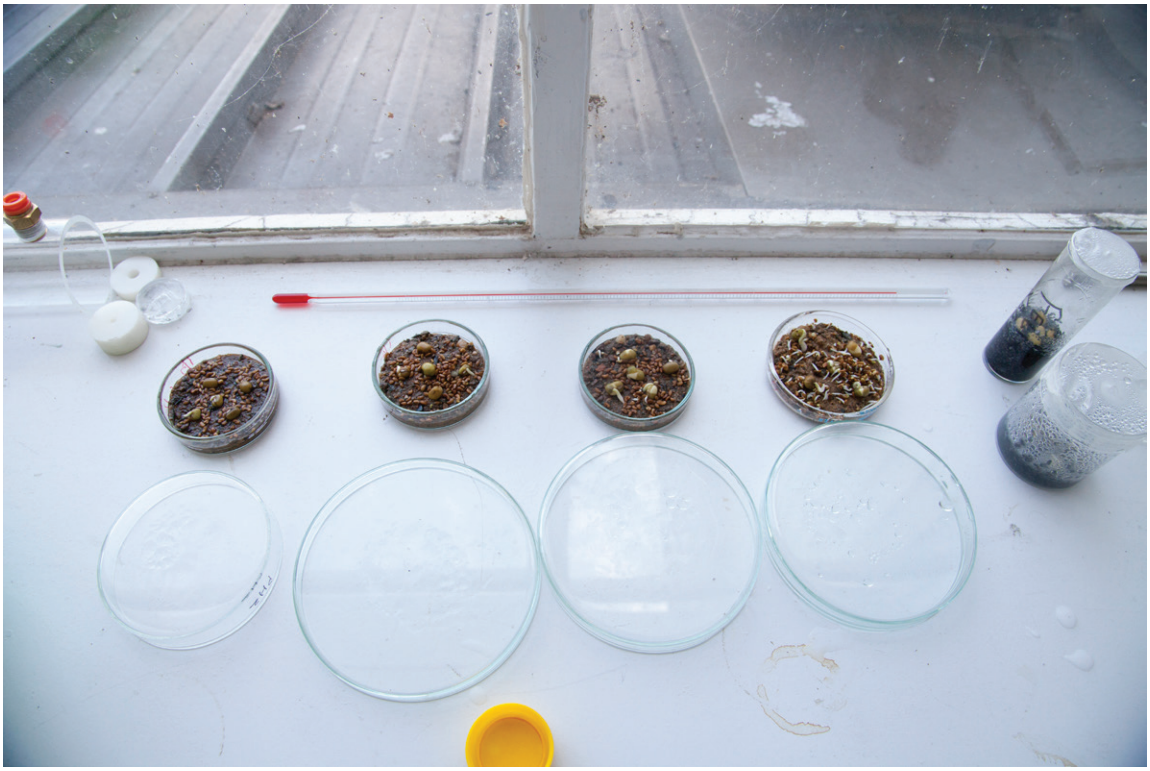


Fig. 3:2. Testing a variety of seeds in the CT-Lab. From right, runner beans, mung beans and sunflower seeds, (2011).

Fig. 3:3. Using controls along the window ledges in the CT-Lab, I tested how long the seeds would take to sprout in various conditions to estimate the growth rate when being scanned, (2011).



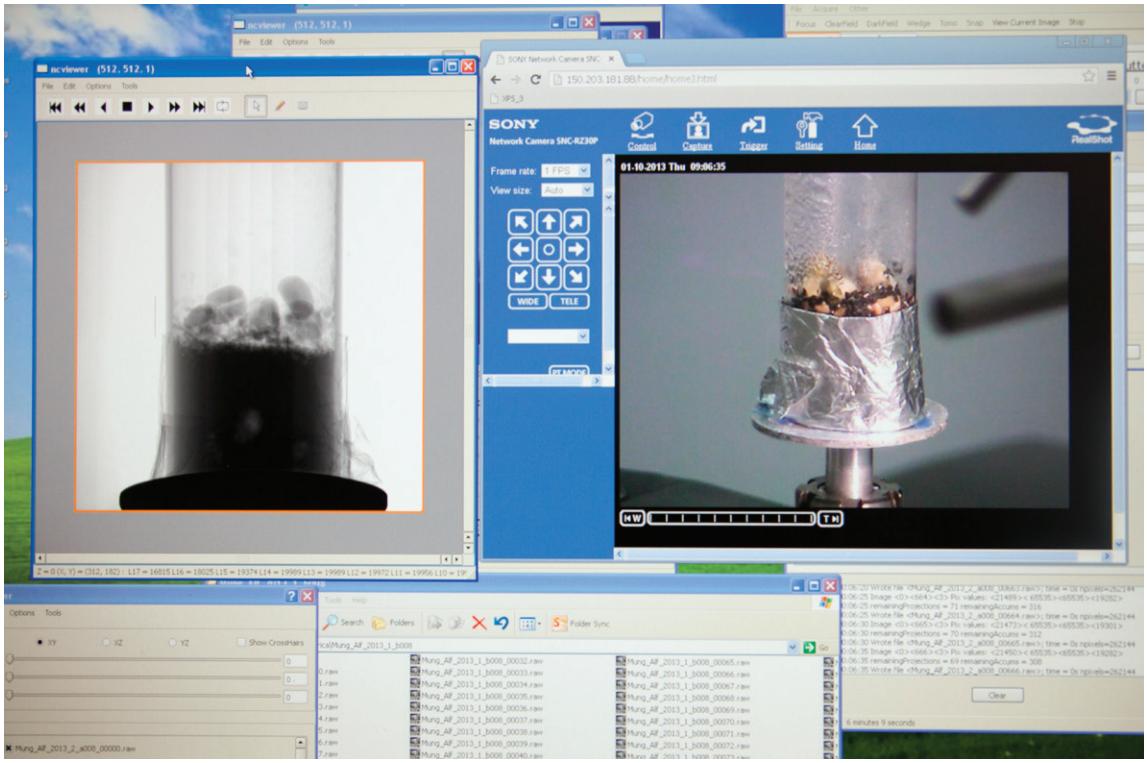


Fig. 3:4. Observing an experiment on its second day of the scanning process. CT-Lab monitor shows a 2D X-ray image on the left, and on the right the specimen is checked in real time via a webcam.(2011).

To test what kind, shape and size of plastic dishes and tubes would work best for this type of scanning I set up a number of control experiments inside and outside the CT Lab. [See Fig.3:3] The length of sprouting time varies with seed type and conditions; for example, in an optimal environment I observed that alfalfa and mung beans only take one or two days to sprout, whereas larger beans and legumes can take up to 14 days. These tests revealed that soaking of the seeds for at least 12 hours prior to scanning reduces the amount of time required in the CT Lab. Alfalfa and mung proved to be the hardiest and fastest growers, particularly in the extreme conditions while being imaged with radiation.

Through this process I discovered it is not an easy task trying to control an organic event, especially in relation to the conditions required for micro-CT scanning. In many scans the seeds would swell promisingly only to die. Issues encountered included lack of natural sunlight, dehydration and inhibited growth rates due to the radiation doses. I found that installing a UV lamp next to the CT helped the seeds to develop, but the heat of the lamp caused the moisture in the test tube to evaporate more rapidly. Water cannot be added during the scan because any sudden movement, variation or interference affects the registration and thus the quality of the data. I had to test the saturation levels required to keep the seeds hydrated for as long as possible without drowning or drying them out.

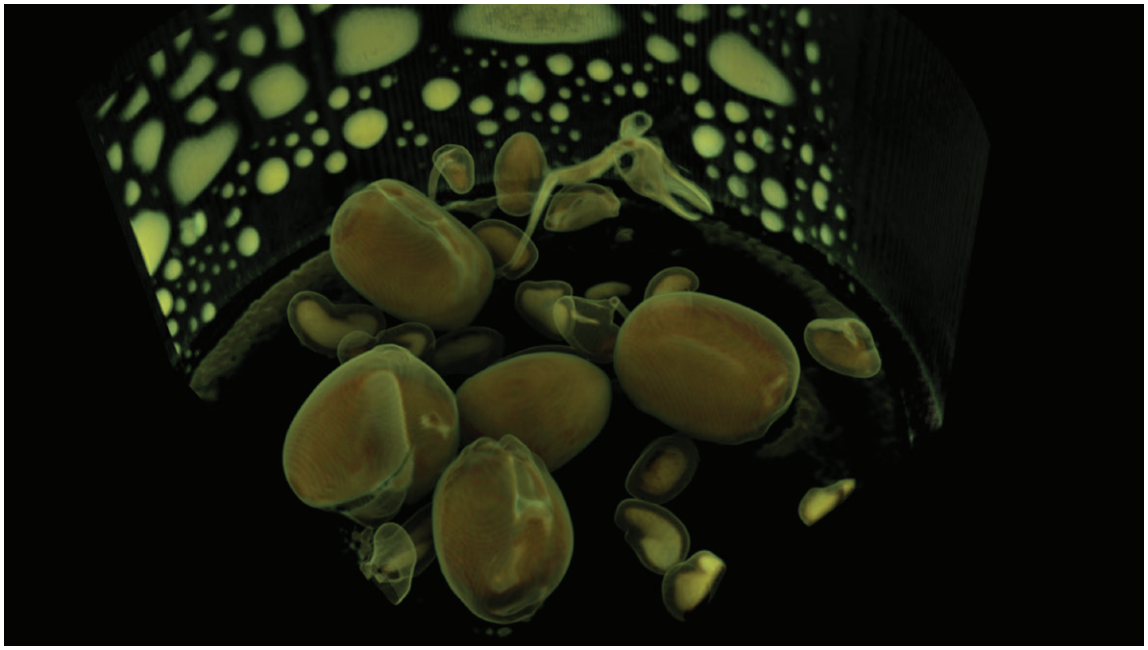
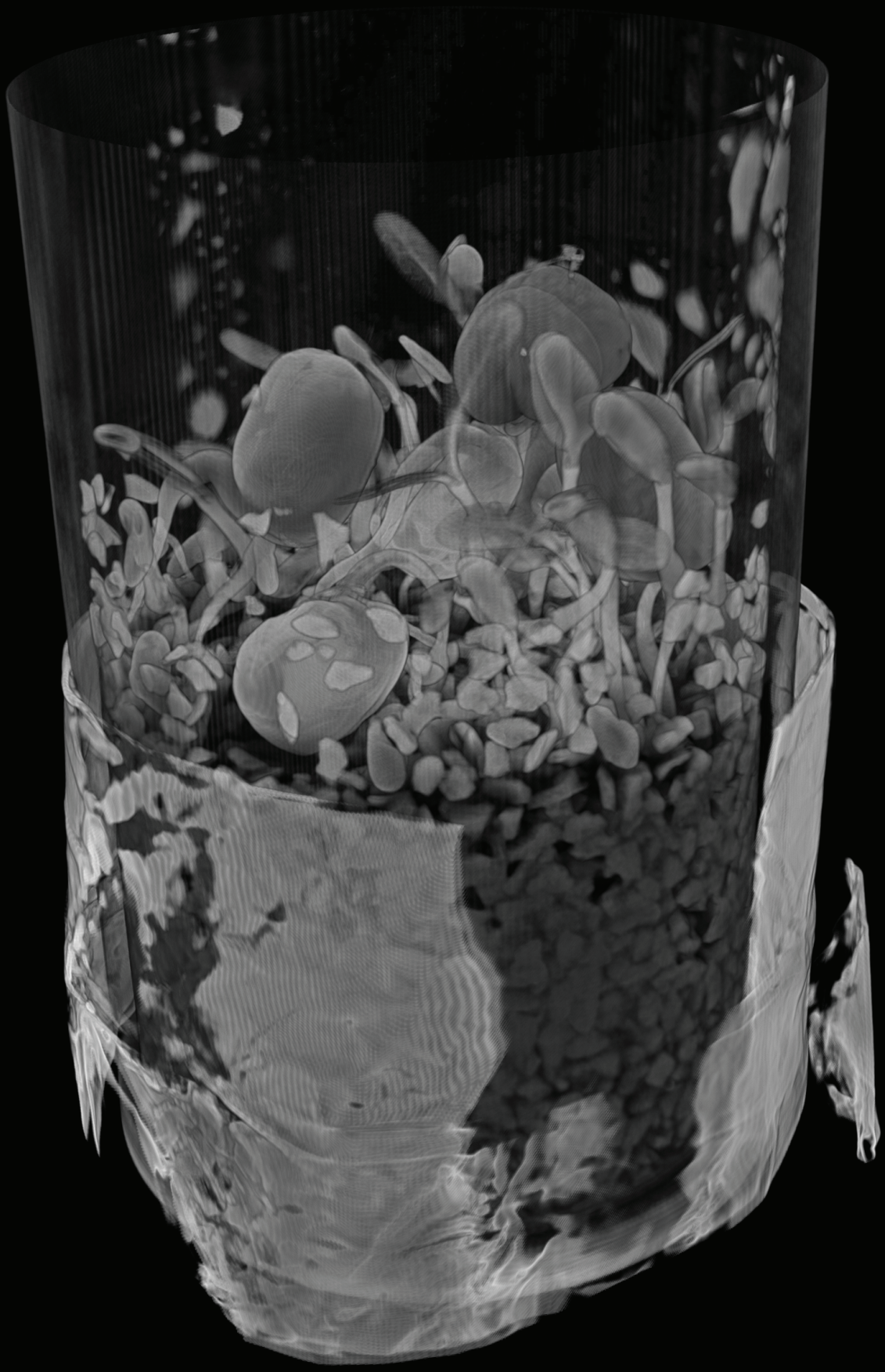


Fig. 3:5. A dataset imaged in *Drishti* showing dead seeds and a sickly mung bean sprout. Condensation droplets can be seen forming inside the test tube at the back, (2011-2015).

Fig. 3:6. (Right) A dataset imaged in *Drishti* revealing sprouts and leaves during a four-day scan of mung beans and alfalfa , (2011).

Through trial and error, and many failed attempts, I managed to acquire three usable dynamic datasets. The first capture has sixteen separate volumes capturing a single mung bean and a radish growing to root stage over a nine-hour period. [Fig 4:1. p.62] The second has 14 separate volumes taken over a 20 hour period and captures five mung beans attempting to grow before dying. [See Fig 3:5] The third and most successful dynamic dataset has 40 separate volumes taken over the duration of four days and nights. This last volume captures mung beans struggling to make the first leaf while the alfalfa show several new leaves opening up in the last dataset. [See Fig. 3:6]

The process of germinating seeds for micro-CT has taught me how grim it is to grow seeds in an inhospitable environment. In the laboratory I had eagerly anticipated the first signs of life, the swelling of the seed, the emerging root and then the breaking case as the seed head lifts up and pushes forward a new leaf. Instead I became used to identifying the first signs of decline, the quiet dip of the head, the perceptible shrinking stem. Experiencing this disappointment and frustration I began to recognise in my dying seeds a kind of operatic narrative, such as a farmer standing before a failing crop. It caused me to thing about the concept of the Anthropocene and how we are now faced with such on a grand scale. Examining this idea I realised that I was testing the complete threshold of life through the process of growing seeds in the laboratory. On a much smaller scale my test tubes had become microcosms of global warming, environmental degradation and uncertainty. I saw that the resulting seed imagery had the potential to allow me to further connect my research with narratives about life and death.



Verisimilitudes

The processes I explored to acquire data in the laboratory were driven by my objective to capture images that would be as visually interesting as possible. This raised questions about how the seeds should look aesthetically. While the resulting virtual models of these germinating seeds are based on accurate computational data of the original event, in *Drishti* the options for me to manipulate and render the data are infinite according to my own aesthetic judgement. The raw data is in black and white and contains a range of information that may or may not be useful in the final work. [See Fig.3.6] However in my manipulation of the data I was able to edit and use colour, shadow, tone, contrast and transparency to determine the final image.

In the early stages of my research I was not yet able to animate the time-lapse, so I experimented with ways to visually express growth over time. Using two volumes from fourteen of the nine-hour capture, I focused on the larger mung bean which had begun to grow a root. I used a cropping tool to isolate the data from the other seeds and the gelatine base, then overlaid the first and last datasets which show the variation of growth. By exploring a range of tones, shadows and degrees of transparency I was able to differentiate the shape of the seed at the beginning of the scan, to the sprout at the end. [See Fig. 3:7, and 3:20 p.60, for a variation]

While I was not interested in trying to render the virtual data to look naturalistic, as one might find these seeds in reality, the virtual nature of the volumetric data lends a high level verisimilitude to the original form. Even when it is artificially coloured the virtual data has, 'the appearance of being true or real in its likeness or resemblance to truth, fact or probability,'[50] The drama of this 'realism' is an aesthetic that belongs to the genre of contemporary scientific imaging which colourfully captures microscopic phenomena in high definition. I wondered therefore if my images would suggest a more objective view of the world by evoking the scientific eye, and work against inspiring more imaginative dimensions, or create new subjective experiences in the final works of art.

To better understand the aims of my work in context of scientific imaging I referred to Lorrain Daston and Peter Galison's book, *Objectivity.* They discuss how the visual language of science derives from the implementation of techniques and innovations in the pursuit of knowledge and truth. To be objective is to see without inference and interpretation, and to, 'aspire to knowledge that bears no trace of the knower ¬ knowledge unmarked by prejudice or skill, fantasy or judgment.' [51] The authors discuss how the history of scientific documentation can be characterized by three distinctive visions of objectivity. The first is 'truth-to-nature,' which the authors describe as a precursor to objectivity; it

[50] "Verisimilitude, n.". OED Online, Oxford University Press.

[51] Lorrain Daston, Peter Galison. *Objectivity*, Zone books, New York, 2007, 17.

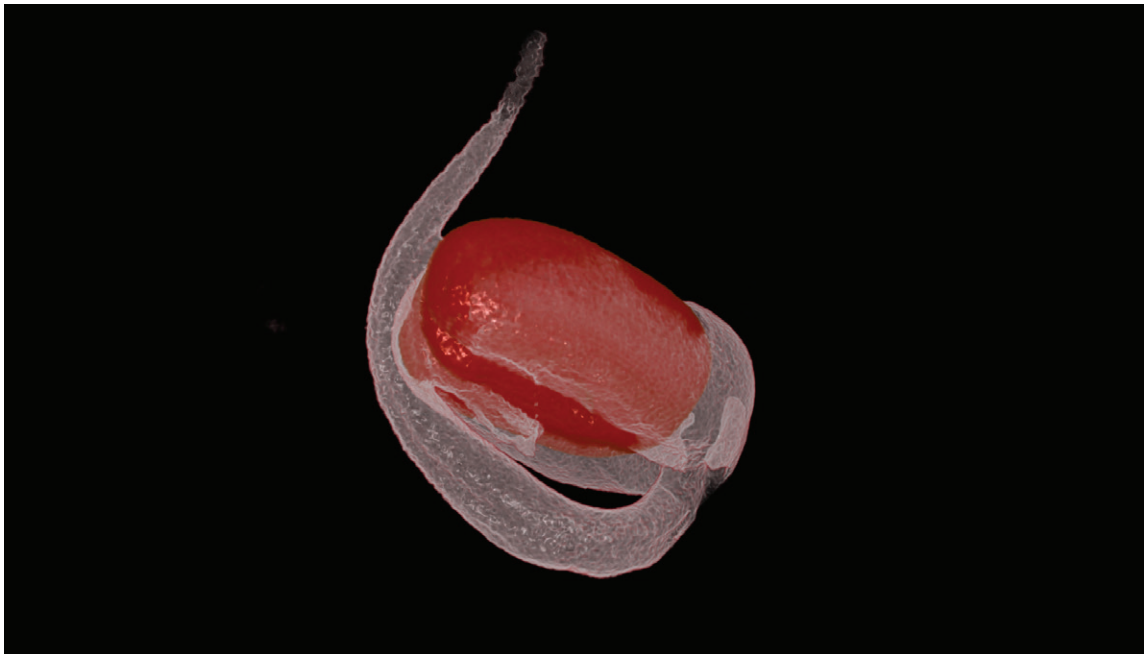


Fig. 3:7. A mung bean sprout imaged in *Drishti,* showing the variation in growth from the bean to the sprout over a nine hour period, (2011).

emerged as 'prominent epistemic virtue'[52] in the early 18th century and aimed to uphold a universal truth from what can be observed by the naked eye. This type of vision combines both the detail of observation and its aesthetic transformation through representation. As this requires the 'expert' in collaboration with an artist, Daston and Galison have labelled this 'double sight.'

This is followed by a second vision, 'blind sight' or 'mechanical objectivity': the process of striving for representation unhampered by personal vision of the observer. This vision requires an undistorted sight, where what was previously considered realistic or natural is no longer relevant to the evidence at hand.[53] In the mid 20th century, this era is followed by the third and final vision of 'trained judgment'. Here the expert is reinstated because of their ability to interpret the raw data generated through the process of mechanical objectivity. This vision strengthened as, 'more and more scientists wanted an interpreting, physiognomic vision, not the blind sight of mechanical objectivity.' [54]

Considering these terms in relation to my research, I recognised that the software *Drishti* is a product that has evolved from the growing demands of this third vision of objectivity. As a scientific tool it relies heavily on 'trained judgment', allowing the user to create an ideal of how they want their work to be viewed. The addition of colour and opacity to the raw data is entirely subjective, based on the user's aesthetic choice. In *Objectivity*, the authors do not suggest that 'trained judgment' is a return to the 'truth-to-nature', instead these three visions can co-exist because they remain historically significant to each other.

[52] Daston & Galison, *Objectivity*, 58.

[53] *Ibid*., 58.

[54] *Ibid*., 335.

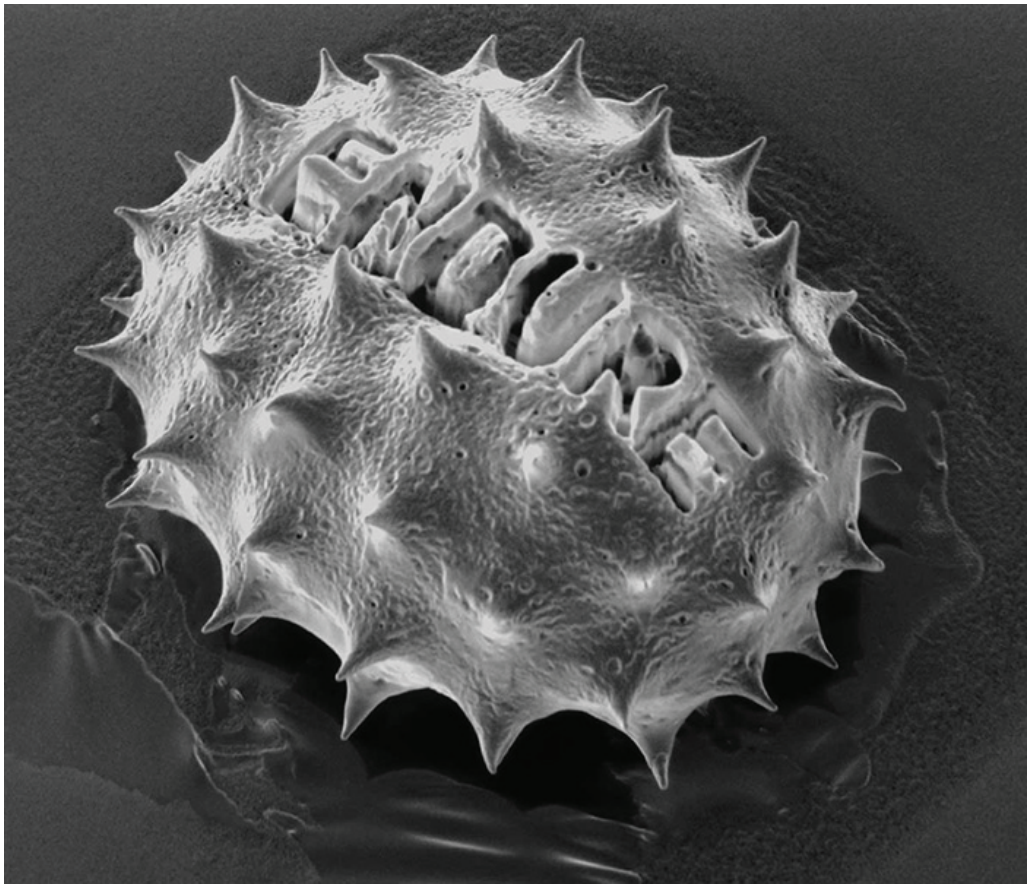


Fig. 3:8.
Stephanie Valentin,
Zinnia 2, 2002, from
Pollinate, (etched pollen
grain - magnification
5,000x) Gelatin silver
print, 18 x 21cm,
edition of 7,
Stills Gallery.

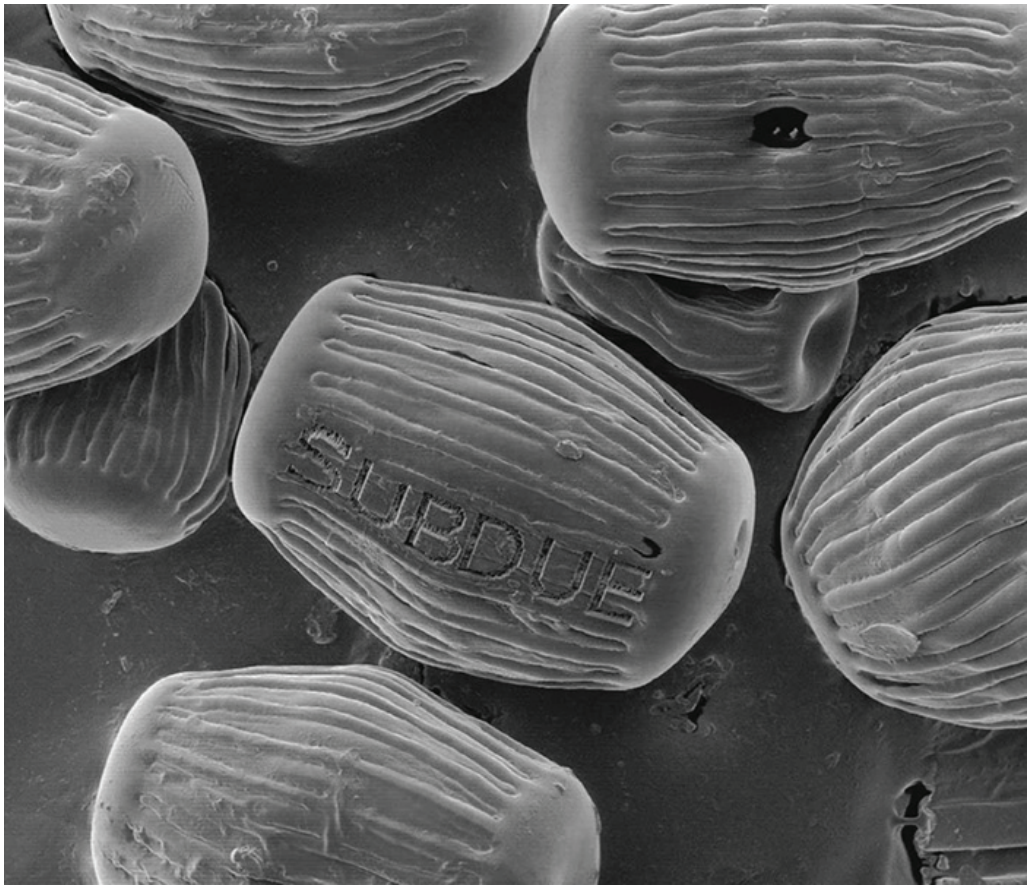


Fig. 3:9.
Stephanie Valentin,
Polygala (subdue),
2002, from *Pollinate*,
(etched pollen grain -
magnification 4,00x),
Gelatin silver print
18 x 21cm, edition of 7,
Stills Gallery.

In science, a truth is widely held to be the constitutive aim of an inquiry which it is gained through the pursuit of facts and knowledge. Karl Popper's thesis on the logic of verisimilitude led him to conjecture that even falsehoods may be closer to the truth than truth, therefore reasoning that propositions, hypotheses or assumptions – whether true or false – can be classified according to their degrees of *closeness* to the truth, *truthlikeness*, or their *verisimilitude*.[55] While I am not intending to prove seeds germinating though factual evidence, I am visualising this data to search for a different kind of truth. What I am hoping to do is to lead audiences closer to thinking about the transformative experience of seeds germinating as metaphor, without a too literal interpretation.

Looking more closely: Stephanie Valentin and Maria Fernanda Cardoso

In *Art & Science*, Siân Ede discusses how scientific images are different from artistic pursuits because, unlike art, scientific research is not subject to a 'ceaseless revision of meaning.'[56] As an artist I am free to transcend and to distort reality. Therefore in order to position the intent of my use of scientific imaging within a contemporary art practice, I have considered works by the artists Stephanie Valentin and Maria Fernanda Cardoso who explore scientific visualisation as both a means and a metaphor within their practice. Their work highlights how the comparative scale of microscopy offers observers the opportunity to participate in artworks which create new meanings across time and circumstance. Both artists also create works of art that play with the idea of verisimilitude in order to reveal things that exist beyond the reach of normal vision, as a way to further question ideas about our relationship to nature.

Valentin's series *Pollinate*, 2002, [See Figs. 3:8-3:9] presents black and white photographic images of pollen magnified 5000 times by an electron microscope. Valentin says of this work that she is fascinated by, 'our innate attraction to other living organisms and the biological world.'[57] The images in the series have the 'raw data' appeal of evidence-based images found in peer-reviewed science journals. What makes them different is the artist's method of intervention in the embodiment of words in microscopic form. Each image reveals an intricately formed pollen grain bearing a message in a single word such as *endure*, *subdue*, or *enchant.* These words are engraved into the surface with ion beam technology. Appearing as messages or codes intended to reflect our human desires and appetites for nature, Valentin explains that these words are 'a potent and poetic reminder of the ecological and cultural implications of scientific endeavours.'[58]

[55] Oddie, Graham, "Truthlikeness", The Stanford Encyclopedia of Philosophy (Spring 2016 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/spr2016/entries/truthlikeness/>.

[56] Siân Ede, *Art & Science*, I.B.Tauris & Co Ltd, London, NY, 2008, 187.

[57] Lucy Cormack, "Science meets art in Stephanie Valentin's Closer Exhibition," *The Sydney Morning Herald*, 2014.

[58] Stephanie Valentin quoted in an artist statement press release *Pollinate*, Stills Gallery, 2002.

Fig. 3:10. William Henry Fox Talbot, Photomicrograph of Moth Wings, (1840), Calotype negative, 11.3 x 15.4 cm, National Media Museum, Bradford, England.

Twenty-first century microscope lenses enable us to observe things that are undetectable to the human eye and, combined with computer technologies, our vision is extended even further into the sub-atomic structures of life on earth. Siân Ede proposes that these resulting images of cellular and molecular structures present, 'extraordinary subject matter by bringing together a scientific detachment with an aesthetic which may unwittingly be part of the current visual zeitgeist.'[59] The zeitgeist to which Ede refers is the proliferation of scientific images which influence our visual knowledge of the world. Valentin's *Pollinate* series references this genre of imaging, however, by reverting to black and white photography she is also challenging the credulity of high resolution colour digital photography in an era where this kind of visual scientific evidence has been elevated to a status of authority.

In order be able to better place Valentin's work as well as my own research in context of scientific imaging, I further investigated historical perspectives. Jennifer Tucker's *Nature Exposed: Photography as Eyewitness in Victorian Science*, studies the rise of the photographic image as scientific evidence, and the ideal of mechanical objectivity in the mid 19th century. The concurrent development of lenses also began to challenge the legitimacy of human sight itself. As Tucker writes, 'the power of these new scientific instruments such as the camera, the microscope, and the telescope resided in their power to enhance perception

[59] Ede, *Art & Science* ,188.

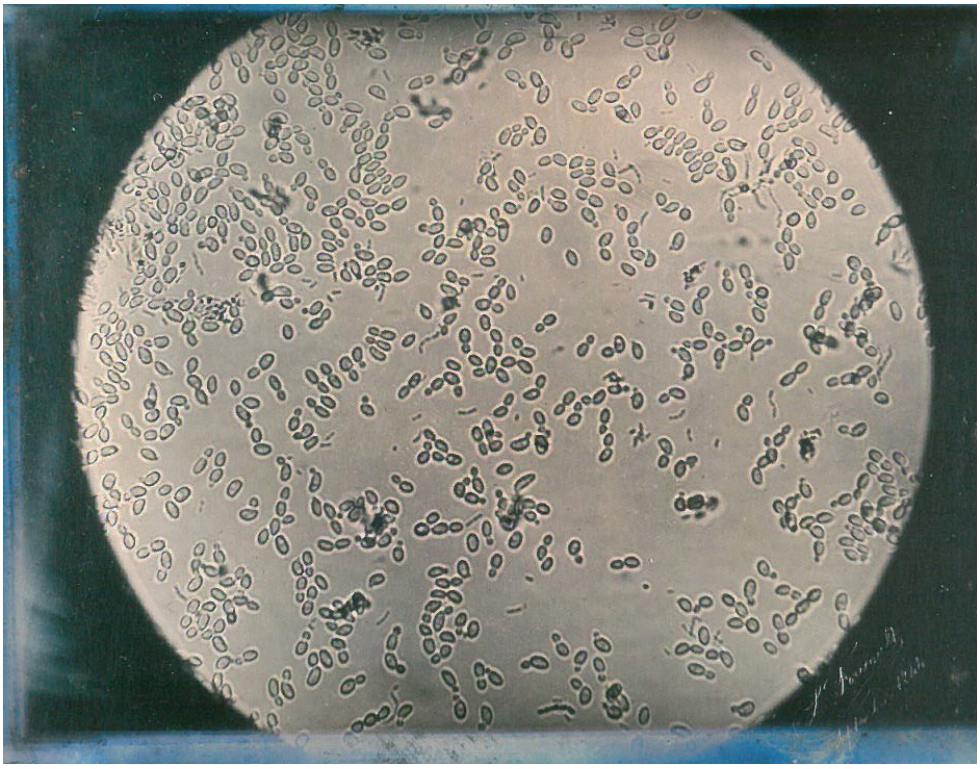


Fig. 3:11. Jean Bernard Léon Faucult, *Ferments of sweet urine* (1840), daguerreotype, 9.6 x 13cm, Société Française de Photographie, Paris.

and constitute new perceptual objects.'[60] Photography curator Corey Keller also identifies that, 'it is important not to read the powerful impulse toward photographing the invisible world as merely an exercise of the medium's improved capacities.'[61] Instead, the drive to make pictures of imperceptible phenomena was propelled by a changing cultural understanding that the world contained much more information than ordinary human sight could perceive.

Just like Valentin's *Pollinate*, the realism in early photomicrography invokes the palpable and the immediate, as in William Henry Fox Talbot's photomicrograph, *Wings of a lantern fly*, (1840). [Fig 3:10] More ambiguous images, such as Jean Bernard Léon Faucult's daguerreotype, *Ferments of sweet urine* (1840), [Fig 3:11] could lend themselves to a whole range of interpretations. Historically the microscopic lens is a device that disrupts traditional understandings of perspectival space as developed in the Renaissance. By collapsing space between the viewer and the object, the object is enlarged in relation to normal perceptual scales. Therefore public dissemination of these photographs challenged the conventions of perspective, sight, knowledge and perception, providing new models for representations of reality. Kellor makes the point that this genre of photography is evidence that scientists knew very well that the increased capacity for

[60] Jennifer Tucker, *Nature Exposed: Photography as Eyewitness in Victorian Science*. Baltimore: Johns Hopkins University Press, 2006, 7.

[61] Cory Keller, "Sight Unseen: picturing the invisible," *Brought to Light, photography and the invisible 1840 to 1900*, San Francisco Museum of Art, 2008, 29.

the resulting images to endorse science was held in the power to transform, 'ordinary sight into an 'hallucinatory' spectacle.'[62]

Valentin's encoded pollens are both palpable and immediate, and as objects they mine the visual language of the scientific that challenges ordinary sight with Kellor's 'hallucinatory spectacle.'. However whereas scientific images aim to reveal factual evidence free of human interference, Valentin creates works of art that disrupt rational lines of thought to create a more tangential truth. It is also a way of questioning the exclusion of human experience through the processes of mechanical objectivity.

In the context of my analysis of Valentin's images, my new work relates these ideas of working with scientific tropes as both a medium and metaphor. My use of 4D micro-CT explores ideas of truth in science alongside the subjective experience of discovery as expressed through my proposed 'fifth dimension'. I am not setting out to undermine the purpose of science to reveal new truths or support evidence, but the resulting images of germinating seeds present 'the scientific' in a way that is poetic and imaginative. By using the visual language of science through its imagery, my work is also proposing to create metaphoric readings that can appear indistinguishable from 'hard evidence'.

Similarly Maria Fernanda Cardoso's series of resin-based 3D printed insect penises, *Intromittent organs of the Allabunus distincta harvestman*, (2008-2009), relies on 'the scientific' in order to create different kinds of truths. [See Figs. 3:12-3:13] Fernanda Cardoso's practice is based on her exploration of how humans have an inherent curiosity about

[62] Keller, "Sight Unseen: picturing the invisible," 25.

Fig. 3:12. (Left) Maria Fernanda Cardoso, *Intromittent organs of the Allabunus distincta harvestman*, (2008-2009), resin, glass, metal. Museum of Copulatory Organs (MoCO), 2012.

Fig. 3:13. (Right) Maria Fernanda Cardoso, *Intromittent organs of the Allabunus distincta harvestman*, (2008-2009), (Detail) resin, glass, metal. Museum of Copulatory Organs (MoCO), 2012.

complex forms found in nature. By studying microcomputed imaging of the morphology of insect genitalia, Fernanda Cardoso created anatomically correct objects representing the copulatory organs of moths. As part of her research for this series, she investigated the importance of taxonomy of insect genitalia to identify diversity in evolutionary traits. These works are part of her installation the Museum of Copulatory Organs (MoCO), 2012.

The artist's playful response to the research for this work is that, 'its not the size that matters, it is shape.'[63] Delicately structured, these organs appear more aligned to botanical forms found in the stamen of orchids or lilies than the human phallus. Each 3D printed penis measures approximately 28 cm and is displayed within phallus-like glass bell jars making the smooth, creamy-white, sculptural objects appear more sexually aligned to human scale than they might otherwise. Here, the artist has used the tropes of microscopic imaging to present works which have both a 'truth' accuracy in their rendering as well as playfully pointing to the sexual common ground between insects and humans.

[63] Maria Fernanda Cardoso, *Intromittent organs of the Allabunus distincta harvestman*, 2008-2009, Museum of Copulatory Organs (MoCO), 2012..

Fig. 3:14. (Left) Venus's Flower Basket, *Euplectella Aspergillum*, or Deep Sea Glass Sponge (c. 1850), Natural History Museum, London. I came across this speciment when I was researching the Blaschka glass in the Coral and Sponge collection which led me to consider Maria Fernanda Cardoso.

Fig. 3:15. (Right) Deep Sea Glass Sponge, *Euplectella Aspergillum* (c. 1890), Photographer: C Bento © Australian Museum, Sydney.

While the artist's intention for this phallic format is to play with sexual innuendo, [64] she is also referencing the history of epistemology. The glass sleeve penises led me to view them as the kind of objects that were collected by scientists in the 19th century when piecing together clues to evolution. [See Figs 3:14-3:15] Her work also makes references to the history of such collecting that began with the cabinets of curiosities of the 17th and 18th centuries. These cabinets represent the growing fascination, desire and commercial market for surprising and novel specimens and fragments found in nature (and art) from around the world. Evoking curiosity and enchantment, these items and collections are part of the history of human endeavours to define ourselves in relation to nature. Also called *Wunderkammern* (cabinets of wonders), they are viewed as the foundations for enlightened knowledge and the subsequent development of objective and rationalist studies of the natural world. The cabinets, which originally referred to rooms full of such collections, paved the way for 19th century museum collections and fields of taxonomic systems. Instrumental in promoting scientific thought they also helped build evidence for evolutionary theories.

[64] ABC Arts Documentary, *Professor Maria Fernanda Cardoso and the Museum of Copulatory Organs*, 2012

The intention for the *Intromittent organs of the Allabunus distincta harvestman* is to arouse in the viewer a lust for knowledge about the world in the same way the objects of the *Wunderkammern* did. In *The Book of Barely Imagined Beings*, the natural historian Caspar Henderson reflects on the significance of *Wunderkammern* and how, 'like our ancestors, we are continually asking ourselves, consciously or unconsciously, "what has it got to do with me, my physical existence, the things I hope for and the things I fear?"'[65]

Our continuing curiosity about things in the natural world is about establishing reason – we seek it out as a possible way to locate the meaning and purpose of human life, or at least understand it better. Henderson explains in relation to the portrayal of fauna, 'that for much of human history attempts to understand and define ourselves have been closely linked to how we see and represent other animals.'[66] While methods and fashions for representation of things in nature may change over time, the fundamental human desire and fascination for difference remains the same.

Reflecting on these ideas in relation to my research led me to question the kind of metaphors my germinating seeds create – what can we possibly understand about ourselves and human life on this planet by imaging the emergence of plant life in 4D? In capturing and visualising the moment of germination from the exterior and interior of the seeds, I am creating a different kind spectacle by bringing to life phenomena that occur beyond normal boundaries of human perception. Considering how this experience could be another element of the 'fifth dimension', I linked these ideas back to my earlier considerations of Elíasson's employment of phenomenology. In this new view of virtual germinating seeds we are no longer the detached observers looking in, as our position is realigned to a kind of cellular vision. Perhaps this new perspective can be included in the self-reflective experience and provide an opportunity to re-examine our physical existence in relation to nature. I bring these ideas back into my discussion in Chapter five.

Dr Wolfgang Stuppy, the spectacle of seeds

To follow my line of questioning about contemporary scientific visualisation in my own practice I researched examples that would relate to both seeds and to environmental conservation. The work of Dr Wolfgang Stuppy, an internationally renowned and leading seed morphologist at the Millennium Seed Bank (MSB) in the UK, was relevant in this regard. On a field trip in 2012, I was granted a two-week research residency at the MSB at Wakehurst, West Sussex. Here I had the remarkable opportunity to spend several days with Stuppy in the laboratory discussing his expertise and image-making processes with a Scanning Electron Microscope, (SEM). I discuss my conversations with him while at the MSB in Chapter four.

[65] Caspar Henderson, *The Book of Barely Imagined Beings*: a 21st Century Bestiary, Granta, 2012, xiii.

[66] Henderson, *The Book of Barely Imagined Beings*, xii.

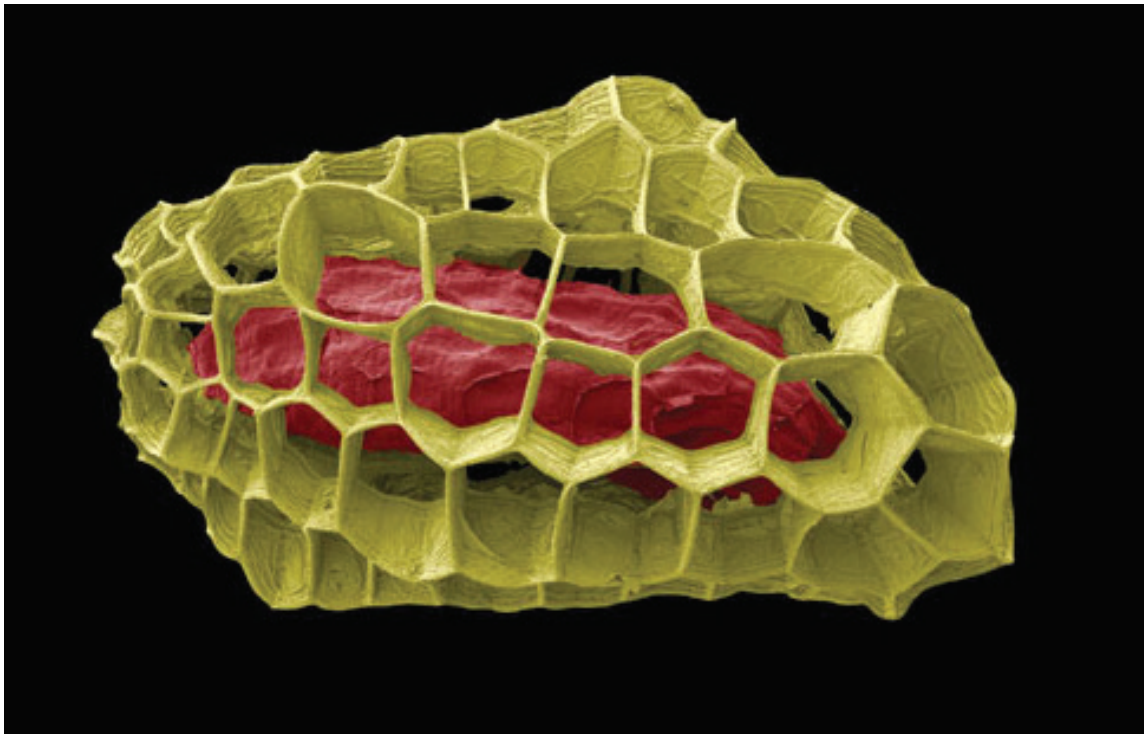


Fig. 3:16. Rob Kesseler, Wolfgang Stuppy, *Lamourouxia viscosa*, (2006), (Mexico), honeycomb structure found in wind-dispersed seeds, 1.2 mm. Image courtesy Wolfgang Stuppy.

Stuppy uses the SEM to produce high-resolution images of seeds to promote the field of botanical evolution and conservation. [Fig 3:16-3:17] The publication *Seeds – Time Capsules of Life* (2009), supports his research on the evolution, dispersal, anatomy and structure of seeds and fruits. The publication aims to bring to the attention of the general public the unique and unseen beauty of seeds and pollen by presenting a view of them not commonly seen outside scientific circles. Enlarging them to a scale well beyond the proportion of the original microscopic object, the delicately coloured forms reveal intricate mathematical surfaces and hyperbolic structures which predict how and why such plants have evolved. As plants are sessile, fixed in one place, it is only in seed form they can be dispersed. They have evolved in various ways to best utilise external elements, such as fire, wind, water, or the habits of creatures and humans. As Stuppy writes, 'this amazing diversity, of which the tiniest examples are often of breathtaking beauty and exquisite sophistication, is largely the result of the pursuit of different strategies of dispersal.'[67]

Stuppy's seductive images of seeds are the result of a process of visual construction and enhancement in collaboration with artist Rob Kessler. In the first stage raw data is acquired through the SEM which produces highly detailed images at a range of one nanometre. The focus of the SEM is so powerful it only captures a fraction of the surface of the seed or pollen at any one time. Stuppy's images begin whereas as a multitude of tiled sections which are stitched together in a graphics program to create the completed

[67] Robert Kessler, Wolfgang Stuppy, *Seeds, Time Capsules of Life*, Papadakis publishing, UK, 2nd Edition, 2014, 26.

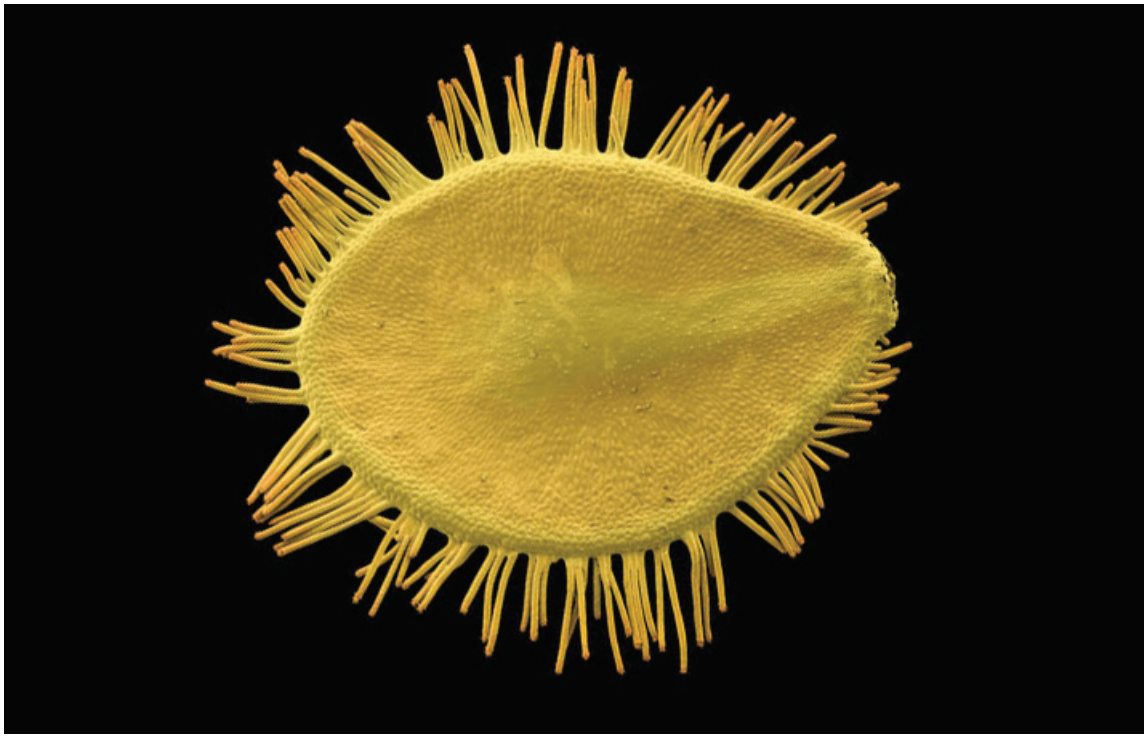


Fig. 3:17. Rob Kesseler, Wolfgang Stuppy, *Nyphoides peltata,* (2006), (Europe), bristly hairs allow the seed to float on water, and disperse by attaching to feathers of waterbirds, 0.5 mm. Image courtesy Wolfgang Stuppy.

image. Stuppy then digitally 'fixes' the image to delete imperfections, such as broken edges or cracks, to make the specimen appear as perfect as possible. This idealisation of the image follows a convention found in scientific documentation, particularly for specialist fields in biology, where illustrations of specimens are 'tidied up' as universal representations of type.

The raw data of the seeds and pollen is captured in grey-scale, so the addition of colouring effects is applied by Kesseler. The actual specimens rarely have detectable colour so the natural colours found in the fully grown plant specimen determine the range of colours used by the artist. Kesseler carefully arranges these vivid tones and contrasts the shadows and highlights to accentuate the structures in order to create the completed hyper-realistic effect. They highlight our continuing fascination with the invisible and our on-going confidence in scientific technologies to deliver factual evidence, even if the results are actually highly fabricated.

The technique Stuppy employs to visually enhance the seeds creates a sense of verisimilitude in order to dramatise the visual experience and inspire emotional responses. By creating a visual hook, his aim is to educate the general public on the important role plant diversity plays in the future habitability of the planet and in human survival. Stuppy has deliberately transformed the raw, abstract data into more identifiable objects to bring the invisible structure of seeds and pollen to our attention. The purpose

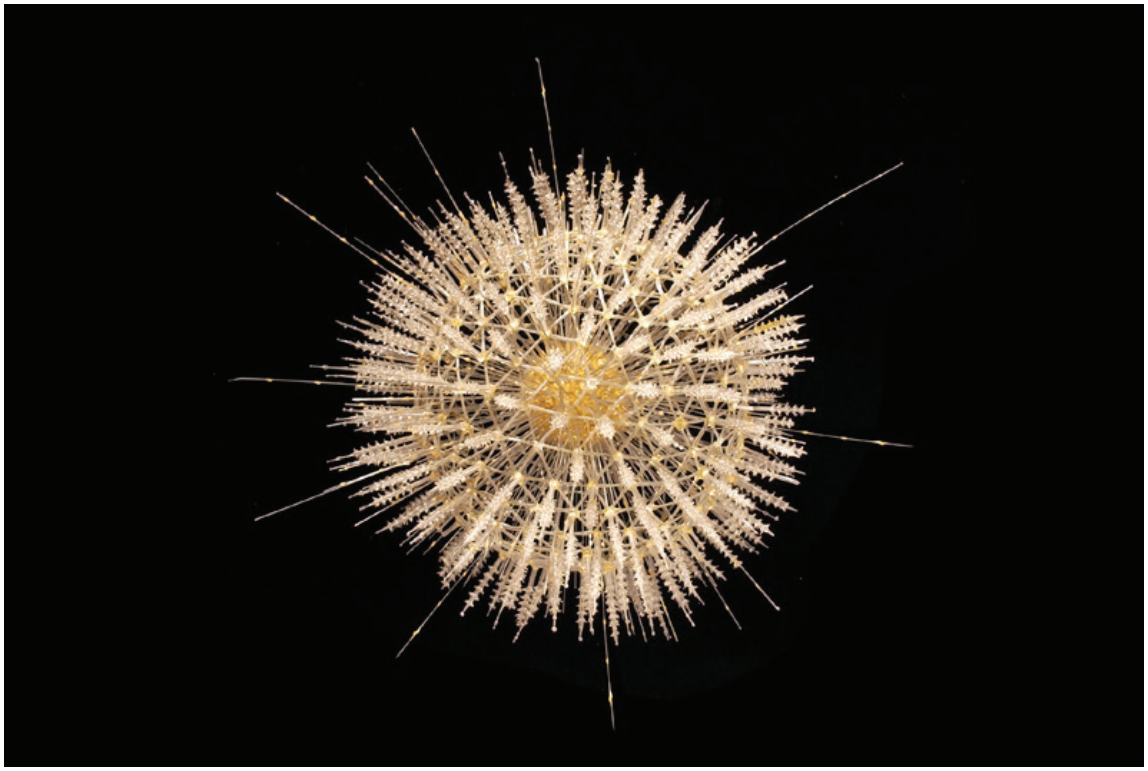


Fig. 3:18. A Blaschka glass model of the radiolarian *Aulosphaera elegantissima Haeckel*, (1862). The central mass of cytoplasm, the axiopoda and the spherical silica shell are magnified about 500 times and reproduced in glass. Natural History Museum, London.

of creating these seductive images of seeds is to ignite a sense of wonder through the act of seeing something extraordinary for the first time. Studying Stuppy's processes and images allowed me to make some invaluable associations with my practice, in particular the idea of making work that can inspire emotions such as awe and wonder, but can also allow an audience to experience something for the first time. This added weight to my speculation that the imaginative possibilities of wonder might be an important element that will create meaningful connections in my work to thinking about this era of environmental uncertainty. I discuss these ideas in the next chapter.[68]

A 21st century view of the Blaschka Glass

During my field trip to the UK, I made some further connections around my practice in the context of scientific imaging while studying examples of the exquisite 19th century glass models made by Leopold Blaschka and his son Rudolf Blaschka. In London after my residency at the MSB, I was provided access to the Natural History Museum's Blaschka collection which includes early examples of invertebrate marine life and radiolarians, single celled organisms. Artisans from Dresden, the Blaschka duo perfected the technique of flame worked glass to create three-dimensional reproductions of specimens such as marine animals, corals, invertebrates and flowering plants.

[68] I first presented a working paper on these ideas about Dr Wolfgang Stuppy's images in relation to my research practice at the Postgraduate Photography Symposium, at the MCA's Centre for Creative Learning, 31 August 2012.

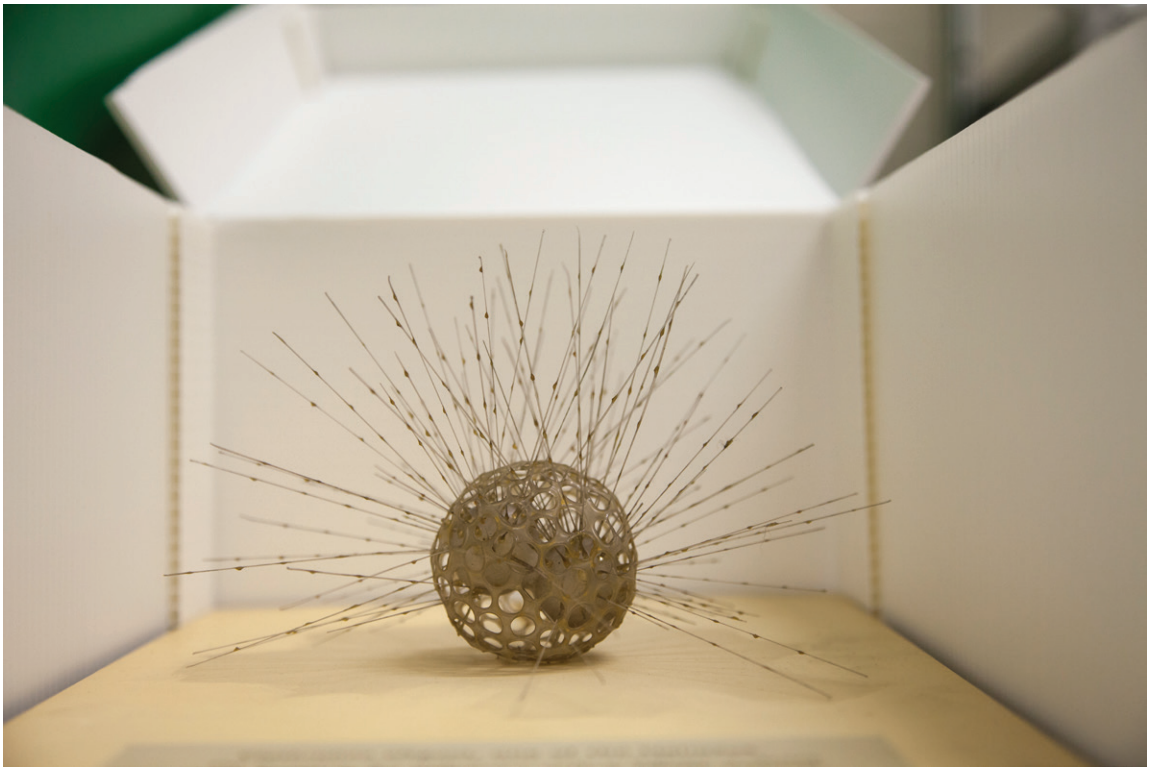


Fig. 3:19. A Blaschka glass model of the *Clathrulina elegans*, one of the *Heliozoa*, a microbial organism with stiff slender arms radiating from its spherical body. Natural History Museum, London, (2012).

These objects were commissioned by the burgeoning museum market in Europe and North America in the mid to late 1800s. The resulting colourful and translucent glass objects replaced the pickled looking specimens preserved in spirit jars on museum shelves, fostering a renewed public interest and visitation numbers. While intended for public displays, the Blaschka glass models also served a purpose for scientific instruction as they were useful in bringing to life phenomena and things found in nature that were difficult to preserve or reveal in two dimensional images. Their glass works are informed by accurate descriptions or actual specimens collected by scientists. These included studies from deep oceanic exploration furthered by advancing diving technologies. Other botanical specimens, particularly those from the Harvard University Botanical Museum, are based on microscopic studies of algae, fungus, and chlorophyll. These were instrumental in the study of evolutionary traits and diversity of primitive plant life. When these models were later tested for accuracy in comparison to scientific data, the Blaschka's models were proved to demonstrate fidelity to evident details.[69] [See Fig. 3:18]

The radiolarians I studied were too fragile to handle, [See Fig. 3:19] but observing them a century later, the Blaschka glass still evokes the same curiosity and imagination through the power of actualisation or, as Daston and Gallison have termed it, 'double sight'.[70]

69 Margaret Parke, 'The glass flowers of Harvard's Botanical Museum," *Endeavour*, Volume 7, Issue 3, 1983, 116-122.

70 Daston & Galison, *Objectivity*, 58.

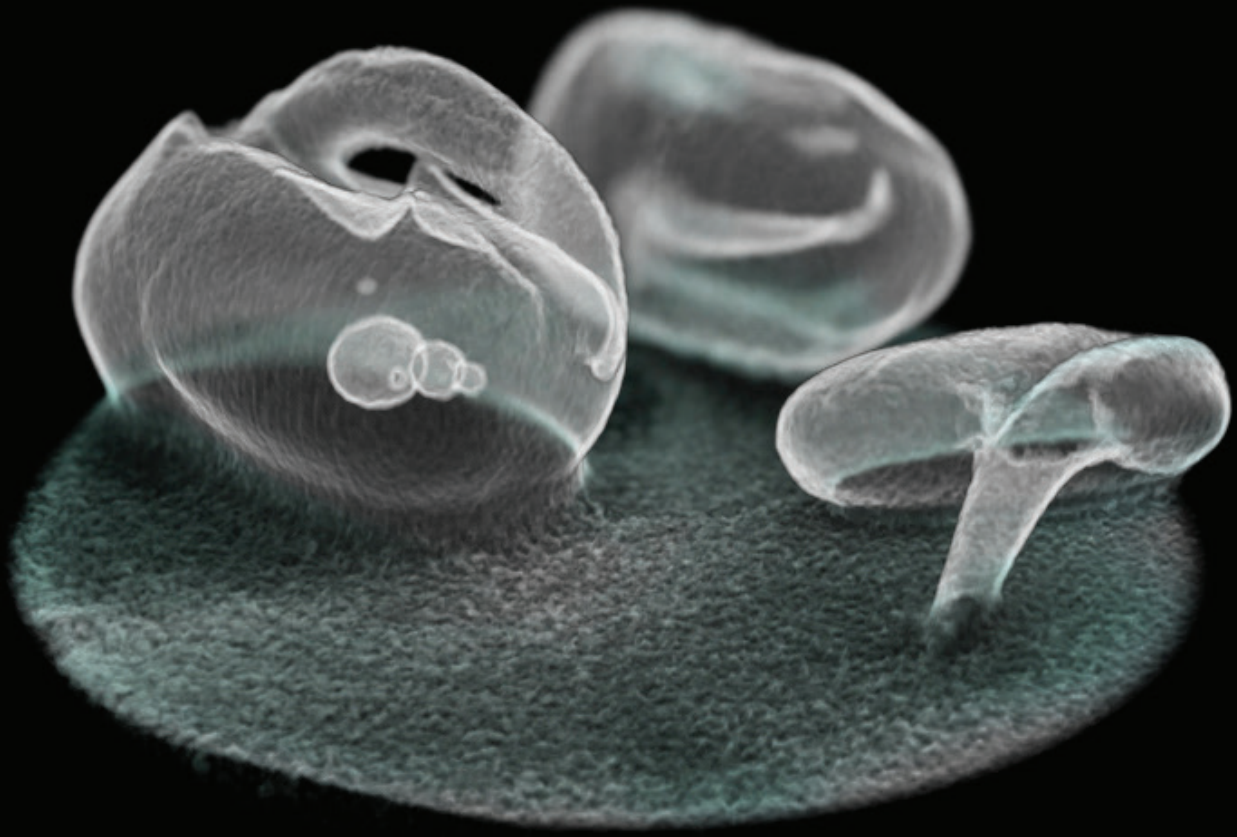
The materiality of the glass objects is highly seductive and wondrous in itself. Being in the presence of these curious objects, it was interesting to consider that no matter how accurately the Blaschkas sought objectively to represent imperceptible phenomena found in nature, the objects still embody a significant kind of aesthetic, in the translucency of the glass, the exquisite craftsmanship in form and in the application of colour.

Rendering my data in Vizlab, I was often struck by the extraordinary range the software *Drishti* allows me when adjusting levels of transparency and colour. It lends itself to delicate rendering and subtlety in tone, enabling me to create finely textured translucent surfaces with the diaphanous qualities of the Blaschka glass. In comparison to these glass objects, my virtual models of germinating seeds are based on absolutely accurate computational data, yet they are still rendered with an aesthetic judgement. This gave me the opportunity to consider how the function of *Drishti* in the 21st century follows the same principle of these fragile glass objects to instruct and provide exploratory experiences beyond 2D representations of scientific data. The tradition of scientific modelling provides a rational and objective way to represent objects and processes, but 3D models also provide a more physical and subjective experience of observation.

Today the awesome leverage of super-computational power has further enabled computer-simulated objects or environments to become essential tools within scientific and technological disciplines to actualise data. Virtual modelling technology and software, such as micro-CT and *Drishti*, aim to present objects or phenomena in a manner of verisimilitude. This follows in the tradition of scientific modelling to provide a rational and objective way to represent objects and processes while communicating theories and concepts. However, the increased capability to view data in three or four dimensions has also radically repositioned the viewpoint of the observer within the virtual space, whether in real-time or seen as animated sequences.

The modelling function of *Drishti* to visualise, manipulate and simulate virtually represented objects *in silico* has extended the opportunity for simultaneous objective and subjective experiences. In exploring verisimilitude through the qualities of the artistic rendering of my data, it could also connect to ideas beyond the 'truth', fostering the imaginative responses and creating dramatic effect. I also began to think more about a possible dialectic of objectivity and subjectivity, reality and imagination, which might be present in states of wonder grounded in the experience of the moment, lending itself further to additional dimensions of individual experience and self reflection, such as the 'fifth dimension'. I turn my discussion to this in the next chapter.

Fig. 3:20. A mung bean sprout imaged in *Drishti*, showing the variation in growth from the bean to the sprout over a nine hour period, (2011).



Chapter Four

A matter of time

The agency of wonder and seeing something for the first time

By the beginning of 2012, the batches of raw tomographic data had become available to me for processing. Looking at each dataset individually in *Drishti* I discovered a wide range of phenomena I had not predicted or seen before. In the nine-hour capture of a mung bean and a radish developing shoots, I observed curious expanding bubble formations beneath the delicate architecture of the seed coat, or *testa*. I could see the development of the first leaf, or *cotyledon*, as the formation began to split the bean. Where the *testa* met the gelatine bed, the data reveals a subtle interaction between two surfaces as a thin film of moisture is drawn up into the seed. [See Fig. 4:1]

I discovered that these bubble formations inside the seed are mysterious even to scientists working in the field of biology. Several explanations that have been put forward about such bubbles include the possibility of respiration where the seeds' metabolism activates, following imbibition (soaking up water), and starts respiring.[71] If the seed coat has trapped CO2, this process may have built pressurised bubbles inside the seed itself. To find out if this is a common feature of germination that helps split the seed coat as the first leaf develops or is an artefact of the X-rayed process, I would need to conduct more rigorous scientific trials which are not within the scope of this PhD research.

In the previous chapter I explored how by capturing and visualising the moment of germination from the exterior and interior of the seeds, this work brings to life phenomena that occurs beyond normal boundaries of human perception. This led me to further question how the work might be viewed without a detached, objective scientific

[71] As suggested by Adrienne Nicotra, Professor, Evolution, Ecology and Genetics, Research School of Biology, The Australian National University, via email 5/11/15

Fig. 4:1. A mung bean sprout and a radish germinate (a failed seed at the back) after five hours during a nine hour capture. Imaged in *Drishti,* reveals a curious bubble formation in the mung bean, (2011-2016)

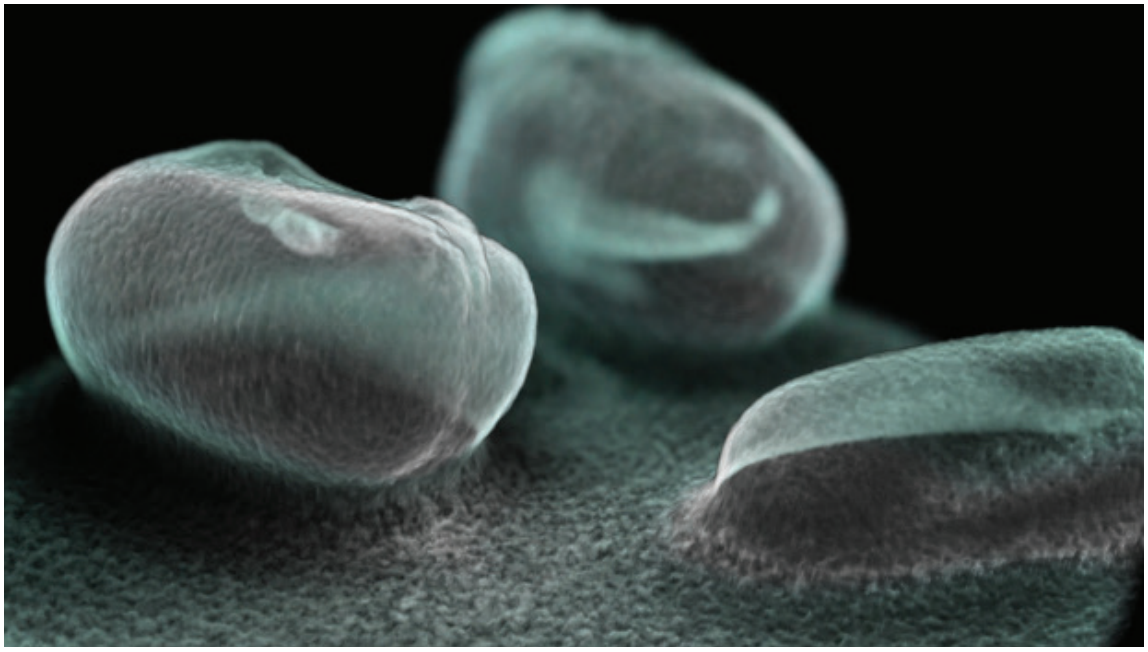


Fig. 4:2. A mung bean sprout and a radish germinate (a failed seed a the back) at the beginning of a nine hour capture. Imaged in *Drishti,* reveals a curious bubble formation in the mung bean, (2011-2016).

eye. Will the spectacle of these seeds germinating in 4D lend itself instead to notions of the sublime — the power of life's waking moment encapsulated in the seed representing the wonder of nature's immensity and mystery? I thought about this while researching the art of Fernanda Cardoso and Valentin, the images of Stuppy, and the Blaschka glass. I had assumed I would be able to make clear distinctions between the scientific and artistic outcomes in order to position my own work within this interdisciplinary field. However, what I discovered was a common thread in all of these works — their power to captivate the viewer derived from the experience of wonder in seeing something for the first time.

This directed me to consider the emotional experience of wonder as perhaps a useful phenomenological tool. English language definitions of wonder refer to things that cause astonishment, embody a quality of surprise or create a feeling of admiration. Mir, the root word of admiration, is the Latin for wonder and the root of miracle, *miracula* and related to *spectacular*.[72] In relation to the spectacular event captured in volumetric time-lapse, and miracle of life seen in the germinating seed, it occurred to me that the experience of wonder in seeing something new or different for the first time might be considered a key element in the final work of art. This meant broadening my understanding of wonder in the context of the potential experience of my 4D germinating seeds.

In *Wonder, the Rainbow, and the Aesthetics of Rare Experiences*, (1998) Philip Fisher examines the function of wonder in the visual world, and in particular to events that are not

[72] "wonder, n.". OED Online, Oxford University Press.. .

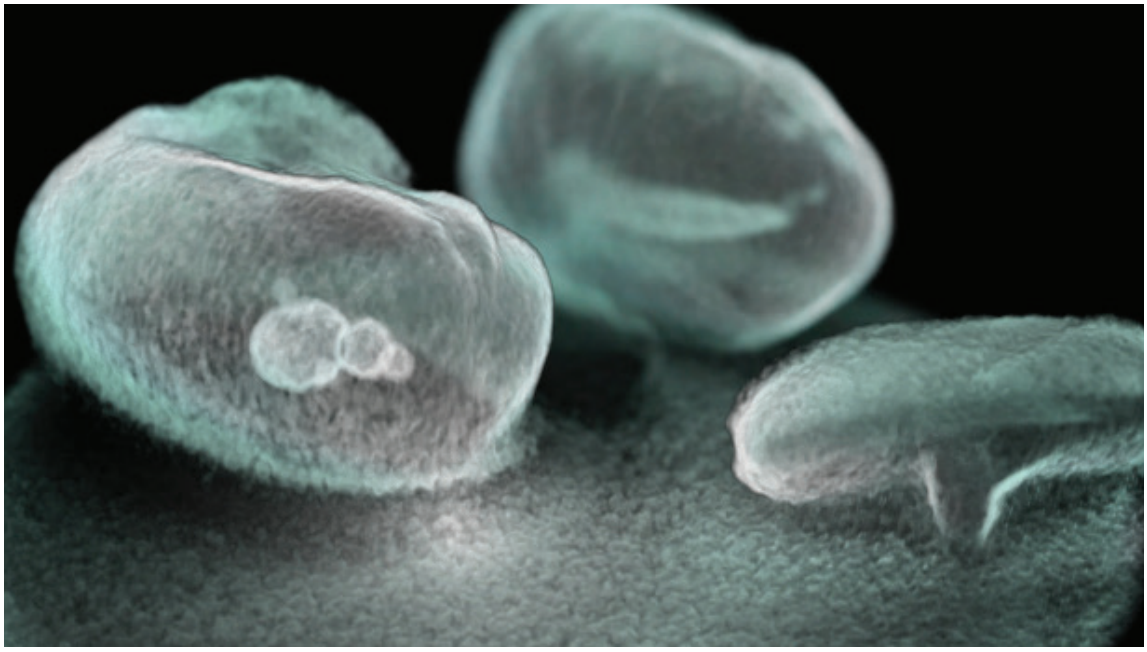


Fig. 4:3. A mung bean sprout and a radish germinate (a failed seed a the back) at the beginning of a nine hour capture. Imaged in *Drishti,* reveals a curious bubble formation in the mung bean, (2011-2016).

ordinarily experienced in the everyday. Whether in science or art, he argues that surprise and novelty arouse feelings of wonder, and this drives the curiosity and the desire to further knowledge. Examining wonder from the perspective of the development of the philosophy of aesthetics, such as René Descartes' *Passions of the Soul*, he discusses how wonder can inspire deeply intellectual feelings leading 'us back to reflection on our selves and our powers,'[73] an outcome being of significant value in the aesthetics of rare experiences.

Fisher stresses that there is a clear distinction between the experience of the wonder and the sublime. Where the sublime is considered superior to wonder in motivating intellectual thought and feelings, he warns that notions of the sublime are embedded in a history of romanticism which masks anti-technological sentiment and quasi-religious aesthetics, where 'fear and surprise, power and danger occur in a rich blend.'[74] Wonder, on the other hand, while it is less acknowledged in modernity, 'involves the aestheticisation of delight, or of the pleasure principle.'[75] Using examples in mathematics, science and art, Fisher shows how wonder creates a sensation of discovery which drives steps of thought through learning, rational knowledge, and the experience of solving problems. Wonder therefore, as a moment of learning, is relative as it concerns what is new to the individual.[76]

[73] Philip Fisher, *Wonder: The Rainbow, and the Aesthetics of Rare Experiences*, Harvard University Press, 1998, 1.
[74] *Ibid*.
[75] *Ibid*.
[76] *Ibid*., 67.

To establish how scientists evaluate the agency of wonder in learning, I referred to contemporary ethologist and evolutionary biologist Richard Dawkins who emphasises its importance in science in *Unweaving the Rainbow* (2006). The book was inspired by the anti-scientific sentiment which he regularly received in response to his evolutionary biology research, his atheism and his advocacy for the promotion of reason and science against creationism. Dawkins' title, and Fisher's, refers to the line 'unweave a rainbow, as it erewhile made,'[77] in John Keats' poem *Lamina* (1820). He laments the end of spiritual awe and the wonder in life brought about by the 'cold philosophy' of science, which conquers, 'all mysteries by rule and line.' [78] The magical effect of the rainbow was revealed by Isaac Newton in 1670 when he published his discoveries of how light refracts when shone through a prism. In his poem Keats suggests a rejection of this scientific reason in order to return to the primacy of poetic imagination. Arguing that Keats was entirely mistaken, Dawkins writes,

> *The feeling of awed wonder that science can give us is one of the highest experiences of which the human psyche is capable. It is a deep aesthetic passion to rank with the finest that music and poetry can deliver. It is truly one of the things that makes life worth living, and it does so, if anything, more effectively than if it convinces us that the time we have for living it is finite.*[79]

Dawkins also makes the point that fellow scientists don't live in a vacuum devoid of emotional connections to things. Rational knowledge can also be informed through lived experiences of being in the world. For example, even though Newton held strong religious beliefs, his inquisitive drive to examine visible light led to spectroscopy, the study of the interaction between matter and electromagnetic radiation, which is the key to understanding the cosmos.[80]

In his essay 'The atomic scientists, the sense of wonder and the bomb,' Mark Fiege examines how the subjective experiences of mountain hiking and climbing were fundamental to the inspiration and development of nuclear science at the Manhattan Project during the late 1940s. Fiege dispels the myth of 'heartless men in white coats,' experimenting in laboratories to create the most iconic and petrifying weapon of mass destruction in the history of humanity. He argues that, 'behind the cold logic of numbers existed a domain of thought and action crucially important to atomic science yet unacknowledged in its formal discourse.'[81]

[77] John Keats' Lamina, 1820, Part 11, Keat's Kingdom http://www.keatsian.co.uk/

[78] *Ibid.*

[79] Richard Dawkins, *Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder*, Penguin Books, London, 2006, xii.

[80] *Ibid.*, xii.

[81] Mark Fiege, "The Atomic Scientists, the Sense of Wonder, and the Bomb," *Environmental History*, Vol 12, July 2007, 580.

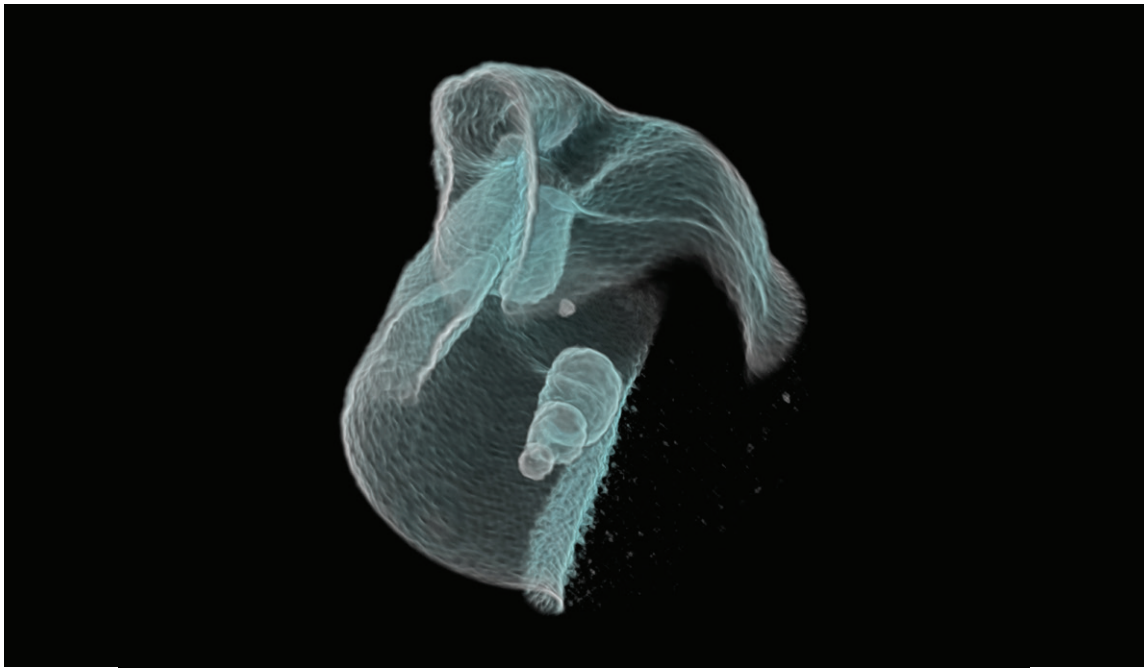


Fig. 4:4. A mung bean sprout Imaged in *Drishti,*
reveals the curious bubble formation beneath the *testa*, (2011-2016).

Fiege describes how this group of scientists, including Robert Oppenheimer, used the physical experience of being in nature to create opportunities for subjective experiences, intuitive and aesthetic judgments and emotional responses which, 'enabled intellectual processes and helped them to image the microscopic nature that they could not see but knew existed.'[82] By the 20th century, all experiences of wonder had been suppressed from scientific research and any human bias had been made formally irrelevant. However, Fiege explains that because the weird and intangible nature of atomic particles defy known laws of gravity, mass, and motion, they also defied normal comprehension. Therefore in order to interpret this invisible subject, scientists had to exercise their imagination, 'a faculty more often associated with artists than with people such as themselves.'[83] While the process of wonder was eliminated from formal papers, scientists spoke about its agency, and the inspiration of the mountains, in conversations and interviews.[84]

In 'Miniature', a chapter in *The Poetics of Space*, Gaston Bachelard uses the example of looking at nature through a magnifying glass in order to describe the difference between a rationalistic scientific observation and a subjective experience of discovery. The history of science is underpinned by the idea of discovery, and formed by a series of 'first time' events. However, Bachelard defines the disciplined objectivity of a laboratory scientist as not about seeing something for the first time, as 'the 'first time' doesn't count.'[85] He

82 Fiege, "The Atomic Scientists," 580-581.

83 *Ibid*., 583.

84 *Ibid*.

85 Gaston Bachelard, *The Poetics of Space* (First published 1958, Presses Universitaires de France. English Translation 1968, The Orion Press, Inc. 1994 Edition, Beacon Press), 156.

Fig. 4:5. The Millennium Seed Bank, Royal Botanic Gardens Kew, Wakehurst Place, West Sussex, UK. During my field trip from 1-14 May, (2012).

writes that as this type of rigorous and rational observation, 'belongs in the domain of 'several times'', and consequently, 'in scientific work we have to digest our surprise psychologically.'[86] Bachelard clarifies that to see something *truly* for the first time we need to forget all our habits of scientific objectivity, 'which requires any new idea to become integrated into a body of tested ideas.'[87] In the act of subjective discovery, in order to access different areas of the psyche, one must be receptive to the newness of the 'poetic image' when it first appears, and then re-appears.[88] Thus the scientific image can illicit feelings of wonder, driving us to want to know more.

In capturing the bubbles I seemed to have stumbled across the visualisation of an unknown phenomenon, although I am not proposing to make any scientific claims. Rather, by considering the power of wonder, I have been able to suggest that my work is exploring how scientific images draw us into the excitement of discovery. In 'wondering' about the world around us, rational and imaginative, logical and poetic, objective and subjective, reasoning can coexist within the whole lived experience. My seeds reveal new things that allow us to continue to wonder about the mysteries of life. In the same way that the metamorphosis of the butterfly pupa is named *imago*, the *imaginal* or mature state, my seeds also provide an image of the emergence of life to create new poetic spaces within the imagination. These perspectives on wonder have been important in further developing my understanding of

86 Bachelard, *The Poetics of Space*, 156

87 *Ibid.*,1.

88 *Ibid.*,1.

Fig. 4:6. Dr Wolfgang Stuppy, demonstrating how to take images with a microscope at the The Millennium Seed Bank, during my field trip from 1-14 May, (2012).

how the 4D germinating seeds have the potential to extend the possibilities for different kinds of perceptive knowledge, such as the sense of mortality or hope for the future.

A last resort: Millennium Seed Bank, UK

In context of my readings on wonder, phenomenology, and experiencing nature, residing at the Millennium Seed Bank (MSB) for two weeks has influenced my ideas, not only about the direction of my research, but my outlook on the future of the planet. My original intention was to meet and talk with Dr Wolfgang Stuppy about his research as a way of drawing on ideas about scientific visualisation and the conservation of seeds in order to make further connections with my practice. My residency at the MSB in the state-of-the art facility on the Wakehurst Reserve in West Sussex, UK, allowed for a period of deep reflection about what the Anthropocene actually means. Staying there also provided me with the oportunity to meet with Dr Wolfgang Stuppy, whose research and images I discuss in Chapter three.

The MSB project is one of the most prominent facilities among an increasing number of seed storage sites now being established globally to conserve biodiversity in plant species around the world. This carefully managed collection is considered an insurance against the global extinction of natural populations of wild plants.[89] Scientists in this field of research have estimated that at least one quarter of the world's species of plants today

[89] Thompson, *Seeds, Sex and Civilization*, 216.

Fig. 4:7. Erica Seccombe, *Vault Door, Millennium Seed Bank, Royal Botanic Gardens, Kew, Wakehurst Place, Sussex, UK* 2012, digital image, 44.4 x 65.5 cm, inkjet print on Canson rag, edition of five, (2012).

are already threatened with imminent extinction, primarily because of human activity. While seeds have long been harvested, stored, traded and modified through selection by humans, the establishment of the MSB heralded a new era of future storage. Its objective differs from the purpose of seed libraries that lend, share, distribute or exchange seeds to promote propagation. Instead, the MSB employs the methodology of *ex situ*, (off site) conservation so that viable seeds can be stored alive for long periods of time for the purpose of restoration and translocation.

Peter Thompson, founder of the MSB, was integral in the relocation of the original seed collection from Kew Gardens in London to Wakehurst Place. As Thompson explains, the MSB was strategically planned to address the imminent threat to species of wild plants globally as, 'seed banking provides the only practical and feasible way to conserve this diversity.'[90] The MSB has the largest *ex situ* plant conservation program and when it is eventually at full capacity the seed collection is estimated to become 100 times larger than that of the Svalbard Global Seed Vault (*Svalbard globale frøhvelv*) in the Arctic. The new MSB facility was opened in 2000 with the aim of conserve more than 25% of the world's most endangered plant species by 2015. Reaching this target, the collection now exceeds 36,333 plant species and 2,115,847,290 seeds.[91] For many of these species this storage is the last resort.

The seed collection resides in a massive underground room lined with reinforced concrete. The high security vault is mostly accessed by a narrow descending spiral staircase onto a shiny metal platform. [See Fig. 4:7] Behind the impressive steel bolted doors, there is more plant species diversity in this one location than anywhere else in the world. Inside, scientists in white lab coats work around a central bench, patiently sorting, weighing, measuring and counting seeds, peering through microscopes and tagging bottles. Along the walls other doors with round porthole windows give views into cold-storage rooms where thousands of labelled bottles, full of collected seeds are shelved in dry and freezing conditions. [See Fig. 4:8] Many seeds are able to remain dormant in these conditions for decades, or centuries, but other species, such as tropical varieties, will not survive freezing.

On working days I joined the scientific teams counting and testing the viability of the stored seed collections. This gave me first-hand experience of what it is to work in such a facility. I spent time patiently counting, x-raying, sorting, labelling and peering down a microscope. Dr Wolfgang Stuppy was at the MSB for several days during my visit and I was able to spend time with him in his laboratory where we discussed his methodologies for imaging seeds. This opportunity also allowed for me to exchange ideas with him regarding some of my work-in-progress in those early stages of data acquisition and

[90] *Ibid*.

[91] Reported 4 August 2015, http://www.kew.org/science-conservation/collections/millennium-seed-bank/about/millennium-seed-bank-faqs#howmany

Fig. 4:8. A view through the cold store window at The Millennium Seed Bank, Royal Botanic Gardens Kew, Wakehurst Place, West Sussex, UK, during my field trip from 1-14 May, (2012).

rendering. Stuppy could see the potential in my data to affect the kind of wonder he is employing in his own captivating images. What affected me most however, was his bleak outlook on the future which confirmed my readings on the subjects such as extinction and global warming in context of the Anthropocene.

Stuppy shared his concerns that not enough action has been taken to conserve plants because the majority of people do not understand the gravity of this extinction rate, and the importance of bio-diversity. This is because we generally do not appreciate that when a species disappears, no matter how small or seemingly insignificant, it takes with it an elaborate piece of our vast and complicated life support system affecting many other species in the same eco-system, including ourselves. The ultimate tragedy is that each extinct species that took millions of years to evolve is lost forever.[92] As discussed in the previous chapter, Stuppy's images of seeds attempt to draw people in and inspire them with wonder in order to connect them with these ideas, and to encourage them to learn more about the world around them.

Talking to Stuppy I recognised the parallel concepts in line with my readings of the Anthropocene by Will Steffen and Paul J Crutzen, and journal articles on the subject of extinction. Science is proving that the sixth extinction is happening at an accelerated

[92] From my conversation with Dr Wolfgang Stuppy, 5 May 2012, Millennium Seed Bank, Wakehurst Place, West Sussex, UK

Fig. 4:9. A view of the residential wing at The Millennium Seed Bank. The vault is below, the Glasshouse above. My room is indicated by the chair. 1-14 May, (2012).

rate and is due predominately to human activity such as land clearing for agriculture, logging and development. In the article 'Biodiversity: Extinction by numbers,' the authors provide an estimate that with the current rate of habitat destruction each decade will see the disappearance of a thousand species of plant and animals per every one million. Based on this expectation, 'the extinction curve should accelerate rapidly to a peak by the middle of the twenty-first century if the rate of forest clearing remains constant.'[93]

As an evolutionary biologist, Stuppy has studied the development of plants across the last five mass extinctions on Earth. Fossil records and modern data provide evidence that global biodiversity took between four million and twenty million years to recover after every extinction event. Considering that humans have existed for only two hundred thousand years, scientists like Stuppy understand the improbability that we will be around to see biodiversity restore itself after this current mass extinction. His view is that unless there is global agreement to radically change human activities and implement more effective conservation measures immediately, then any current conservation efforts, such as the MSB, will be in vain.[94] This sense of urgency, to find ways to motivate against inaction in order to avert this crisis, supports my readings of Lesley Duxbury and Sasha Engelmann. Their view of phenomenological methodologies in contemporary installation art is that

93 Stuart L. Pimm & Peter Raven, "Biodiversity: Extinction by numbers," *Nature* 403, 843-845 (24 February 2000)

94 From my conversation with Dr Wolfgang Stuppy, 5 May 2012, Millennium Seed Bank, Wakehurst Place, West Sussex, UK

Fig. 4:10. Testing the viablity of a seed collection reveals that a percentage of these seeds had a bacterial infection. The Millennium Seed Bank, Royal Botanic Gardens Kew, Wakehurst Place, West Sussex, UK, 1-14 May, (2012).

it can create opportunities for individuals to motivate more meaningful experiences of nature in order to more fully comprehend this environmental change. Perhaps because the hard facts and numbers of endangered plant species is of a far greater quantity than can be imagined, my work could motivate more meaningful connections with nature through the experience of seeing a plant germinate from a new perspective.

After discussing the reality of extinction with Stuppy and working alongside the other scientists during the day I would return to my room in the evenings. [See Fig. 4:8] After 5pm the MSB staff and public visitors would leave the grounds. Only the security guard and 15 other live-in research residents remained in the building over night. I found living in this vacuum-sealed environment above a subterranean vault full of the world's seeds strange and isolating. It felt as though my fellow researchers and I were the very last people left on Earth, a feeling shared by the other residents, some of whom had lived at the MSB for periods of six months. On several occasions over the two weeks I awoke from nightmares of nuclear disaster.

Finding this experience to be incredibly affecting, I could see a connection with the experience intended for the audience in Ólafur Elíasson's *The Weather Project* as they stood in the smoky haze and half light of an artificial sun. I realised that installation is about the suspension of time. It creates the sensation of extending the moment into infinity. At the MSB I also felt grounded in the moment of living on the precipice of an

unimaginable future. It made me consider how finite extinction is, and I found it difficult to grapple with these ideas without feeling incredible sadness. The frozen vaults of seeds at the MSB had inspired me to think about seeds and their future viability — each seed embodying a potential future for survival. While at the MSB I made the connection that dormancy in a seed is a form of suspended animation. In this deferred state the seeds in the vault contain all our hopes and anxiety for the future of our planet. Each seed embodies an imagined moment of germination to reconstruct future landscapes.

A view of the future: contructed landscapes

Returning from my field trip I wanted to find ways to link ideas of time, seeds, extinction, dormancy and germination and to the unknown future landscapes of the Anthropocenic age. My question is, why is it that collectively we find it so hard to act effectively in the face of such devastating consequences when scientists like Stuppy are bringing these facts to our attention? I found the essay, 'The end is not near,' by the philosopher, J.L Schellenberg proved useful in considering the difficulty we have in understanding our place in the grander scale of scientific-time.

Schellenberg proposes humans cannot imagine that time will infinitely continue without us because, 'looking forward from where we are into the abyss of future time, imagining what yet may be, is not something we're used to doing.'[95] In relation to human time-scales, it is only very recently in our existence that we have accepted the notion of evolution and geological time. Little over 200 years ago European thought was still founded on the creationist theory from the Book of *Genesis,* that the Earth had only existed for two or three millennia. In the 21st century the history of the world and the universe can now be understood from a scientific perspective; such as the information revealed by Professor Senden's fossilised *Gogonasus,* our ancestor from which humans evolved 380 million years ago. Perceiving humans to be at the end of their evolutionary journey, we tend to think in terms of the past, not the future.

In his essay, 'The Climate of History: Four Theses,' the historian Dipesh Chakrabarty discusses this predicament. The reality of the Anthropocene and its consequences takes us to the very limits of historical understanding. He writes therefore, 'it is not surprising then that the crisis of climate change should produce anxieties precisely around futures that we cannot visualize.'[96] This is because it relates to how we perceive time. In Gilles Deleuze's philosophical thesis *Difference and Repetition*, the measuring and ordering of time is something we do in the mind. In reality, time exists exterior to the mind and outside

[95] J. L. Schellenberg, "The End is not near: why do we assume the future will be short,"*Aeon Magazine*, 10 February 2014, http://aeon.co/magazine/philosophy/why-do-we-assume-the-future-will-be-short/

[96] Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry*, Vol. 35, No. 2 (Winter 2009), The University of Chicago Press, 21.

Fig. 4:11. A view of the Canberra National Arboretum, (2012)

Fig. 4:12. Giant Redwood, Sierra Redwood Big Tree, *Sequoiadendro Giganteum*, (California) 1890, listed as a vulnerable species, Wakehurst Place, Royal Botanic Gardens, Kew (2012).

of individual consciousness. In this sense, Chakrabaty writes that it is difficult to posit in a historical sense what is new or unknown, such as environmental change, because it is too difficult to picture the future in our mind without reference to an immediate past experience;

> *The discipline of history exists on the assumption that our past, present, and future are connected by a certain continuity of human experience. We normally envisage the future with the help of the same faculty that allows us to picture the past.*[97]

In view of my readings on the subject of the Anthropocene, and my experience at the MSB, I wanted to test how I could articulate these ideas through my studio practice. Instead of juxtaposing past and present, I wanted to experiment with the concept of the present and future as an alternative way to think about the idea of time-lapse of germinating seeds. I did this by creating a new work-in-progress at the end of 2012, entitled *Constructed Landscape.*

Constructed Landscape was inspired by exploring the giant trees in the forest on the Wakehurst reserve surrounding the MSB. It was there that I started to make connections with the National Arboretum in Canberra, a place where I frequently walk. In 2012 the arboretum was in its infancy, a landscape populated by patterned rows of spindly

[97] Chakrabarty, "The Climate of History," 197.

saplings in red plastic tubes. [See Fig. 4.11] It occurred to me that in my life-time I may not live long enough to see some of these trees grow to their full maturity as they are at Wakehurst. For example, the Giant Sequoia, or Californian Red Wood [See Fig. 4.12] is estimated to grow to 40 metres in 50 years, and can grow to a full height of 80 metres. Seeds take a short time to sprout, but to capture a time-lapse of these trees at the Canberra Arboretum growing to full height would take as long as a century.

As time is compressed into seconds in my time-lapse capture of seeds germinating, I was interested to see what would happen if I extended, or stretched the experience of time instead of accelerating it. I wanted to further explore the idea of the sensation of living in the moment, while thinking about the future. To do this I selected and compiled 300 photographs which I had taken of the Canberra Arboretum on my many visits. I organised them so that they were not sequential in the order of time they were taken, but sorted according to various positions and perspectives to give a sense that the viewer is taking a slow walk through the landscape.

Animating the still images I used a filter to create the lengthiest transition possible from one single image to the next. I set a consistent tonal range of green across the whole work to limit variations in time and colour to create a sense of one single moment (not days, weeks or seasons). As the images slowly transition, the double exposures create new possibilities for interpreting the position and pattern of the saplings planted across the landscape. [See Fig. 4:13] The duration of the work lasts 3 hours and 52 minutes, far longer than an average person would spend watching a moving image in a gallery space.

I had the opportunity to exhibit *Constructed Landscape* at ANCA Gallery in Dickson, ACT in October 2012. I ran the movie as a large, single, looped projection onto the gallery wall. To further explore the concept of time in this piece, I contrasted the projection by placing on the adjacent wall a single printed photograph I had taken of the vault door at the MSB. [See Fig. 4:7. p. 70.] Alongside the image I placed text explaining the location and purpose of the MSB, describing how, behind the vault door more, species of plants are located in one space than anywhere else on the planet. By juxtaposing the single image of the seed bank and the long movie sequence of an arboretum in its infancy I wanted to explore the correlation between the idea of the dormancy of seeds and future, or virtual landscapes that are beyond our imagination. The question I was asking was: what it will be like to live in the near future where the environment is predominantly reconstructed as the natural spaces on Earth are further reduced?

Not long after exhibiting *Constructed Landscape*, I met Dr Tim Brown from the ANU Research School of Biology who is leading research in plant genomics for climate adaption. I discovered a part of his research involves a section of gum trees at the National Arboretum Canberra, *Eucalyptus Tricarpa* (red gum) and *Corimbia muculata*

Fig. 4:13. Erica Seccombe *Constructed landscape* 2012 (detail) single channel, digital projection, dimensions variable, duration 3:52hrs. Exhibited in *Crossing the Rubicon*.

Fig. 4:14. Work in Progress, twelve 3D printed objects, gypsum powder, ink, resin, 10 cm radius, 12 objects, (2013).

(spotted gum). These species of gums are native to regions in Queensland and have been relocated further south to test sustainability in a dryer climate as temperatures become too hot for the species to thrive in their own habitat. In relation to my own work I was interested to learn that Dr Brown was in the early stages of a time-lapse project focussing on these trees. He has begun collecting a wide range of data acquired from satellite, drones and high resolution mega pixel imaging sources that will continue to record these trees throughout this century and into the next. This is being undertaken with the view that future generations will have a virtual experience of these trees developing from the perspective of a 100 year time-lapse, demonstrating how climate change began to take affect in the early 21st Century. This discovery proved to me that my ideas for works of art exploring nature and the experience of time in relation to the Anthropocene are developing in parallel to current research is being undertaken in other disciplines.

Printing time

During my research candidacy I produced a series of 3D printed objects called *Printing Time*, as a work-in-progress supported by the ANU Vice-Chancellor's College Visiting Artist Fellows Scheme (VCCVAFS). This gave me the opportunity to further explore ideas of time by 3D printing my virtual volumetric datasets. In 2013 the Department of Applied Mathematics purchased a Z-Printer 650 which creates 3D objects in a very similar manner to a colour inkjet printer with a full suite of coloured ink cartridges.

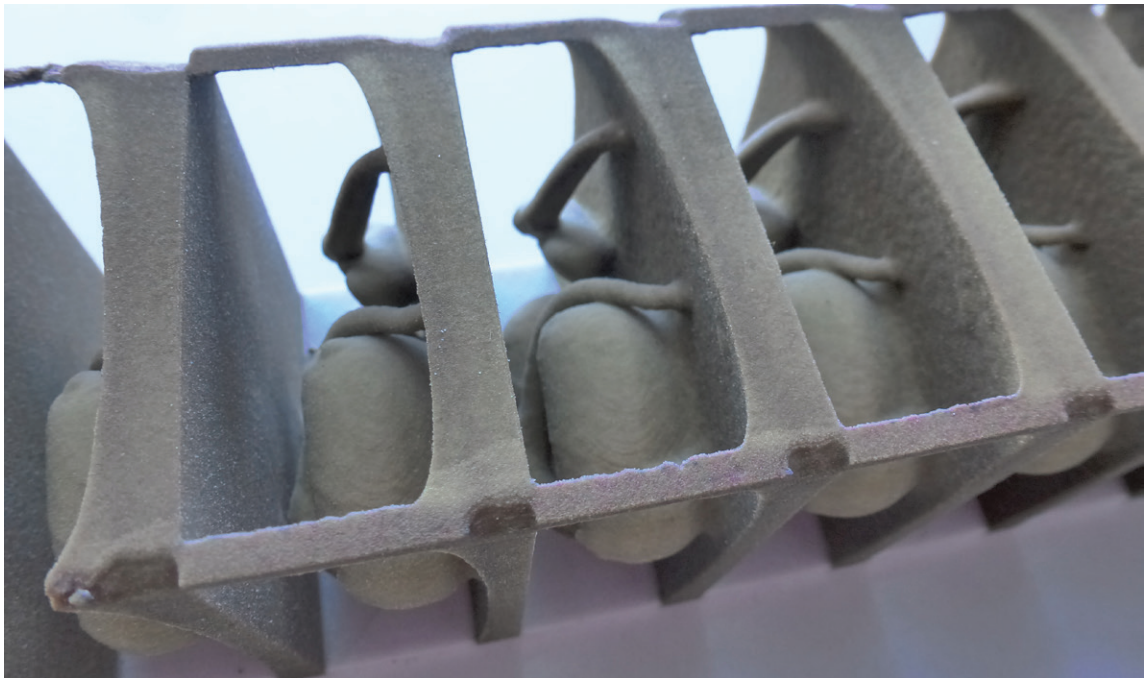


Fig. 4:15. (Above) Work in Progress, 3D film stack, (detail) 3D printed object, gypsum powder, ink, resin, , 20 x 15 x 15 cm, (2013).

Fig. 4:16. Work in Progress, 3D printed objects, gypsum powder, ink, resin, (2013).

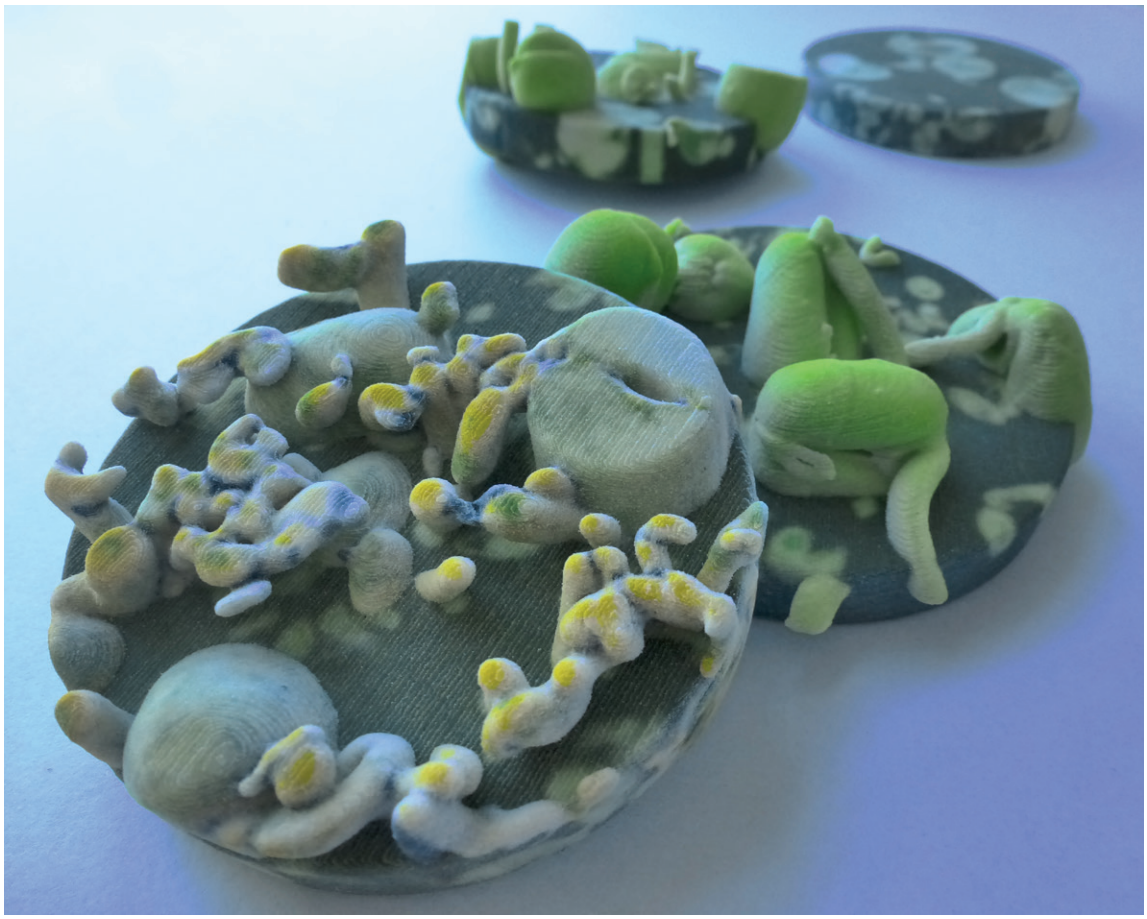


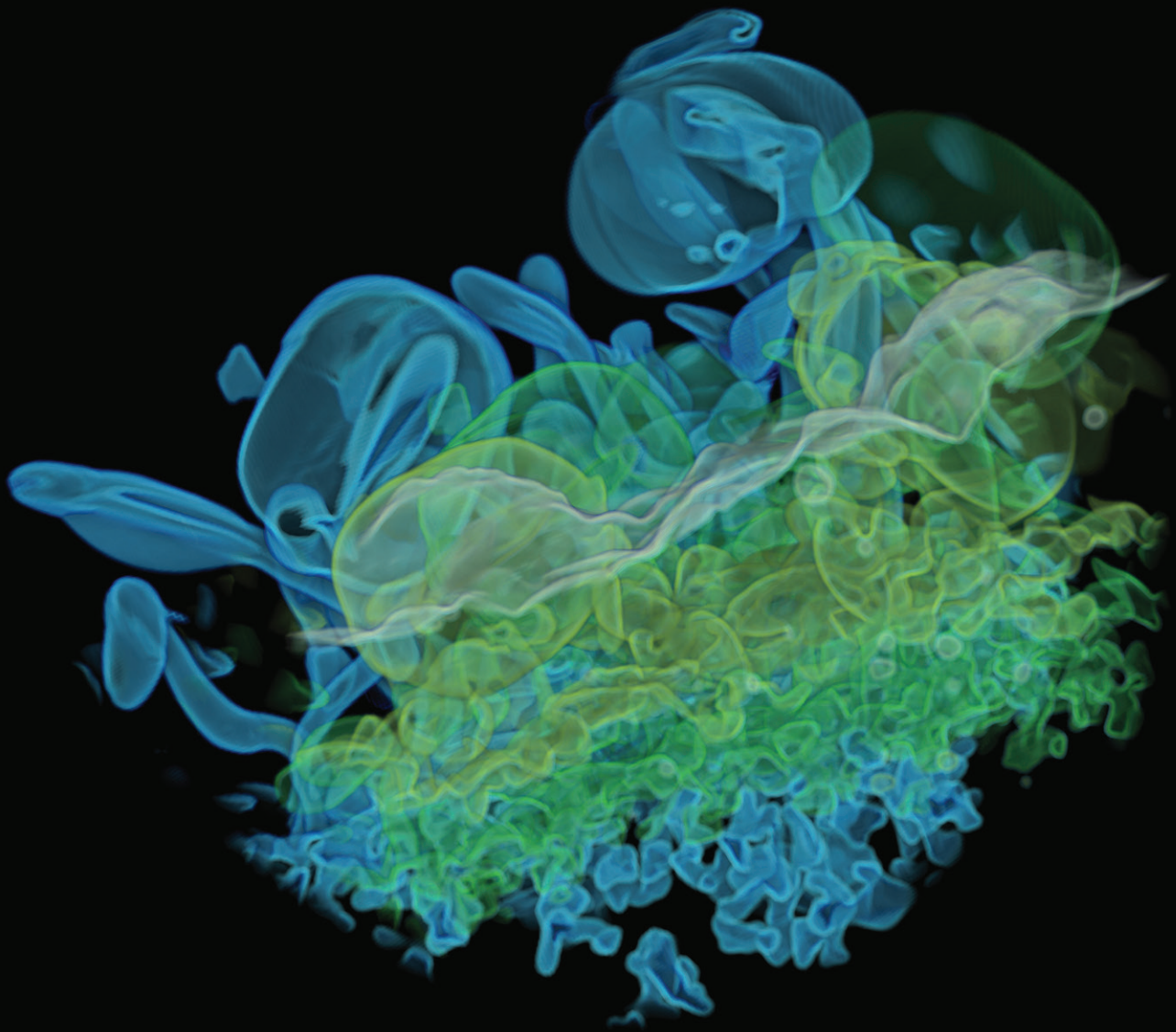
Fig. 4:17. Erica Seccombe, *Printing Time,* 3D printed objects, gypsum powder, ink, resin, 2013, 12 x 3D printed objects, approx. 10 cm diameter, 2-3 cm in height, gypsum, inkjet ink, resin, created 2014. Installation view at Dominik Mersch Gallery, Sydney, (8-31 May 2014).

Digitally translating the colour and shape of the volumetric datasets, it prints onto horizontal slices of paper-thin deposits of white gypsum powder to build the 3D form in sequential layers. The inks contain a binder so that each fine layer is bound together and unwanted powder can be removed after the printing process has completed. The object is then sealed and stabilized with a resin coat. This material and printing process successfully captures volumetric data rendered in *Drishti* demonstrating both the detail and colour of complex shapes.

In my first experimental print in this medium, I developed a dataset by stacking 12 volumes on top of each other as series of sequential moments. Ordering each time-frame in a linear structure resulted in the printed object looking like a 3D film strip. [See Fig.4:15] Exploring different forms with the same datasets, I printed a group of twelve small discs. [Fig. 4:14] These can be arranged to show time-steps of growth from one separate volume to the next. On reflection, these objects did not help me to express the additional dimensions proposed through my research, causing me to question whether virtual time should to be printed in such a conventional form to depict growth or development.

The beans and alfalfa sprouts are very fragile when they are printed, so the leaves and stems would easily break off. To resolve this I created a flat circular disc around the data to contain the more delicate structures within a solid base. Before printing I also tested a bright green colour against black tones to highlight the artificial quality of the organic shapes, rather than trying to match colours in reality. When I printed these objects I realised the shape of the bases and the colour made the objects look like biological experiments in petri dishes, such as starter cultures of bacteria or other life forms. [Figs. 4:16-4:17] While this was not the intentional outcome, I was interested in how the work lent itself to ideas of testing the threshold of life in the scientific laboratory, alluding to attempts to master nature, or perhaps to failed experimentation. When exhibiting this work at Dominik Mersch Gallery, May 2014. I played on this interpretation by arranging the objects on a plinth and installed white lights to create an artificially illuminated effect of grow lamps in a laboratory. [See Fig. 4:17]

Developing this work, I discovered that I could overlay different datasets and create new forms in the printing process. Instead of creating unique and sequential time steps, I could transpose stages of seed growth by embedding one moment in time into another so that time is represented in each object as non-linear. Using this technique I developed a group of twelve 3D prints for *Printing Time.* These tactile objects, the result of the virtual data and time being materialised into a solid form, highlight the potential for my art to create new experiences and perspectives. In the following chapter I demonstrate how I explore the qualities of this volumetric data through the development of stereoscopic projections for exhibition.



Chapter five

Immersive experiences

Time in motion

Exploring different ways to configure time in my works *Constructed Landscape* and *Printing Time* was helpful when thinking about how time can be percieved or experienced. With a view to creating immersive installations with stereoscopic projections, these works in progress also directed my research into motion studies as they related to the time-lapse I was creating with 4D micro-CT. The ability for artists to capture time digitally and photographically and then to postpone, resurrect, reverse, preserve, slow, and quicken it, is a distinctly modern phenomenon. Therefore I looked to draw upon this modern development in order to situate my 4D data within time-lapse photography,

Initially I had searched for historical examples of motion study in Eadweard Muybridge's and Etienne-Jules Marey's chronophotography of the 1880s. Pioneers of proto-cinematic technology, their systemised employment of rapid mechanized shutters revealed indeterminable kinetic effects of bodies in motion. Their original studies of movement were subjected to precise measurements by stopping time incrementally as serial photographs. As I discussed briefly in Chapter two, this new method of capturing motion influenced modern art practice, but they also inspired scientific studies of mathematical measurement and mapping time in both ethnography and physics.

These photographic developments, combined with the increasing sophistication of optical lenses in the 19th century, began to highlight the capacity and limitation of human perception. As discussed in Chapter three, these new instruments reinforced the function of 'mechanical objectivity,' in that the human eye was no longer considered reliable.

Fig. 5:1. An image of four volumetric datasets registered and overlaid to illustrating the development and movment of seeds as they germinate. The white image shows the seed base at the begining of the capture, and the subsequent green and blue images show how the data has changed over time. Image created for a poster entered into the Nikon Image Competition, Natural History Museum, London, (2014).

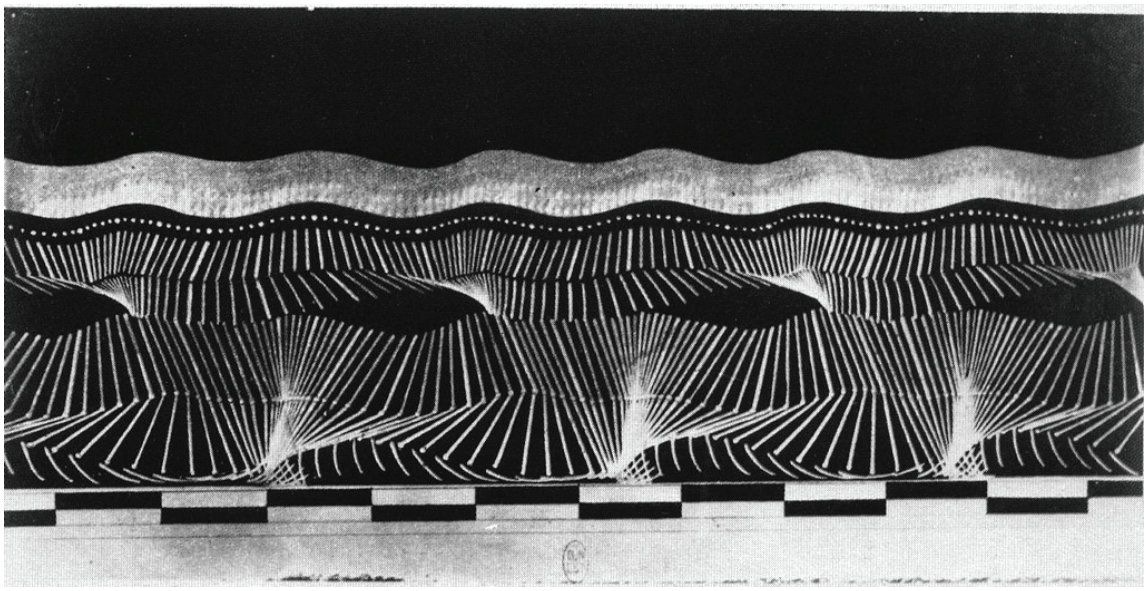


Fig. 5.2. Etienne-Jules Marey, *Geometric chronophotograph of the man in the black suit*, (1883).

Jonathon Crary explains in *Techniques of the Observer*, 'the widespread preoccupation with the defects of human vision defined evermore precisely an outline of the normal, and generated new technologies for imposing a normative vision on the observer.'[98] This mechanical extension of the human eye was also seen to employ greater efficiency and endurance. It became of critical interest to a wide range of social applications, within the scientific management of labour, the rationalisation of knowledge and the construction of new social powers, thus furthering the modernised experience of time through increased industrialisation. In, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (1992) the author Aaron Rabinbach discusses how Etienne-Jules Marey's early chronophotographic studies were useful for determining the economy of physical movement in specific tasks. Marey's image, *Geometric chronophotograph of the man in the black suit*, (1883) illustrates the pattern of movement of a man wearing a black suit with white markings. [See Fig. 5:2] Rabinbach uses this work as an example of how the maximum efficiency of labor power and productivity became the primary focus, while the body of the worker was eliminated from the picture.[99]

In considering the complex history of the mechanisation of the body in relation to time lapse, I started to think about how time in the 21st Century is viewed as having being accelerated. Our lives are set to the fast pace of a digital society with twenty-four hour accessibility, and with the expectation that any demand will be met with immediacy. I returned to consider the tomato crops of the *Costa del Polythene*, where the plants are subjected to the pressures of industry for fruit production all year round. Instead

[98] Jonathan Crary, *Techniques of the Observer*: *on vision and modernity in the nineteenth century*, MIT paperback edition, 1992, 16.

[99] Aaron Rabinbach, T*he Human Motor: Energy, Fatigue, and the Origins of Modernity*, University of California, 1992, 116-117.

Fig.5:3. Dr John Nash Ott, detail from a time-lapse of a pumpkin developing (1950),

of following natural cycles and seasonal rythyms, agriculture is being set to a faster, artificial pace to meet the mass consumption of ever increasing harvest yields. Artificial light is often used to extend photoperiods in order to speed up their growth. Genetic modification of ideal traits also assists maximum productivities. I reflected that perhaps the concept of capitalised and industrialised time might be relatable to the processes and methods I used to germinate seeds, and how they might be experienced as time-lapse. However, at this stage I was not yet sure how to articulate this idea. In the final chapter I discuss how I resolved these ideas in relation to the concept of seasonal time and the Anthropocene.

Searching for examples of scientific time-lapse studies of plant growth to conceptualise my work led me to the cinematography by Dr John Nash Ott. In the 1950s Ott was the pioneer of full colour time-lapse animation of plants and he is considered the founder of the field of photobiology. As an innovation in time-lapse photography he discovered how to optimise the potential for plant growth in studio environments by using certain spectra of light. Ott mastered the control of light frequencies in combination with automated camera tracking when he was commissioned by Walt Disney Productions to create time-lapse of the development of pumpkins on vines. [See Fig. 5:4] These studies were created to inform the animators at Disney how to illustrate with naturalistic effect, the magical transformation of a pumpkin into Cinderella's coach.[100] Examples of his early experimentations of budding pumpkin flowers wilting and dying are reminiscent of my own failed attempts in the laboratory. In later investigations, Ott set out to prove how movement, growth, form and sexual behavior in plants, animals and humans, are

[100] Dr John Nash Ott, *Exploring the Spectrum*, The Effects of Natural and Artificial Light on Living Organisms. A Documentary About the Work of Dr. John Nash Ott, Filmed and Directed by John Nash Ott, DVD released 2008. Natural Energy Works, http://www.orgonelab.org/cart/xspectrum.htm.

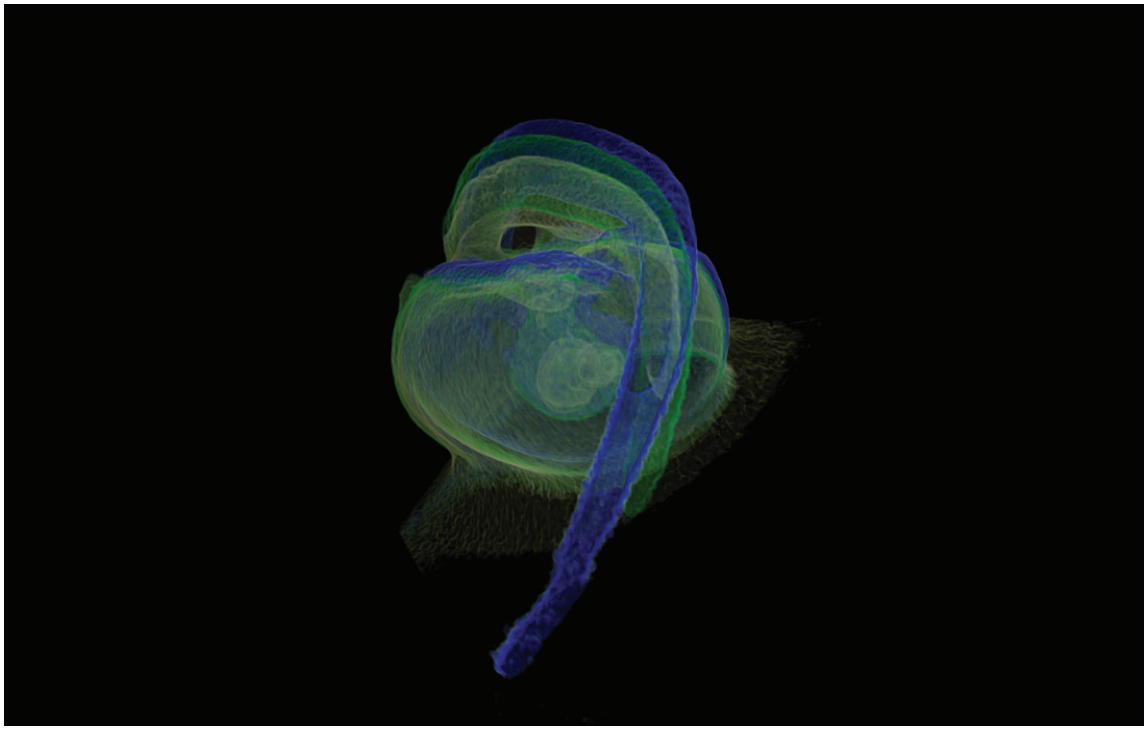


Fig.5:4. An image illustrating the growth and direction of movement through three volumetric datasets of a mung bean, captured over a nine-hour period, (2012-15)

adversely affected by significant bioenergetic changes in our natural living conditions, such as the lack of ultra violet frequencies in artificial light.

More recent high definition developments in the field of time-lapse photography are evident in David Attenborough's BBC nature documentaries such as the *Kingdom of Plants* and *Secret Life of Plants*. These time-lapse sequences are taken over months and years in both natural and controlled environments. Large spans of time are reduced to seconds with time-lapse in order to scientifically rationalise the phenomena of plant movement and behaviour in the context of evolutionary traits. We witness vine stems twisting and winding up toward the light, carnivorous plants snapping up insects, exotic flowers opening and mushroom rings expanding.

Studying these affects, I concluded that in revealing these natural phenomena that can't be perceived in real time, time-lapse will always have that magical, fairytale quality exemplified by the pumpkin turning into the coach. Mediated through documentaries, popular culture and social media, time-lapse footage informs our visual knowledge of what timescales – from the planetary to the microscopic – look like when they are accelerated; mold forming, plants growing, flowers blooming, fruit decomposing, cloud and fog formations, tidal flows, ice melts, celestial motions, seasonal changes and humans going about their daily business in cities, construction and demolition sites or traffic.

I was concerned there might be a loss of this 'magic' because I am not using conventional time-lapse photography. In my timelapse sequences of germinating seeds using micro-

Fig.5:5. An image illustrating the six steps in the incremental growth of a mung bean germination over a nine-hour capture of a mung bean, (2012-15).

CT, my challenge was to create a smooth motion between each of the incremental data-sets to enhance the illusion of fluid growth. In conventional time-lapse the fluidity would be created by the number of frames per second. In my work there is a sequence of volumetric volumes collected over the duration of the germination process. Because each volume is captured across evenly timed intervals (half an hour apart), this resulted in 'empty spaces' of lost time occuring between each sequential volume.

To fill in these empty spaces I realised I would have to create an illusion of the incremental effect of growth, as if one data set is morphing into the next. To do this my collaborator Dr Limaye adapted *Drishti* so I could interpolate each volume, or stagger two identical sets of volumes from one frame to the other. Interpolating the data gives the animation an appearance of gradual morphing as one step merges into the next. However, rather than creating a smooth transition of growth the interpolation of volumes tends to give the timelapse a slight pulsing effect in areas where the data changes in density or has to leap from one movement to the next. The pulsing makes the seeds look as if they are pushing into life, and I realised that this characteristic is a visual key that the virtual data is the result of algorithms rather than of photographic evidence.

My first time-lapse animation lasted for 1.24 minutes and shows a mung bean and a radish seed beginning to germinate. This animation resulted from data acquired over a nine-hour period in which the seeds grew two centimetre roots, but no leaf shoots. The third seed in this experiment remains dormant. Interpolating these volumes reveals

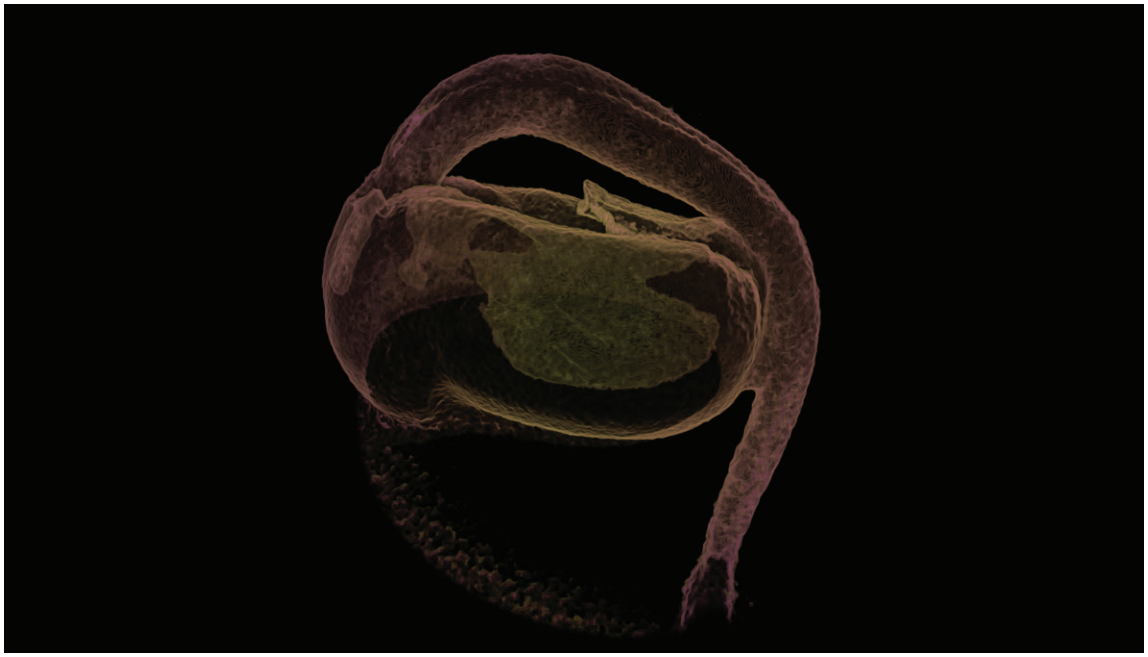


Fig.5:6. A detail from a time-laspe animation showing a nine-hour capture of a mung bean germinating, (2012-15), duration, 1.24 minutes.

that in the beginning there is a quick burst where the water is drawing up and into the beans from the gelatine base they are sitting on. The seeds appear to suddenly expand and contract while forming a fuzzy exterior. It was difficult to render the first three data sets, and two had to be omitted because of their extreme difference in material density. Losing these steps results in a large leap in the growth rate of the root in the first stages, but I found that this did not detract from the overall process. Instead the sequence is compelling as it captures a fluid sense of time-lapse motion and as the roots grow they look as though they are searching for a place to put down anchor and grow.

In this first experiment I chose a colour that would help me differentiate the different material densities in the data. In the first animation I used a tone of green to hint at the original organic source, but also to allude to the seed's unnatural digital state. I rendered the flesh of the seeds transparent in order to view the interior growth simultaneously. Crucially, this allows the viewer to see the mysterious bubbles appear and the root-base expand inside the larger mung bean, while the root extends outward over the *testa*. As a further experiment, I made a second animation in which I single out the larger mungbean by eliminating most of the gelatine base and the neighbouring beans. I tested pink, yellow and red tones to create a more flesh-coloured surface, but also to highlight the interior shape of the expanding bubble. [See Fig. 5.6] Using this render I made an animation moving the position of the eye to follow the seed from various angles, rather than from one static view point. I then made a variation of this animation by trying to eliminate all of the gelatine, which creates an empty region at the base of the bean so that the seed floats in space.

At first I was incredibly frustrated by this data because it seemed incomplete in not reaching leaf stage. However, the more I observed the delicate forms and the unpredicted elements, such as bubbles and the way the roots interact with the gelatin, I began to realise the potential of the data to create a deep sense of wonder. Had I simply wanted a conventional, if not fairy tale, Cinderella-ish view, of a seed germinating to leaf within a computational framework, then it would have been far easier to generate mesh-framed time-lapse animations through CGI or to have used high resolution cinematography. Instead, my process of investigation revealed that capturing dynamism with 4D micro-CT is not just about seeing linear movement over time, but rather it is the discovery of a whole range of interactions and effects that no one has ever seen before as art or in science.

My work with 4D micro-CT departs from the cinematic time-lapses of Ott and Attenborough because I have the ability to move the eye position inside and outside the seed and to change the opacity and transparency of the data. In the movement around and through the surface – as if the viewer is turning the virtual object to explore it as one might turn a Blaschka glass sculpture – the viewer is drawn into the interior of the seed while time is in motion. As an experience of wonder and discovery, this allows for a more engaged or embodied optical experience of the data, that further lends itself to the notion of multi-dimensionality and participation I was hoping to achieve in the final work of art.

Relocating the real[101]

Considering the agency of wonder and the experience of time in my 4D germinating beans made me think further about my intention to display this work within a stereoscopic projection installation. I wanted to test the potential by creating a self-reflective space to experience *Grow*. This would be in an installation format that would explore the phenomenological methodologies which I considered in the work of Ólafur Elíasson. I also wanted to investigate the premise put forward by Lesley Duxbury, that my immersive installation could create new opportunities for individuals to make meaningful connections with nature. By using stereoscopic technology I hoped to enhance the affect of wonder by engaging sensory properties, but also to locate the individual as an active participant within the installation space, rather than as passive observer of the work as displayed on a 2D screen.

Crary's *Techniques of the Observer* has been helpful as a way to consider how the location of an observer within this stereoscopic installation can be interpreted. Crary begins by discussing how in the late 20th century the established cultural relationship and meanings

[101] I established many of the ideas in the following two sections through a peer reviewed paper "Relocating the real: experiencing nature in the fifth dimension," published for the AAANZ 'Inter-discipline' conference proceedings, December, 2014.

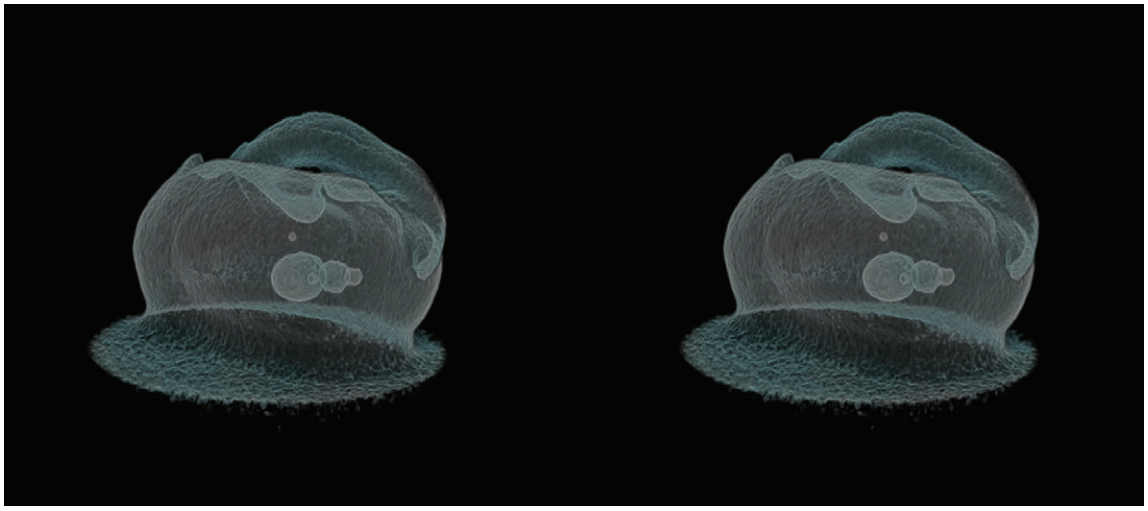


Fig. 5:7. Illustrating the concept of splitting a single image into two, left and right, for stereoscopy, (2015)

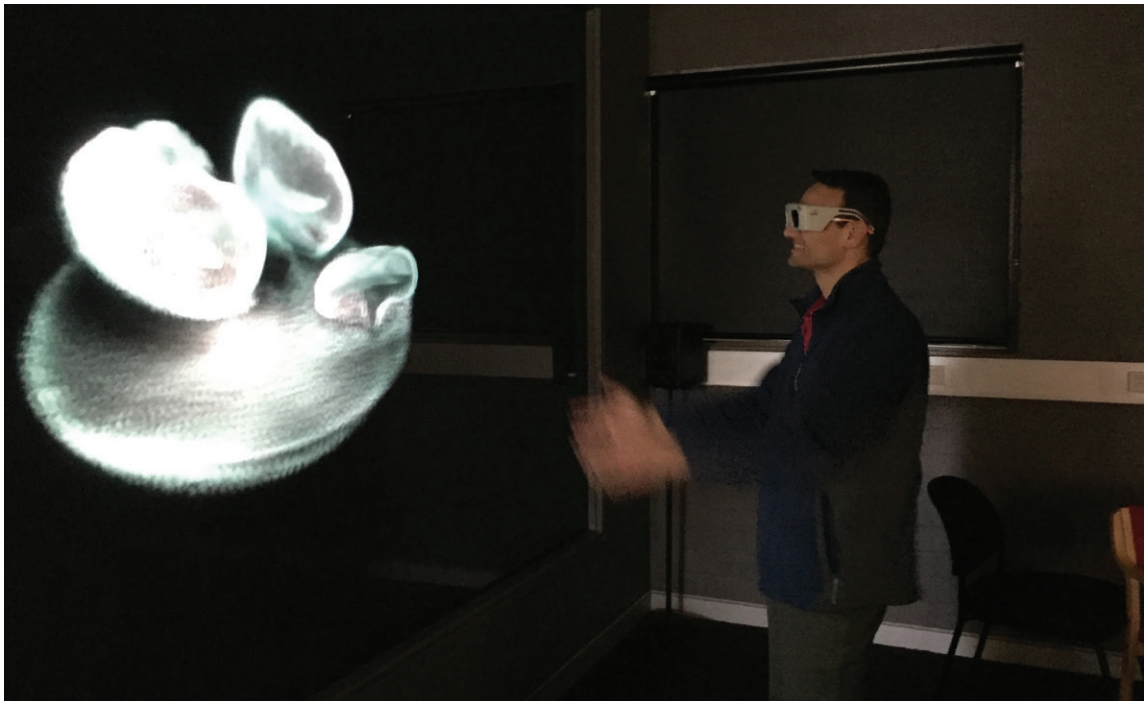
Fig. 5:8. (Right) Ajay Limaye experiencing my germinating seeds in 3D at Vizlab. The optical illusion of stereoscopy cannot be documented in a photograph. Here Limaye is demonstrating with his hands, where the image appears to be in relation to his body, (2016).

between *observer* and *representation* were irrevocably changed by the burgeoning industries of computer graphics and information technologies. As Crary writes, this is because emergent scientific technologies and computational visualisation, 'are relocating vision to a plane severed from a human observer.' [102] Perhaps similar to the image in Marey's chronophotographs, in the way the physical body disappeared behind a pattern of lines, the human eye is no longer located in the real space of an optically perceived world. Crary predicts that the future of visuality would exist mainly in cybernetic or electromagnetic terrains, with images referring mainly to 'millions of bits of mathematical or electronic data.'[103] Here I find myself in the second decade in the 21st century exploring the very visuality that Crary predicted in the early 1990s.

I wondered if a physical severance or distance from the subject through the use of virtual data would seem to negate any 'real' or meaningful experience of nature. The success of Ólafur Elíasson to stimulate sensations of being in the world is due to his ability to combine phenomenological methodologies with simulated natural elements in his installations, He often talks about the relocation of nature in his work, and he does this by using real elements, such as ice, moss or fog, or by employing lights and artificial materials that evoke atmospheric experiences. Examining his work led me to consider that while I wanted my work to connect individuals with a meaningful experience of nature, my use of virtual seeds might only be suggestive of the digital realms of electronic data.

With this question in mind, I found it useful to consider Sue Thomas' *Technobiophilia: nature and cyberspace.* Thomas discusses how encounters with 'real' nature have long

[102] Crary, *Techniques of the Observer,* 1.
[103] *Ibid.*, 2.



proven to be psychologically beneficial but how the experience of nature in a 'virtual' situation can be just as profound as the real thing. Her argument follows the idea that because an increasing number of people are now living in built environments and have less opportunity to interact with nature, experiences that evoke virtual contact with nature are equally affecting. As Thomas writes, 'there is increasing evidence that we respond very similarly to a 'natural' environment, whether it's real or virtual.'[104] In this context my work relocating the real has the potential not only to connect a viewer with nature, but also to allude to the disjuncture between the physical experiences of living in a natural world and to our becoming more dependent on technology and science to mediate our experience and knowledge.

I wanted to test these potential outcomes with immersive stereoscopic projections, to create a new kind of interaction with nature that would enable me to relocate the body within the 'virtual' experience of nature. *Drishti* provides an option to create animations for stereoscopic viewing and to give an optical illusion of three-dimensional depth. Through this depth perception the details in volumetric data are more easily differentiated because the information is no longer organised along the two-dimensional picture plane. At Vizlab I have access to a large rear-projected glass screen 2 metres in length by 1.5 metres high. This allows me to view my work as single projections or with active stereoscopic glasses and quickly test how the rendered data looks when in stereoscopic mode, and outside the frame of the computer monitor.

Contemporary immersive visual platforms, such as Oculus Rift or Google Cardboard, enable the viewer to navigate 3D data via head and eye movement. However, creating

[104] Sue Thomas, "Can we get all the nature we need from the digital world?" *Aeon Magazine*, 2013,

Fig. 5:9. Examples of late 19th stereoscopic photographs from the collection on display at the Museum of the History of Science, Oxford, UK. I visited the museum in June 2012 to view both the stereoscopic images and the collection of antique microscopes in relation to this enquiry.

data for these platforms has not been a focus of my research as the volumetric data still cannot be rendered fast enough in real time. These options will be available to me in the near future, but for the purpose of this research, I have directed my investigation to extend the stereoscopic experience of germinating seeds within the gallery space and by researching the commercially available stereoscopic projectors and screens.

The word stereoscopic derives from the ancient Greek *stereos* which means solid, and *skopeō*, meaning to look or see. The brain perceives a stereoscopic illusion when dual 2D images providing slightly different perspectives of the same object are placed side by side. These two perspectives are offset according to the positions of the left and right eye, and the dual images are perceived to be a single image. This process works to activate the brain's perception of depth through binocular vision. In Vizlab the projector slightly offsets the split screens, playing them simultaneously. The electronic glasses switch between the left and right eye to create the single image, so when I test my germinating seeds in stereo, my rendered datasets appear to float in front of the screen. The illusion is convincing enough to make me feel as though I might be able to hold the projection in my hands. [See Fig. 5:8]

An investigation of the basis of stereoscopic vision was crucial to establish an understanding of my contemporary employment of this technique. It was also useful in drawing out parallel meanings between the virtual nature of my seeds and the immersive optical experience. Writing about the historical significance of stereoscopic

illusions, Crary explains that the ability of the stereoscopic device to produce 'realistic effects' was such a radical reconstruction of optical experiences in the late nineteenth century, it demanded, '…a reconstruction of what 'realism' means.'[105] This is because it is, 'a radical repositioning of the observer's relation to visual representation.'[106] As Crary describes, no matter how mundane the images were, once viewed through a stereoscope the illusory effect rendered them, 'seductive visions of the 'real.'[107] [See Fig. 5:9]

Also relevant to my investigations was the fact that the arrival of stereoscopic images challenged conventional understandings of an individual's point of view, as understood between the classical observer and the object. Crary writes that in stereoscopic vision 'the relation of observer to image is no longer to an object quantified in relation to a position in space.'[108] While it relies upon the fixed physical proximity of the observer the illusion created by stereoscopic vision collapses the space between the viewer and the object. Crary describes this effect as a form of 'ocular possession.'[109] I considered this reading of Crary in relation to my use of computational use of microscopy. As discussed in Chapter three, the microscopic lens is a device that fixes the position of the viewer by challenging traditional understandings of perspective by collapsing space between the viewer and the object. Therefore, my use of stereoscopy further extends this microscopic play with a human perspective of scale, proportion, distance and space by positing the body within what Cory Keller described as the 'hallucinatory spectacle.'[110]

The notion of 'ocular possession' as a sensory state is also a point of interest in the context of a phenomenological approach to contemporary installation art. This is particularly in reference to my earlier readings on the literature around the subject by Susan Best and Marianne Krogh Jensen. As discussed in Chapter one, Best interprets Merleau-Ponty's 'notion of the flesh of the world,'[111] as the physical body being grounded in a continuous reflective sensation of experience. Krogh Jensen similarly suggests that physically locating your own body within the imaginative and sensory state can also 'become something highly material.'[112] Perhaps then, this idea of 'ocular possession' through my use of stereoscopy also helps to relocate the disconnected eye and body firmly within the experience of stereoscopic projections of virtual germinating seeds.

This follows the historical intention of stereoscopic devices to create a subjective sensation of 'being there' within the pictorial frame by shutting out external distractions. In earlier forms, this vision would be limited by having to fix the eyes into the position of the

105 Crary, *Techniques of the Observe*r, 9.
106 *Ibid*., 128.
107 *Ibid*., 132.
108 *Ibid*., 128.
109 *Ibid*., 127.
110 Keller, "Sight Unseen: picturing the invisible," 25.
111 Susan Best, "What is Affect?" 219.
112 Krogh Jenson, "Mapping virtual materiality," 302.

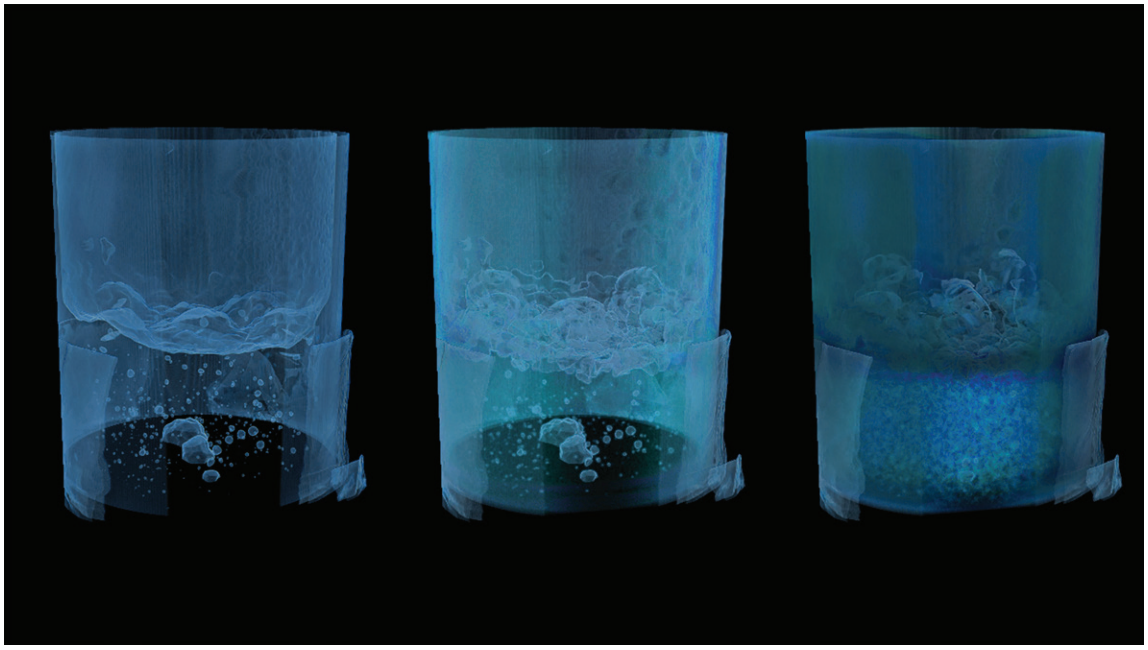
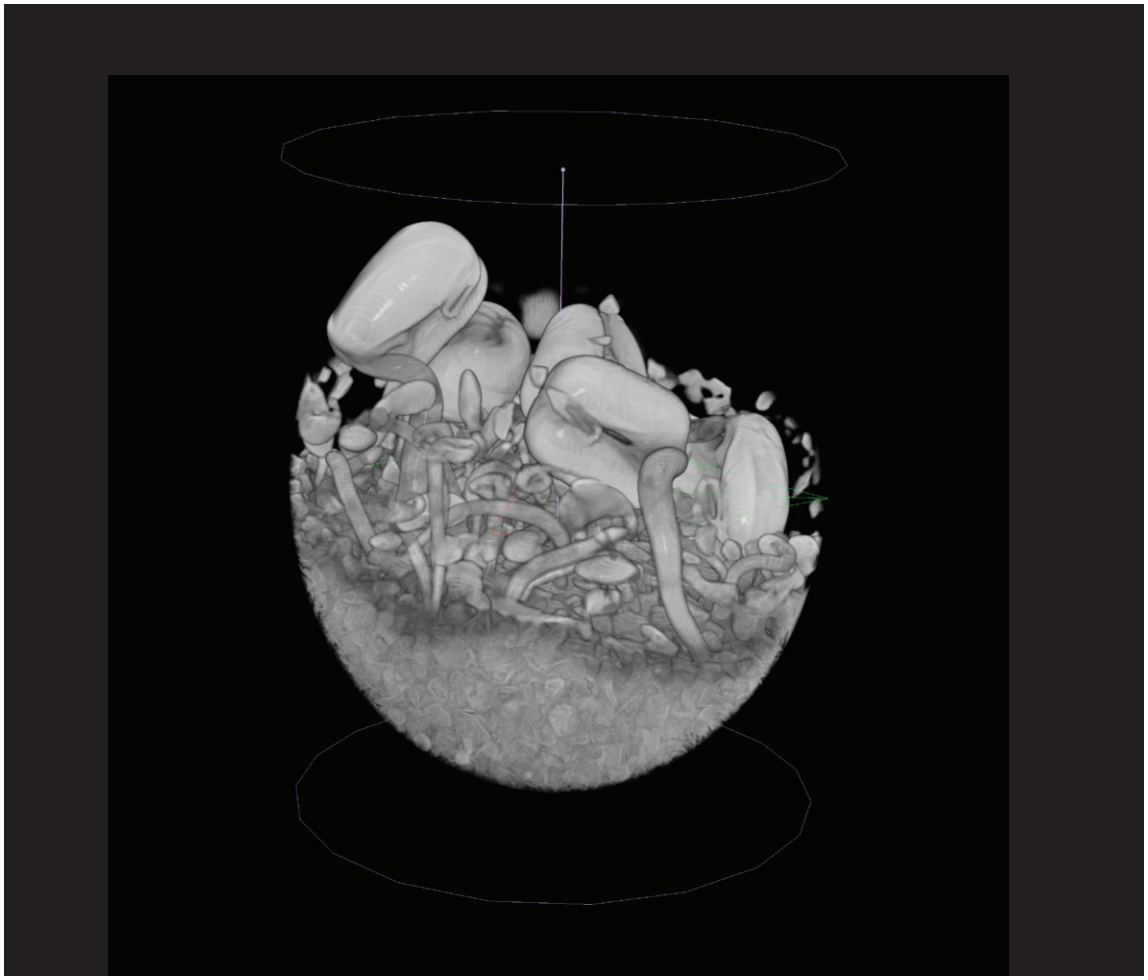


Fig. 5:10. An image demonstrating the difference in material density between volumes as the seeds grow and the water evaporates in the seed bed, (2015-16)

Fig: 5:11.(Below) Illustrating the shape created by the spherical crop tool. In this dataset, the surface of the bed is expanding with the pressure of the sprouting seeds and is creating a variation in density. (2016)



viewfinder. As a contemporary development, even though the optical illusion is only apparent when wearing glasses, the illusion inhabits the same space as the body and the observer is free to move in front of it, from side to side. In experimenting with the stereoscopic projector to create an illusionary spectacle, I discovered that I can recreate the virtual germinating seeds, in a richly visual and sensory form. For me this predicted the potential of stereoscopy to create a self-reflective experience that would add to the multi-dimensional nature of my work. By enhancing the virtual quality of the volumetric data of the germinating seeds, through a simple optical illusion, the individual's experience of being grounded in a moment of self-reflection can create an additional 'fifth dimension'.

Grow: a work in progress

In June 2013 I had the first opportunity to test my ideas for a stereoscopic projection installation when GROW was included in the exhibition, *Synapse: a selection*, at the Powerhouse Museum in Sydney.[113] This opportunity meant I could trial a DepthQ stereoscopic projector which projects a stereoscopic image onto a circular polarized silver screen. A modulator in front of the projector combines the split images so that they can be seen in high definition when viewed with polarized glasses. For this purpose I could purchase paper polarised glasses cheaply in bulk. As I did not have the budget for a customised circular-polarising silver screen I constructed my own. Researching commercial paints which reflect such images stereoscopically, I discovered an affordable paint ('Silver Spoon' made by Dulux) at Bunnings Hardware. When spraypainted evenly onto a flat surface, the particles in the silver paint reflect the 3D illusion. However, having had access to the high definition back-lit screen in Vizlab, I was still concerned that on this makeshift screen the stereoscopic effect would be reduced.

For this exhibition I created a time-lapse animation of virtual seeds germinating by interpolated 40 volumetric datasets that were acquired over a four-day capture of a tightly sown pack of mungbeans and alfalfa seeds. The mungbeans grow promisingly for the majority of this capture but their development stalls before producing a full leaf. Around the mung beans the alfalfa seeds shoot quickly from seed to leaf and, because they are much smaller, the structure of their leaves and shoots is less defined, but the leaves open up in a double spread.

In this sequence of datasets there was a complex variation of material density which interfered with the overall time-lapse sequence. [See Fig. 5:10] I discovered how to overcome this by eliminating a majority of the data using a spherical cropping tool in *Drishti*. [See Fig. 5.11] This created a more evenly distributed visual effect but maintained the full range of seed development. It also created interesting sculptural properties. Beginning

[113] 8 June - 14 July 2013, Synapse: a selection, curated by ANAT, Australian Network for Art and Technology, Powerhouse Museum, Sydney in conjunction with International Symposium of Electronic Arts ISEA, 2013,

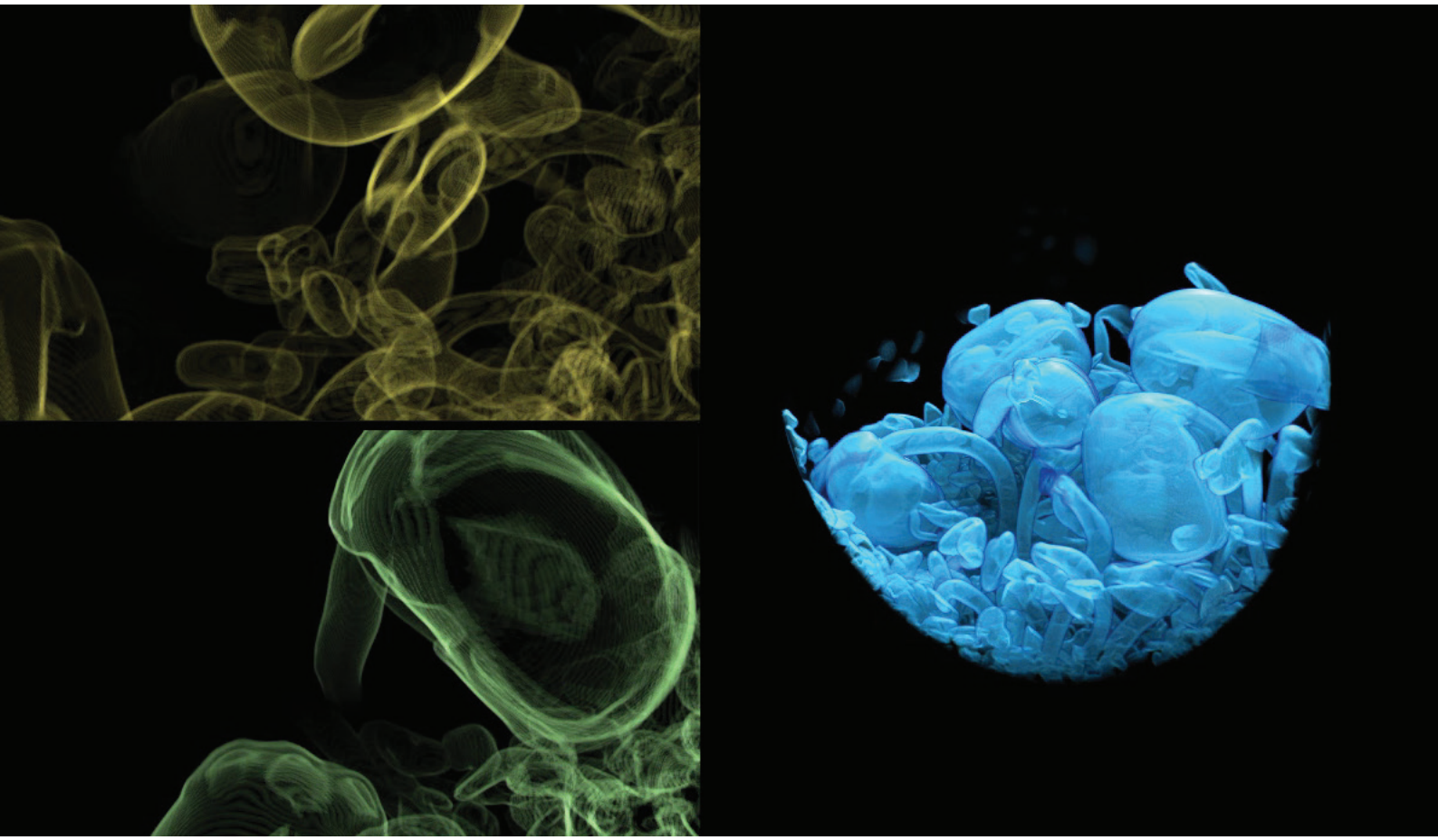


Fig. 5:12. *Grow*, (2013) (detail) stereoscopic projection, exhibited in *Synapse: a selection*, Powerhouse Museum, Sydney. Australian Network for Art and Technology, (ANAT)

as a thin curved disc with the seeds embedded in the surface, the form develops into a spherical shape as the sprouts swell and sprout. By testing various colours and contrasts, including white, I decided to colour the seed ball with a light-blue hue. I wanted to avoid associations with the green of plants, but I chose blue because it alludes to ethereal colours found in nature, such as the sky. A reading of Paul Klee's theory that artists have a right to modify naturalistic colouring in order to release colour from its descriptive role[114] influenced me in this choice. Rather than anchoring the work in reality, the blue seeds could also lend themselves instead to an existing in a space beyond this earthly realm.

I rendered the data as translucent as Blaschka glass, through which incremental stages of growth are seen. To allow the viewer to observe the seed ball from multiple angles I used a 720 degree rotation on a central axis so that the time-lapse transitions can be observed as the sphere rotates slowly clockwise. I then experimented with the speed varing the frames per second to create the right tempo and sense of movment and growth. I didn't want the action of germination to happen too quickly or too slowly, but wanted to maintain the the viewer's interest. The resulting time-lapse animation presents around 9000 frames in just six minutes duration.

[114] Dieter Scholz, Christine Thomson, Eds., The Klee Universe, Staatliche Museen zu Berlin, Hatje Cantz Verlag, Germany, 2008, 207..

The sculptural shape of the rotating blue sphere translated particuarly well within the illusionary space, but it concerned me that I was providing only one single view point. Experimenting with alternative observation points, I placed a cropping tool inside the data to create an internal viewpoint that positions the eye to look from inside the centre of the data, outwards. I found this internal perspective results in interesting but more ambiguous shapes, because at various stages the shapes appear wispy and disconnected and are not immediately recognisable as shoots and seeds. Wanting to test how these different views could be experienced in a single projection, I used a new multiple frame tool that Limaye had implemented in *Drishti.* This feature enables multiple viewpoints simultaneously in the same frame. By dividing the bounding black space into three panels, I positioned the blue seed ball to the right of the frame, and aligned two internal views to the left. To differentiate these internal viewpoints I chose again to reference Klee, using harmonious tones of yellow and green, and a way of hinting at their natural origins. As each panel provides a different view of the same dynamic dataset, it allows the viewer to experience the virtual seeds from multiple perspectives simultaneously. [See Fig. 5:12]

At the Powerhouse Museum I was allocated an enclosed black space measuring 5 x 3 metres. The short projection throw allowed for a screen dimension of 1 x 1.5 metres. Initially I was concerned that the size of the space would not allow people to move freely in front of the screen. However, the benefit was the minimal light interference. In pitch black the stereoscopic illusion successfully floated, almost like a hologram, well forward in front of the screen and the viewer. Projecting *Grow* in this space I noted that the optical illusion of the blue sphere worked extremely well because it was centred within the frame. Where the more ambiguous forms intersected with the edge of the frame, their stereoscopic effect was flatter. This demonstrated to me that to create the most effective illusion, the image would need to remain inside the bounds of the silver screen.

I spent time in the back of the space observing how visitors approached my work. I found that many remained for the full duration of the animation to watch the virtual seeds germinating, or stayed for much longer periods of time to watch the work several times over. Some people preferred to sit transfixed while others played with the optical illusion by moving their body from side to side or sweeping their hands to try and catch the illusionary image. I enjoyed observing people interact with my work, and it is a curious image in itself, to watch groups of people with black glasses on collectively enthralled and looking at the same spectacle.

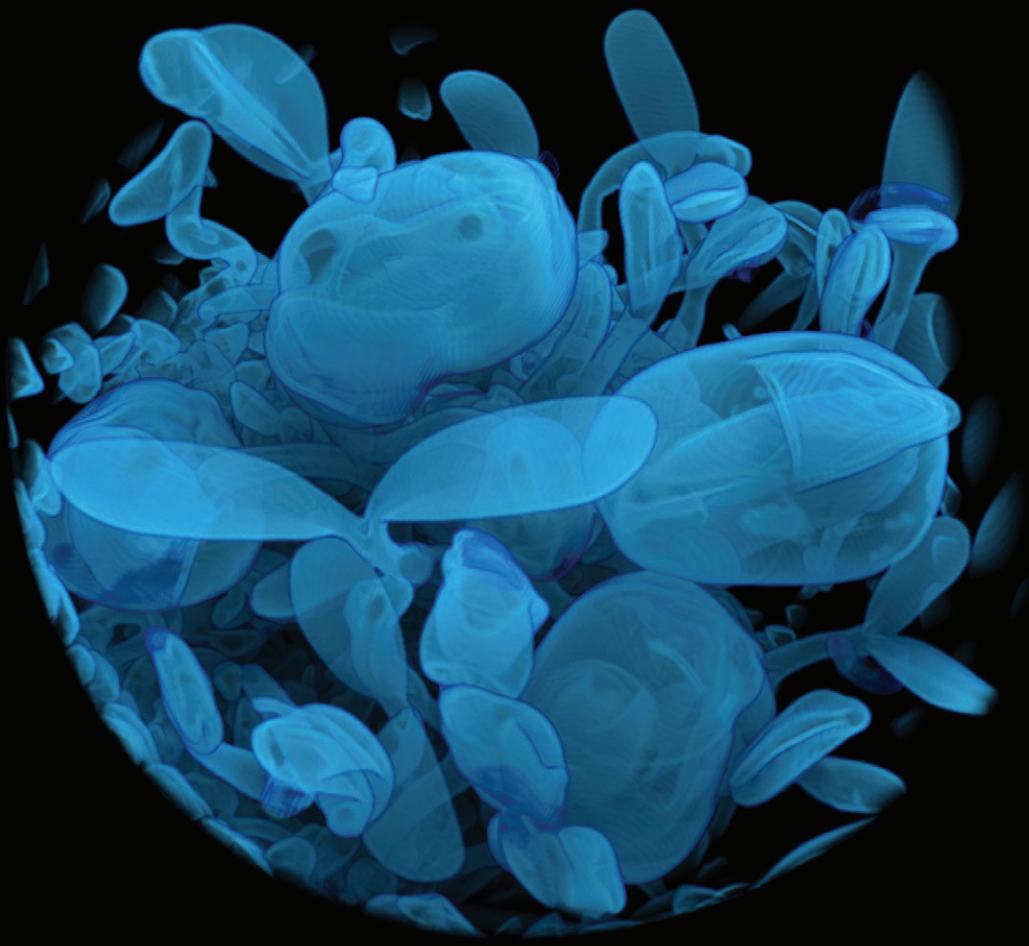
Synapse: a selection, also gave me the opportunity to interview visitors about their experiences of *Grow*. They relayed their experiences to me as being both mesmerising and moving which allowed them to connect the work with the idea of life as being both

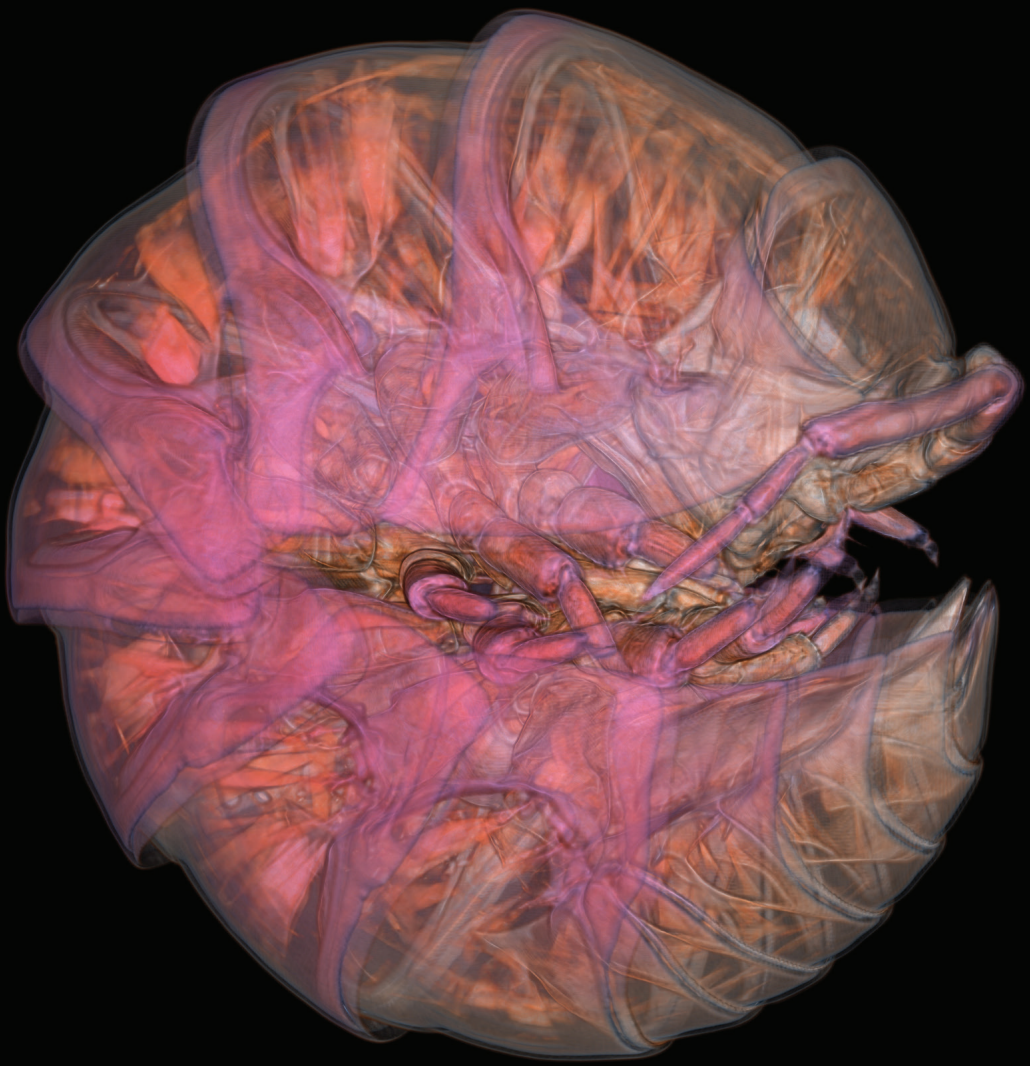
Fig. 5:13. *Grow*, (2013) stereoscopic projection, installation view exhibited in *Synapse: a selection*, Powerhouse Museum, Sydney. Australian Network for Art and Technology, (ANAT)

exquisite and fragile. The stereoscopic affect of the colour, transparency and forms were viewed as highly aesthetic. The projection of the spherical blue seemed to provoke these responses most acutely. There were differing opinions about my use of multiple frames, as most people expressed the opinion that the right frame was more effective in connecting them with ideas of seeds, the mystery of germination and life. Some viewers felt that the left frames were too ambiguous to be of interest, although one visitor viewed the blue sprouting sphere as an allegory for the view of earth from space, and whispy trendrils as the lights of the Aurora Borealis.

Reflecting on these observations of *Grow* – as a work in progress I it found it helpful to make a comparison with images of the audience in Elíasson's *The Weather Project*. In his installation the level of yellow light and mist creates an apocalyptic vision, and the audience, transfixed by their own reflections in the ceiling gather together as if collectively celebrating their witnessing the halt of time. However, in my installation, what I gained from my audience was a different kind of gaze. Because the data materialises in front of them in the dark, and because it can only be seen with the glasses, there appears to be a more individually focused engagement through the experience of curiosity, wonder and hope, as they watch the seeds unfurl and pulse with life and the promise of new beginnings.

Fig. 5:14. (Right) *Grow*, (2013) detail of the blue sphere using the last volume in the four day capture.





Chapter six

Out of season

Notions of relativity

In August 2013 following the exhibition of *Grow* at the Powerhouse Museum, I had an opportunity to use the stereoscopic projector with a new work I entitled *Monster* for *Science Fiction*, an exhibition at Canberra Contemporary Art Space, (CCAS). My installation occupied the main exhibition space which measures 20.4 metres in length by 8.75 metres in width, and with a ceiling height of 4.45 metres from the floor to the beginning of the roof beams. This exhibition allowed me to test the stereoscopic projector for a wider projection distance and larger screen. For this purpose I built a new silver screen 2.98 by 1.68 metres. I wanted to evaluate how this bigger exhibition space would work with a view to exhibiting my final work for examination in the main gallery space at the ANU School of Art. I was uncertain whether the increased scale would deliver the same quality of illusion as the smaller screen did at the Powerhouse.

For *Monster* I created a series of eight stereoscopic movies, which explore the volumetric data of an isopod, a terrestrial crustacean colloquially known as a wood louse, pill bug or slater. The slater, *Armadillium vulgare*, has a segmented exoskeleton that allows it to roll into a tight ball when under threat. These interlocking shell components are similar to the tail of a lobster or the sails of the Sydney Opera House. [See Fig. 6:1] The slater dataset is a single volume originally scanned for a research scientist who was studying how its internal jaw structure evolved by consuming its two front claws. From an artistic point of view I was drawn to the slater by the sculptural shape of the rolled carapace and the architectural muscular structures beneath. Unlike the homogenous starch of my germinating beans, the slater body is a complex structure of muscle and shell which can be defined with great clarity in the transfer functions of *Drishti*.

Fig. 6:1. *Monster* (detail) 2013. Stereoscopic projection, duration 30min, *Science Fiction*, Canberra Contemporary Art Space, 16 August - 28 September 2013, Gorman House, curated by David Broker, funded by the Centenary of Canberra.

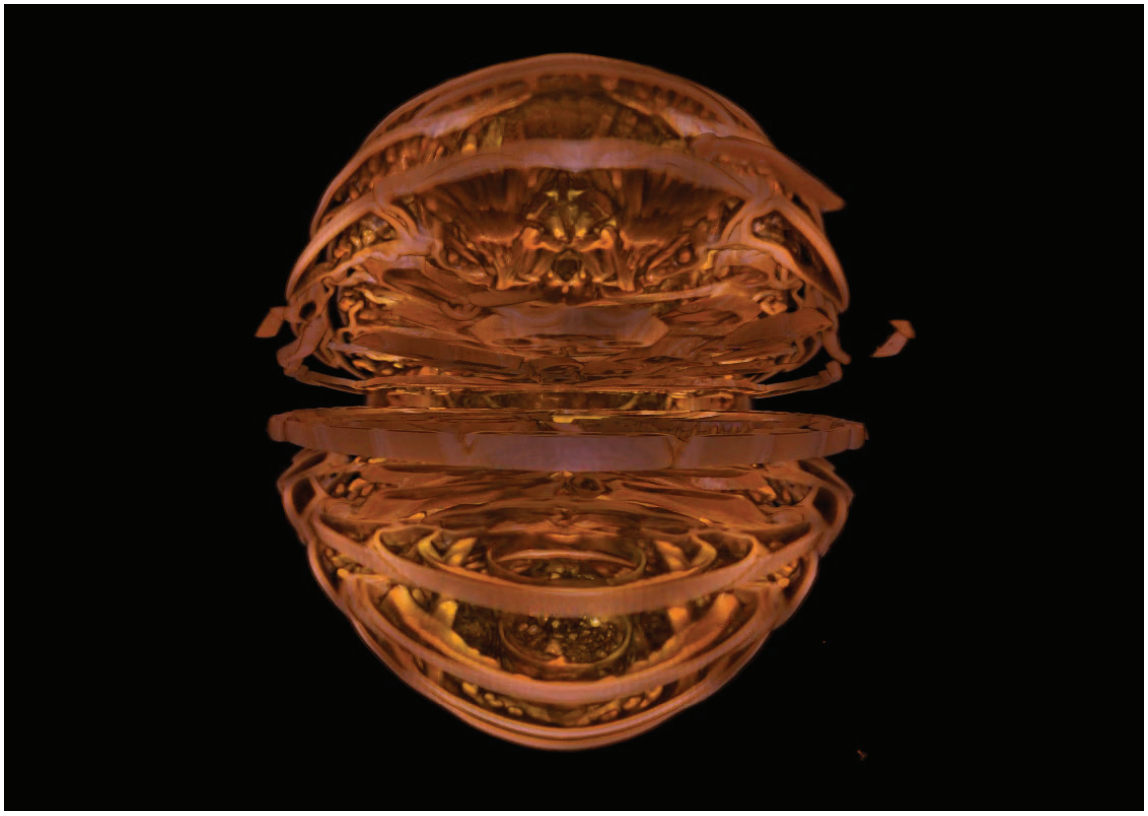


Fig. 6:2. *Monster* (detail) 2013, stereoscopic projection, duration, 30 min.

I used the slater to explore the exhibition theme of science fiction by creating a stereoscopic projection of microscopic phenomena at a monstrous scale. This was a reference to 3D science fiction movies from the 1950s. As the curator David Broker wrote about my work in the exhibition catalogue, I have, 'applied the notion of relativity to suggest that under magnification of the most extreme kind, this benign little creature takes on alien proportions.'[115] To playfully reference the genre of sci-fi comics and movies, and then contemporary scientific imaging, I had the opportunity to feature a still from *Monster* as an anaglyphic image on the cover of *Art Monthly Australia* (issue 232, August 2013). I split the single image into two chromatically opposite colours, one for each eye, so that it could be viewed in 3D when wearing the red/cyan glasses supplied with the magazine.

In creating the projected animations for *Monster*, I was looking for ways to increase the experience of wonder and discovery by leading a viewer to explore visually the familiar slater from new perspectives. In this work I wanted to depart from the more conventional fly through, which would allow the viewer's eye to pass through the exterior surface of the isopod into the underlying spaces as one movement. For this purpose, Dr Limaye and I collaborated to implement new ways of dissecting the virtual slater in *Drishti*. This enabled me to create unique animations that examine multiple perspectives of the slater

[115] David Broker, *Science Fiction*, exhibition catalogue, Canberra Contemporary Art Space, 2013, 2.

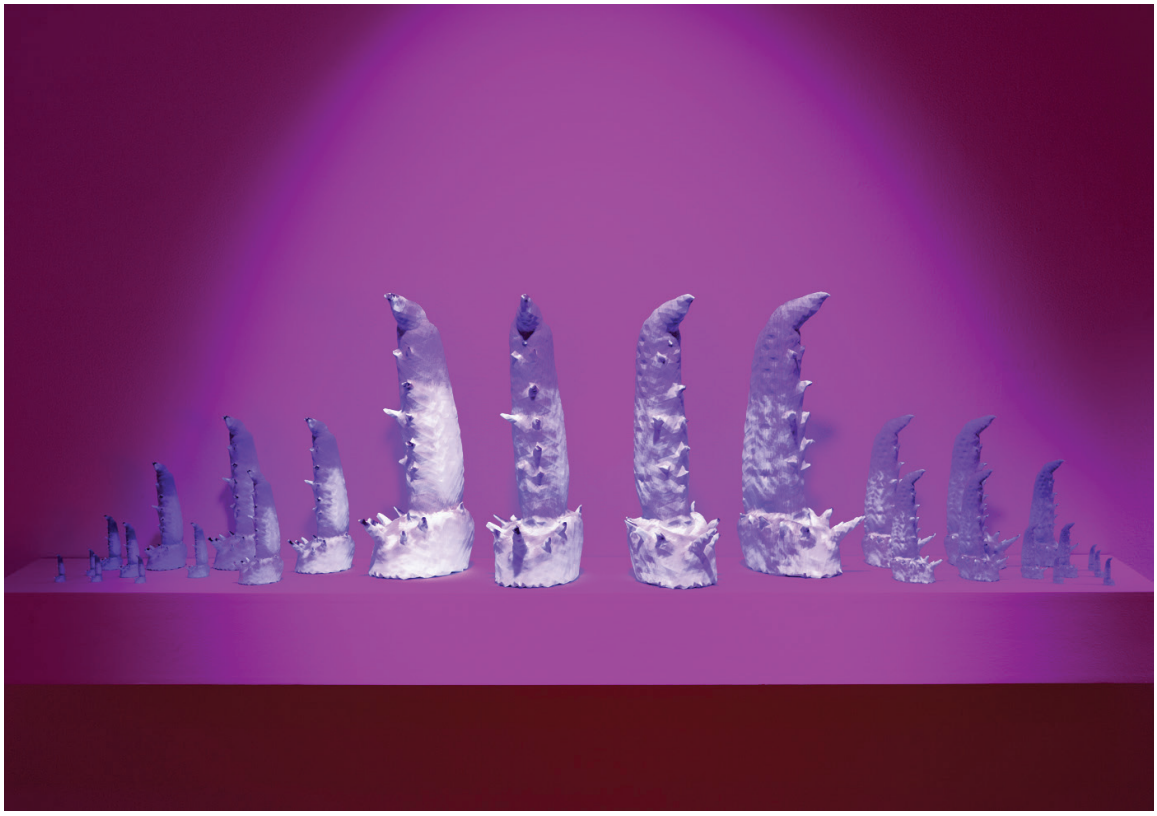


Fig. 6:3. *Modern Prometheus (after Shelley)* (2013), detail, gypsum, ink, resin, max hight 40cm, installation view, Science Fiction, Canberra Contemporary Art Space, photo: Brenton McGeachie

through exploratory dissections, such as halving, opening, stacking, slicing, cropping and merging. [See Fig. 6.2] I sequenced the animations to create a full duration of thirty minutes, setting them on a continuous loop in the gallery space.

For this exhibition I further experimented with 3D printing. I created a number of objects exploring various components of the virtual isopod, such as its legs, internal spaces and carapace. During the printing process I intuitively reasoned that the ink might be fluorescent under a UV light. Testing a range of colours, I discovered that the binder in the inks created a luminescent glow which was increased when I printed the slater parts in purple ink. To enhance this effect in the gallery space I installed six LED UV lights to project onto the objects arranged on five wall-mounted shelves. Under the UV light the printed works emitted a violet glow, reminiscent of blacklight, or light emitting diodes used in scientific experiments to capture information not normally visible to the human eye. I entitled this series of printed objects *Modern Prometheus (after Shelley),* a reference to the mythological story of humans giving life to something dead. [See Fig. 6:2]

Felicitously, the UV lights were dark enough not to interfere with the stereoscopic projection. With the virtual data being projected as a 3D illusion at one end of the gallery, the objects at the other end represented the virtual data re-materialised in different arrangements, forms and scales. For example, I hoped that while observing the very tip of the slater's

Fig. 6:4. *Monster,* 2013, stereoscopic projection, duration, 30 min, exhibition view, opening night, photo, Nat Williams.

claw printed at least 600 times the original scale, [See Fig. 6:2] the viewer would make the imaginative leap that if the whole creature was recreated at that size its body would engulf the entire room.

From this exhibition I established that the stereoscopic projector worked particularly well in a larger space as it a created a more atmospheric experience. The stereoscopic illusion appeared more effective from a wider range of angles. As the space allowed for a larger crowd of people to gather at the same time, the work created an even greater sense of collective wonder. I also noted that the spherical, retracted shape of the slater produced a more convincing illusion when it was centred inside the frame of the screen. This led me to speculate that the spherical form of my blue germinating seeds would be better suited to this new set-up, rather than the abstracted shapes that intersected with the edge of the frame.

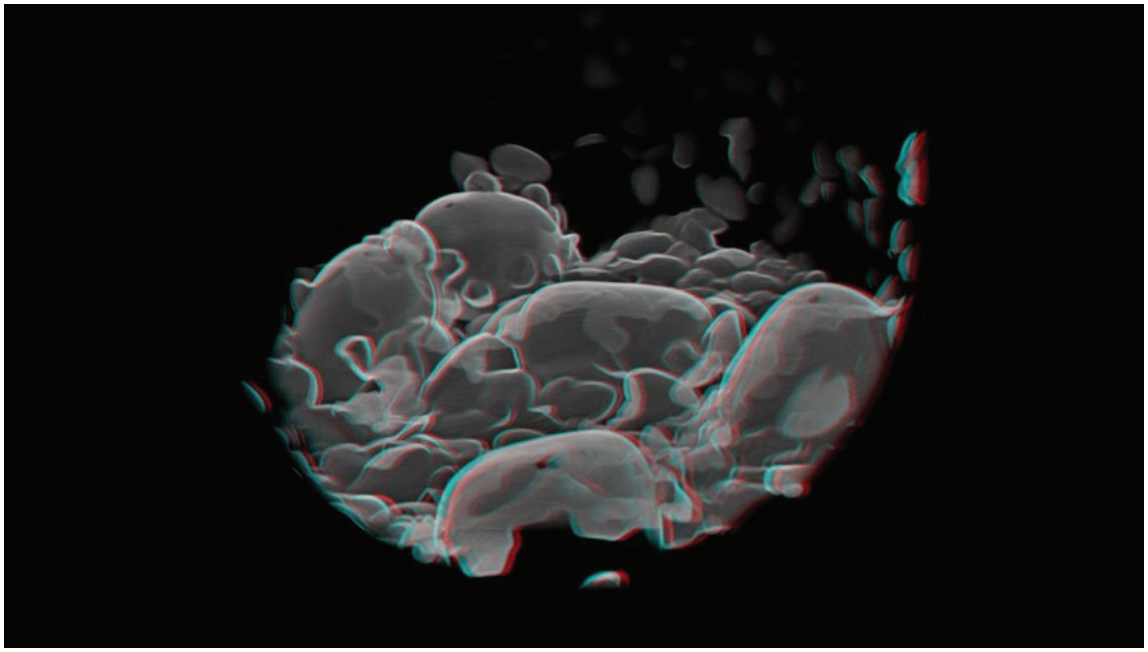
The optical illusion combined with the richness of detail , colour and form was captivating. [See Fig. 6:4] The physicality of the illusionary experience inspired some people to move their arms and body as the projected object slowly moved in front of them. The stereoscopic projection drew people in to watch the entire 30 minute sequence. I had arranged chairs in front of the screen which encouraged some visitors to stay and view the work for one or two more repetitions. [See Fig. 6:5] Reflecting on my observations of the audience watching *Grow* at the Powerhouse, I reasoned that in an expansive, atmospheric space,

Fig. 6:5. *Monster,* (detail) 2013, stereoscopic projection, duration, 30 min, installation view, photo, Brenton McGeachie.

an individual was more likely to remain within the illusionary projection for longer. If so this would increase the possibility of a more profound, subjective experience of the work.

Exhibiting the *Monster* installation for *Science Fiction* helped me to resolve the format for my final stereoscopic projection and I found it useful to compare this work with the visualisation of volumetric germinating seeds. In *Monster* the slater is a single dataset that preserves the virtual material of a static, but a dead organism. In contrast, my germinating seeds bring to life the dynamic emergence of a life form, (even though in reality they died shortly thereafter). While the mung beans and alfalfa do not take us on a journey beyond their first leaves and sprouts, they convey a sense of temporality, of existing and having a relationship with time experienced in the present.

Thinking about the exaggeration of scale I was trying to portray through the projection of *Monster*, I realised that the concept of magnification in *Grow* is not the main focus. Instead, the notion of relativity in this work relates to human time-scales. As explored throughout my research, the consideration of an additional 'fifth dimension'al experience in *Grow* encapsulates the concept of time as a temporal experience. Yet in accelerating the moment when a seed germinates, this work of art asks an audience to consider time-scales beyond our own, such that of plants. Seeds germinate every day, but these seemingly small events do not appear to have any great consequence on our daily lives, unless of course, the life of plants that support our environment becomes impossible to sustain.



Defining the narrative

In the final stages of my candidacy in 2014 I presented my research at several key events that helped me to articulate how I could connect ideas of the Anthropocene to the concept of experiencing nature in the 'fifth dimension'. These presentations, including a Tedx talk, were useful in drawing upon the different threads of knowledge I had researched throughout my candidacy and to define the overall narrative in order to finalise my work.

In June I gave a paper on my research for the Environmental Humanities Conference, *Affective Habitus: new environmental studies in botany, zoology and emotions*.[116] This conference brought together a wide range of academics from the humanities, arts and social sciences to discuss different understandings of our relationship with the physical environment in the context of the Anthropocene. Presenting my research to this audience helped me position my artistic practice within the current scholarship of ecocriticism and gave me the confidence to arrange my ideas in this Exegesis in relation to the Anthropocene to show how it underpins my work. Another benefit I gained from this conference was listening to philosopher Michael Marder read via Skype, his then unpublished paper, 'The sense of seeds, or Seminal Events.' The concepts he outlined enabled me to unite many of the ideas for my new work and its connection with time, inspiring me to title my final work, *Out of Season*. I discuss this in the following sections.

In September 2014, I was invited to present my research at the *Tomography for Scientific Advancement Symposium* (ToScA) at the Natural History Museum in London.[117] This annual conference was launched in 2013 to bring together scientists at the forefront

116 *Environmental Humanities Conference: Affective Habitus: new environmental studies in botany, zoology and emotions*, 20 June 2014.

117 Tomography for Scientific Advancement (ToScA), Natural History Museum, London, 8-10 September 2014,

Fig. 6:7. (Above) Audience with red/cyan glasses on while I talk on stage, Saturday, 11 October 2014, TEDxCanberra 2014 – *Uncharted*, The Playhouse, Canberra Theatre Centre, photo, Tim Brown.

Fig. 6:8. (Left) *Grow*, (detail), anaglyph version, duration, 1 min.

of tomography techniques such as 3D materials imaging and hardware and software development. This was a unique opportunity to present my new work to an audience whose expertise is in the advancement of tomography and its uses. For this occasion I further developed a new time-lapse by reworking the blue sphere of seeds as a single animation. Even though it was not projected stereoscopically, testing this work on a scientific audience proved that the affect and meanings that underpin it can have an emotional impact. The anecdotal feedback I received helped me establish that even though I was not trying to make any scientific claims, my research topic was considered highly relevant and useful in the context of current environmental research aims.

In October 2014, I presented my practice as a talk at the Canberra TEDx event *Unchartered*.[118] This theme required participants to tell their story relating it to the theme of exploring new frontiers. For this purpose I proposed to talk about my use of 4D micro-CT as a visual artist, and how I was exploring the unmapped territory of the 'fifth dimension'. Having only seven minutes to articulate my ideas, I distilled the premise of my practice in relation to the 'fifth dimension' in simple statements so as to appeal to and entertain a wider audience.

I began by explaining the science of 3D and 4D micro-CT and how I came to germinate seeds as an artistic practice. To illustrate how my work connects to the concept of the Anthropocene, I showed a new animation using the dataset in which the seeds died in the early stages of the experiment. [See Fig. 3:4 p.44] This animation allowed me to connect the deaths of the seeds in the laboratory and demonstrate how in this process of experimentation, I was testing the threshold of life. I briefly explained the statistics of the sixth mass extinction on earth. I then showed an anaglyphic time-lapse I had made of the spherical seed shape. [See Fig. 6:8] This specific work is white because the blue would not appear in the anaglyphic version. I also had to speed this animation to one-minute

[118] Saturday, 11 October 2014, TEDxCanberra 2014 – Uncharted, The Playhouse, Canberra Theatre Centre.

duration. It required the audience of 500 to wear red/cyan glasses so that they could experience the animation in 3D. [See Fig. 6:7] In my conclusion I explained my intention was for an audience to subjectively experience this work thereby creating an additional 'fifth dimension', in order to make meaningful connections with nature. Further, I made that point that in a self reflective space to observe an ordinary event like a germinating mung bean, something that we don't normally watch in our daily lives, this work of art can provide an opportunity to contemplate our time on Earth as a way to remember that all life is momentary.

A growing sense of seeds

For this research candidacy I have read environmental literature which describes how human beings depend on nature for survival, yet our impact on our natural environments has magnified. Humankind has altered and reshaped the planet's environment in all its forms. Globally, this mastery of nature is unprecedented and the ideology that drives this enterprise is of European origin. Michael Marder applies European philosophy to contemporary environmental thinking as way of challenging established ideas of ontology in the face of environmental crisis. His book *Plant-Thinking: a philosophy of vegetal life*, (2013) re-examines definitions of thinking through the study of vegetal life and plant behaviour. In relation to humans and other non-human species, plants are considered non-conscious, and non-cognitive entities, rending them at the far end of the teleological scale. Marder's argument is that by learning from the existential features of plant thinking, we can redefine our own existence in the world. I read this book when it was published in 2013, and while I could draw parallel ideas with aspects of my research, I was not convinced that Marder's philosophy could be related to my premise of germinating seeds for 4D micro-CT.

However, at the Environmental Humanities Conference in 2014 I was privileged to listen to Marder read his then unpublished essay, 'The sense of seeds, or seminal events.' This paper advances the event of germination as a metaphoric model for new ways of thinking about how humans can change the historical prejudice of defining ourselves in a hierarchy above plant and animal life.[119] His idea of the germinating seed as an allegory for the human experience and the limits to our existence resonated with the objectives of my research practice. In using germinating seeds to reposition the observer through a relationship to time-scales and new imaginative dimensions, (such as the 'fifth dimension'), I too am attempting to transcend established narratives about humans and nature.

[119] Michael Marder, *Plant-Thinking: a philosophy of vegetal life*, Columbia University Press, 2013

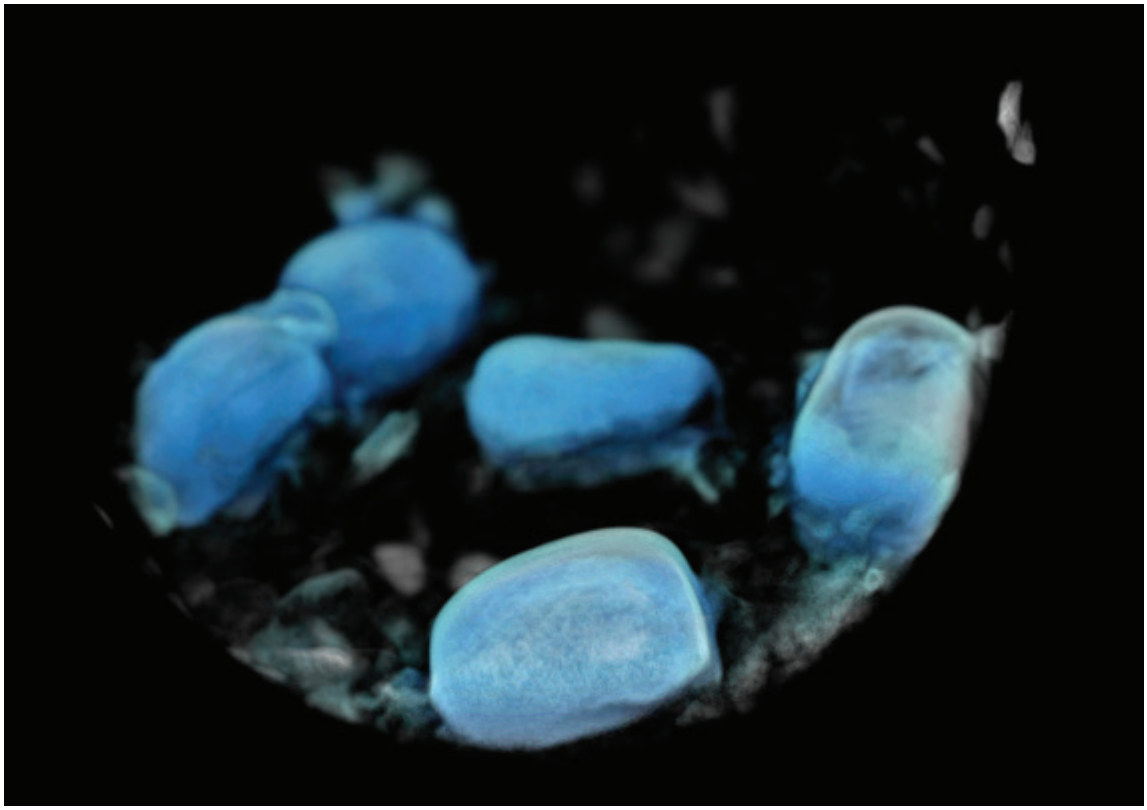


Fig. 6:9. *Out of Season*, 2016, (detail) 6 min stereoscopic projection installation.

I am particularly interested in how Marder examines the event of germination as an out-come, or 'out-coming', and unlike the birth of non-sessile life forms,

> *plants come out and are eventuated differently, because in germinating and growing they do not cut themselves loose from their source; do not die in an instant of transcendence; do not displace themselves in order to face the world; do not reach a destination.*[120]

He argues that these differences carry profound ontological significance, which should, 'prompt us to reconsider the meaning of the event commencing from vegetal processes and out-comes, notably from seeds.'[121] This new consideration can perhaps lead us to better understand the diversity of lived experiences in the world so we can appreciate that there is not just one single entity, such as the human experience, which is applicable .to all other life forms or events. This brought me back to the findings I had made about my own work as pertaining to the human experience of time-scales in relation to a plant.

In December 2014, I further explored this idea of the human experience in relation to plants by making new work entitled, *Virtual Life*. I chose an image from the blue sphere in *Grow*, that shows the seeds in a developed stage. [See Fig. 6:10] I then printed this

[120] Michael Marder, "The sense of seeds, or Seminal Events," Environmental Philosophy, Vol. 12, Issue 1, Spring 2015, 88.

[121] *Ibid*., 88..

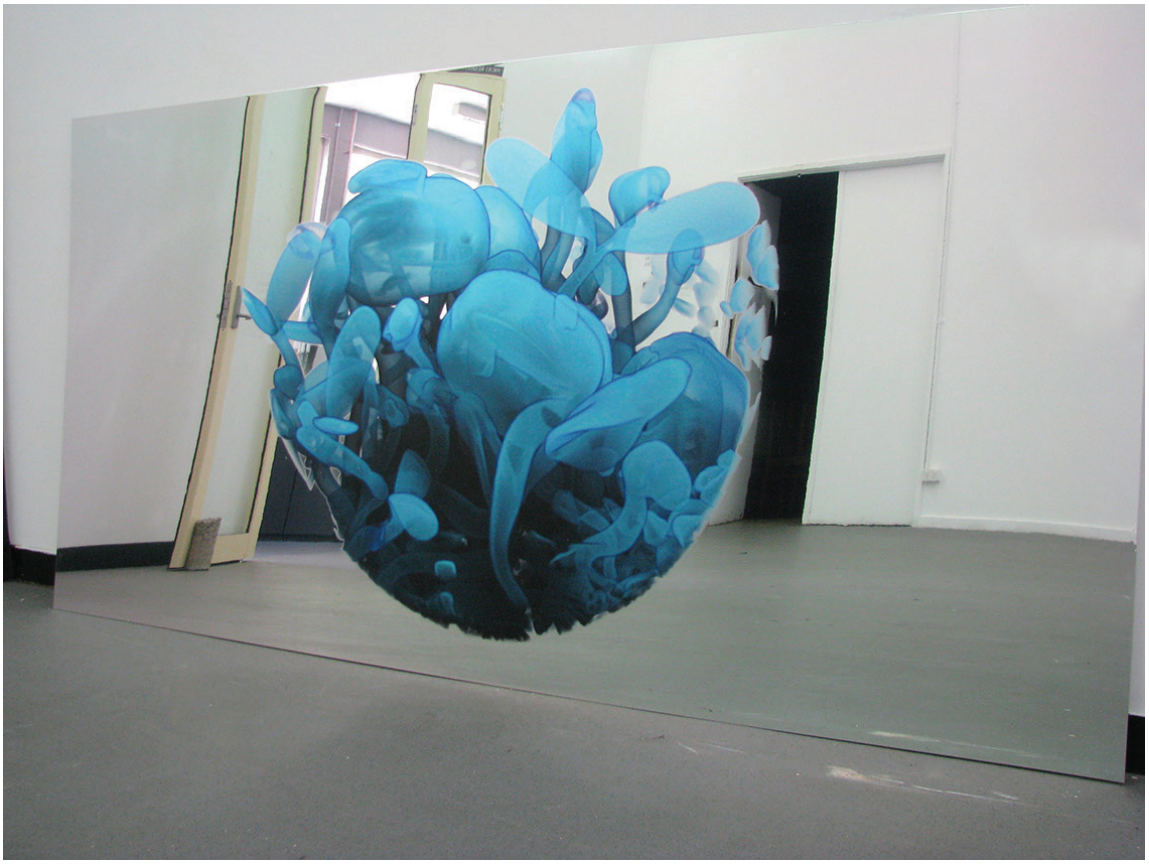


Fig. 6:10. *Virtual Life*, 2014, Solvent print on aluminium composite board, 1220 mm x 2400 mm, 2014. Printed at the School of Art, Inkjet Research Facility, ANU College of Arts & Social Sciences

work onto a highly mirrored surface so as to best represent the beautiful translucency of X-ray in combination with the three-dimensional qualities of virtual data. Although this is a two-dimensional representation of my work, the reflective material creates an optical experience to make it look as if the image is floating in space like a hologram. *Virtual Life* was selected for exhibition in January 2015 for the inaugural *Paramour Prize: art and innovation*, at the Casula Powerhouse Art Centre, Liverpool, NSW.[122] In the exhibition space the virtual seeds proved to cast their own shadow, as if hinting at the possibility of their physical existence. Not only does the work reflect the surrounding environment, observers could catch their own reflections in the image in a moment of self-reflection. I could see how the mirrored reflection of ourselves, in and through the germinating seeds, could be interpreted as the kind of critical self-examination through the study of plants that Marder is referring to.

In the context of examing ourselves more critically, Marder observes how philosophy has used the idea of the outward growth of plants as an allegory for human enlightenment. The meaning of the word *grow* can be understood as relating to how we might perceive an individual's inner development. By extending oneself (like a plant) in different directions through spiritual, mental, physical betterment, or finitude, exemplifies the notion of a

[122] *Paramour Prize: art and innovation*, Casula Powerhouse Art Centre, Liverpool, NSW, 31 Janruary - 1 February 2015.

fully embodied adult. In this sense he describes the physicality of a seed as it germinates, shooting upward towards the light, and rooting downwards into the soil, orienting its form within a 'lived space'. Not wanting to confine or reduce this idea to process, Marder writes, 'it develops *in and as the middle*, in the absence of a clearly demarcated origin, a traumatic break, or separation from its other.' [123] Marder likens this to our own existence, for, 'although the umbilical cord is cut, we are rooted in the other as much as in ourselves,'[124] meaning of course that humans share the same biosphere as all living creatures on Earth.

As I thought about this I recognised there are useful connections to make with both my title of my research *Grow,* and the way my virtual seeds perpetually germinate within the digital environment. In my work there is no sense of gravitational force. Because my germinating seeds can be observed from any angle they are detached from Earthly elements such as soil, sun, rain. As virtual nature they exist only in the present, continuously germinating and extending outward; they never fulfil their destiny. In the earlier stages of my practice I saw the germinating seeds as pertaining to operative narratives of life and death, that even in the struggle to come into life there is the possibility of new beginnings – just as the dormant seeds stored at the Millennium Seed Bank embody promised futures. However my reading of Marder in relation to my research has deepened my interpretation of the virtual event. Just as Ólafur Elíasson's *The Weather Project* prolongs the sun setting on an uncertain future, my virtual germinating seeds are trapped in time through perpetually lived moments. They exist in a state of suspended animation and never quite reach their full potential.

Marder warns of the dangers of perpetual growth without reason, likening it to the inward growth of a toenail. By not reaching a state of full potential, inward growth becomes a site of pathology and an analogy for a millennium of human psychic behaviour in the west,

> *Figuratively speaking, instead of living, one festers, and the sad results of this planet-wide trans-generational collective festering, which now goes under the name "the Anthropocene," are observable in the environmental crisis that has gripped our world.*[125]

Out of season

In developing my final work for exhibition, I wanted to find in this Exegesis to express ideas about cyclical or seasonal time. Early on in my research I sometimes found I was not sure how to position it meaningfully within the narrative of my ideas. In the previous chapter I discussed how, in the 21st century, there is a sense that time has accelerated from

123 Marder, "The sense of seeds," 89.

124 *Ibid*., 90.

125 *Ibid*.

the demands and pressures of industrialisation. Perhaps too there is a feeling of running out of time as we contemplate the Anthropocene. I wanted to explore this idea by thinking about the natural cycles of the seasons in the context of the germinating seeds but I had struggled to clearly articulate what significance it had. However, as my inquiry began to draw to a conclusion my discovery of Marder's 'The sense of seeds, or seminal events' prompted me to reconsider ideas of seeds, temporality and the seasons, in relation to the actual event of germination and my research questions about environmental crisis. I also returned to reassess Paul Klee's *Pflanzenwachstum* (Growth of plants), 1921. This painting has proven important in how I have come to understand my own work as a reflection of the present.

Pflanzenwachstum formalises a representation of cyclical time and is characteristic of Klee's preoccupation with the processes of change and metamorphosis, growth, movement and the seasons. In Dennis J. Schmidt's essay 'Klee's Gardens,' he discusses the significance of gardens in Klee's oeuvre in relation to subjective experience. Gardens cultivated by human hands were for Klee representative of the human connection to creation, both in the life-giving sense, and in the act of creating art. He viewed the garden as neither nature nor art, but an intersection between human intention and natural life.[126] Schmidt argues that in Klee's work the garden provides an image of growth that opens up possibilities for understanding the human place in the world. I found this reading meaningful because it reminded me of my first attempts to grow seeds in the laboratory. In the physical act of sowing these seeds, planting each one by hand, I wasn't growing a garden in the traditional sense, but I was trying to cultivate new meanings and connections between art and life.

Schmidt explains that Klee's pleasure in gardening reflected his belief in *genesis*, and that creation is a secret that exceeds all understanding.[127] In the garden, renewal and rebirth is experienced through the changing of the seasons. The English word for season derives from the Latin verb *serere*, to sow. The metamorphosis of seed to plant is also the moment of the mystery of life, when one form becomes another, or comes into being, or into fruition. The seasonal process of transformation from seed to plant, to seed again, symbolises the cycles of birth, death and rebirth.

When studying *Pflanzenwachstum* at the beginning of my candidacy, I was searching for influences of chronophotography and the the study of time and movement on modernist practice. However, in revisiting this painting at the end of my research in consideration of Marder, I realised that while Klee was exploring a modernist vision of time and space, his study of the growth of plants expressed his belief in an everlasting pattern of growth and renewal. This is because *Pflanzenwachstum* was created in an era predating the

126 Dennis J. Schmidt, "Klee's Gardens," *Research in Phenomenlology* 43, 2013.

127 *Ibid*., 403.

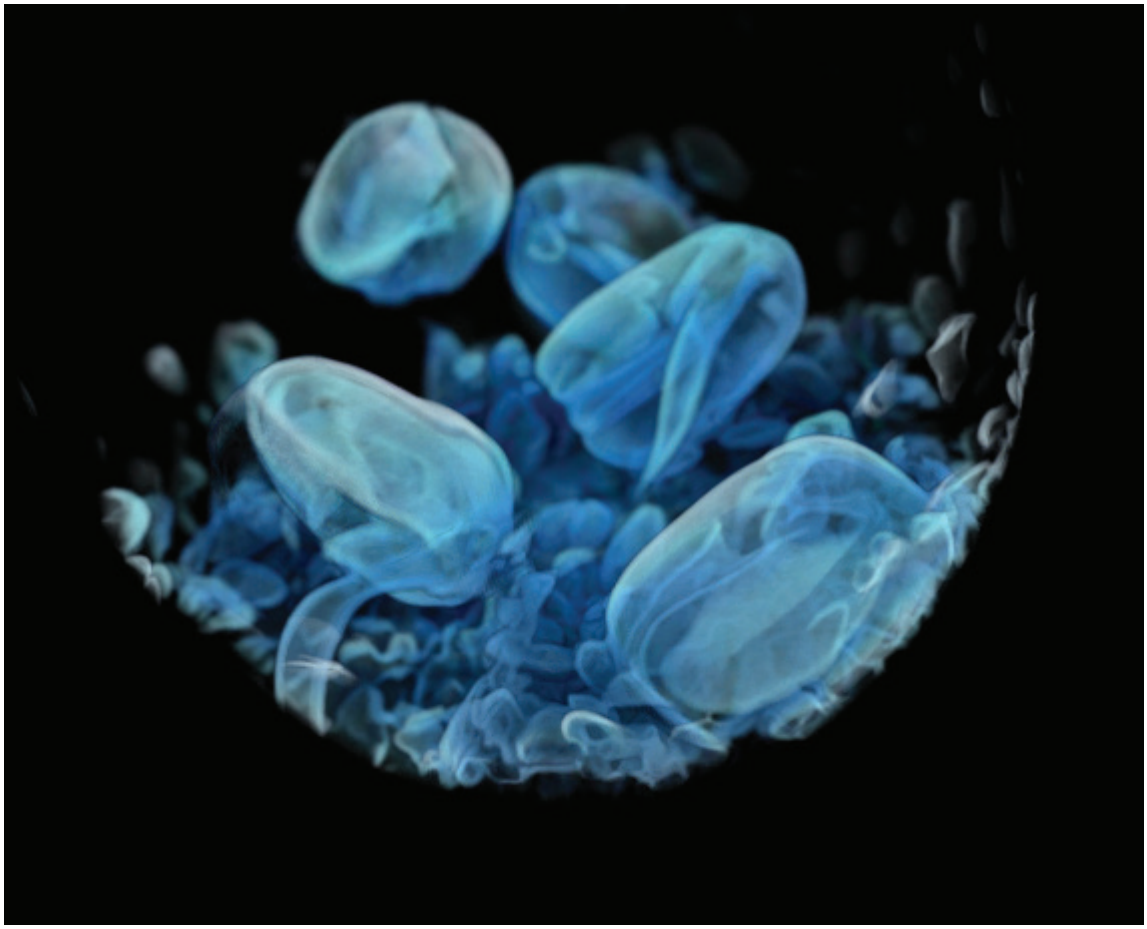


Fig. 6:11. *Out of Season*, 2016, (detail) 6 min stereoscopic projection installation.

environmental crisis we are experiencing in the 21st century. For Marder, 'living at the rhythm of the seasons means respecting the time of plants, expecting their events, and, along with them, successively opening oneself to various elements.'[128]As the Moon and Sun rhythmically rise and set, the changing seasons also mark the passage of time: a time for tilling, a time for planting, a time for harvesting. The significance of this certainty of life's renewal as continuous is referenced in ancient texts and biblical scripture. As is written in Ecclesiastes, 'To every thing there is a season, and a time to every purpose under the heaven: A time to be born, and a time to die; a time to plant, and a time to pluck up [up root] that which is planted.'[129]

Analysing this perception of time in his essay, 'The climate of history: four theses,' Dipesh Chakrabarty discusses how the human relationship to nature has changed in the face of climate change. He contends that as our belief in nature's endless cyclic relationship with humanity is founded on ancient history in European thought we tend to assume that the history of the human relationship to the environment is so slow as to be almost

[128] Marder, "The sense of seeds," 90.

[129] *The Holy Bible*, The King James Version, Old Testament, "Ecclesiastes," (*Eccl. 3, Verse 1)* Hendrickson Publishers Edition, 2011, 325.

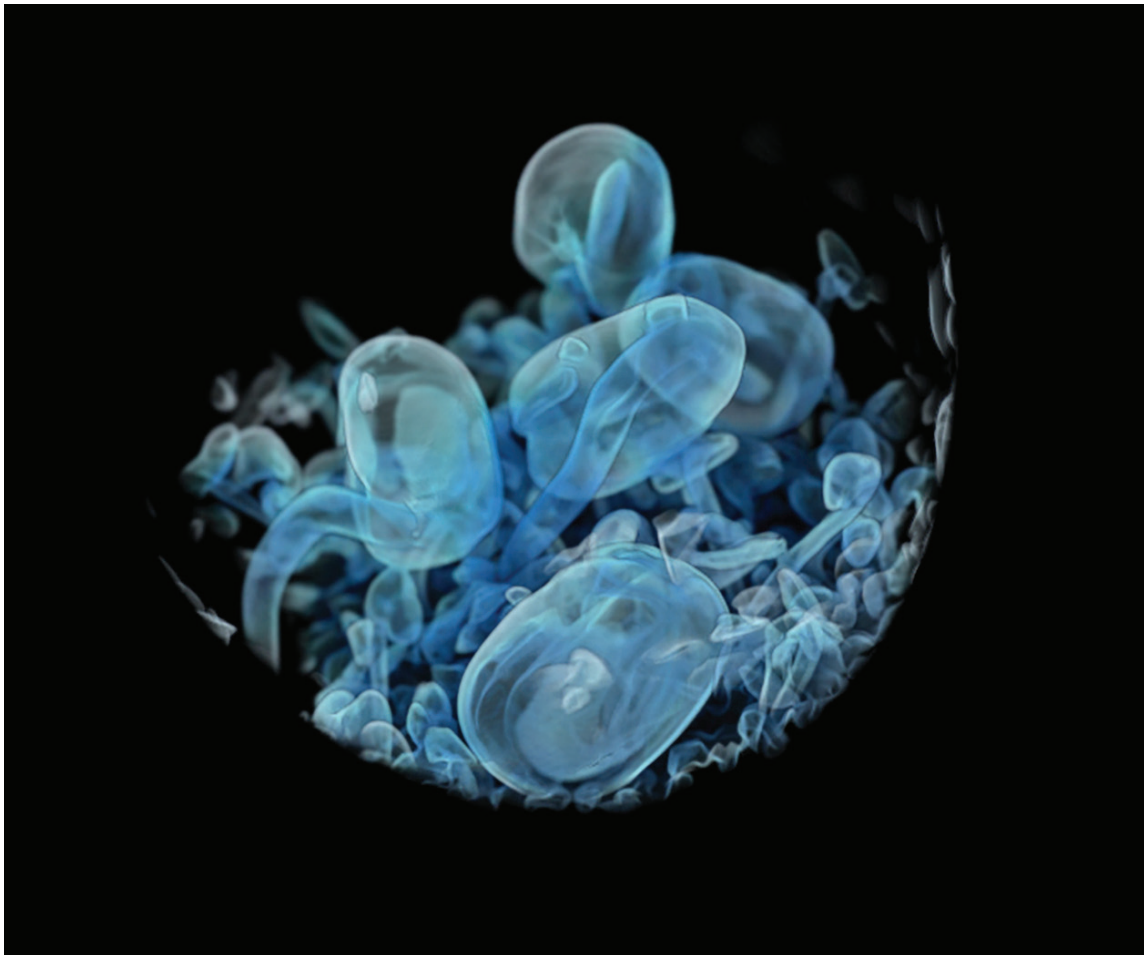


Fig. 6:12. *Out of Season*, 2016, (detail) 6 min stereoscopic projection installation.

timeless.[130] The widespread scientific evidence of environmental uncertainty in the face of global warming was not available to Klee's generation. Chakrabarty writes, our generation lives with the knowledge that we are most likely to witness, 'a tipping point at which this slow and apparently timeless backdrop for human actions transforms itself with a speed that can only spell disaster for human beings.'[131] My research for *Grow* has been motivated by this uncertainty for the future of the environment, as these are the concerns I am experiencing in my life-time. I have been driven by the need to express through my practice, a response to the now.

Scientific studies communicate statistics describing how local seasonal patterns of sun, rain and snow are shifting due to the rising temperatures of global warming. In despite of this this there is evidence that the levels of Co2 in the atmosphere are still increasing with human industry. In 'The sense of seeds, or seminal events,' Marder states that a corruption of the seasons is already forewarned in *Ecclesiastes*, where, 'vegetal seasons

130 Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry* 35 (Winter 2009). The University of Chicago, 2008, 205.

131 *Ibid*., 205.

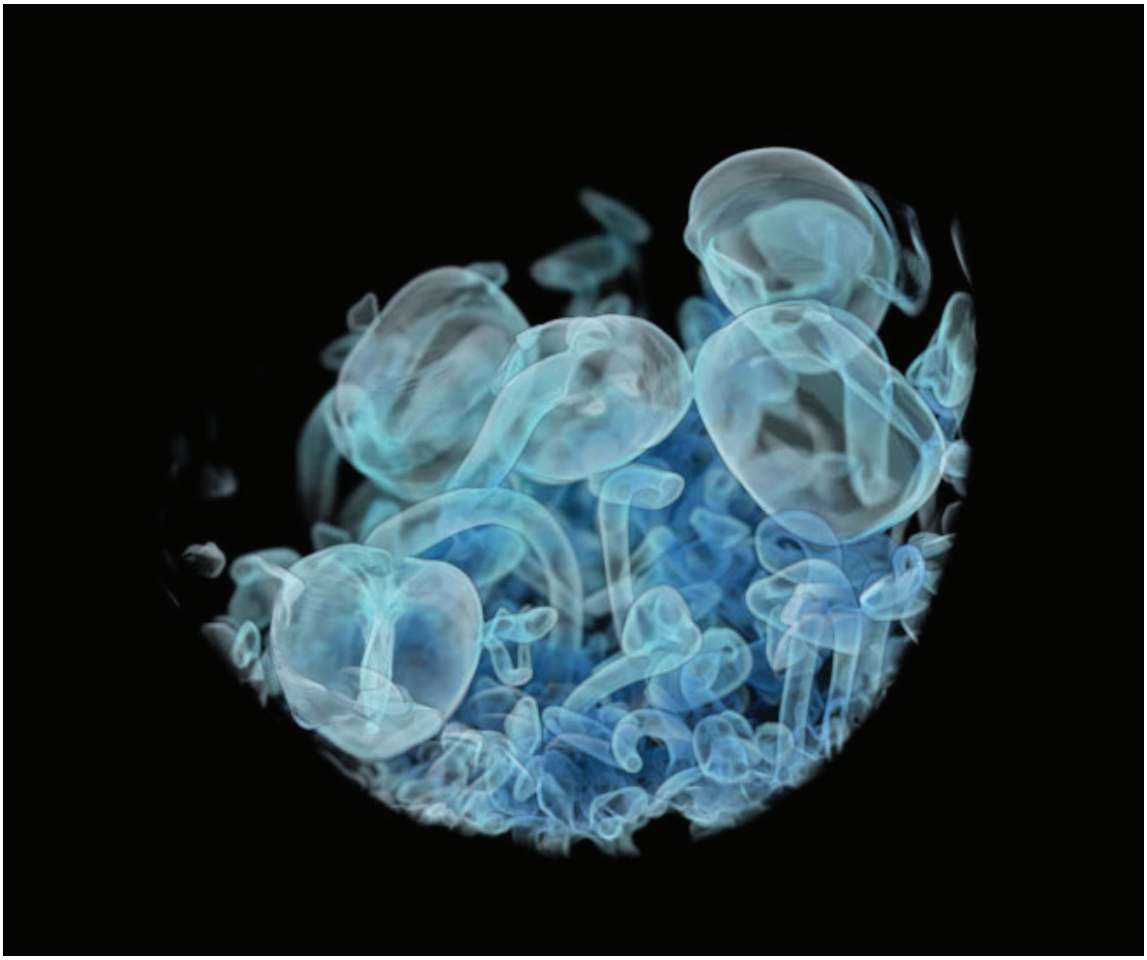


Fig. 6:13. *Out of Season*, 2016, (detail) 6 min stereoscopic projection installation.

are reduced to planting or sowing and the excoriation of plants, without leaving any time for care or cultivation.'[132] The continuing exploitation of nature for short-term economic gains has set the blue print for catastrophe.

Marder proposes that to perpetuate this relationship in the face of scientific evidence is a form of nihilistic behaviour, as we are deliberately destroying the very living space we are dependant upon;

> *Nihilistic culture suppresses the origination of culture in the work of cultivation, for the most part exerted on vegetal nature, the work which demands patience, the capacity to wait for the crops or for the time the plants themselves require to mature, and attunement to the changes of seasons.*[133]

Marder points to sites of corruption in the age of nihilism, in contemporary technological agricultural practices, where – just like the Costa del Polythene – plants are engineered to grow out of season for human consumption all year round. Quoting Nietzsche who

[132] Marder, "The sense of seeds," 94..

[133] *Ibid.*, 97

predicted, 'the kind of culture, that would be a 'fruit out of season,''[134] Marder writes that, 'to live out of season is to ignore the alterations and alternations of planetary time and to exist out of tune with the milestones of vegetal temporality: germination, growth, blossoming, and fruition.'[135]

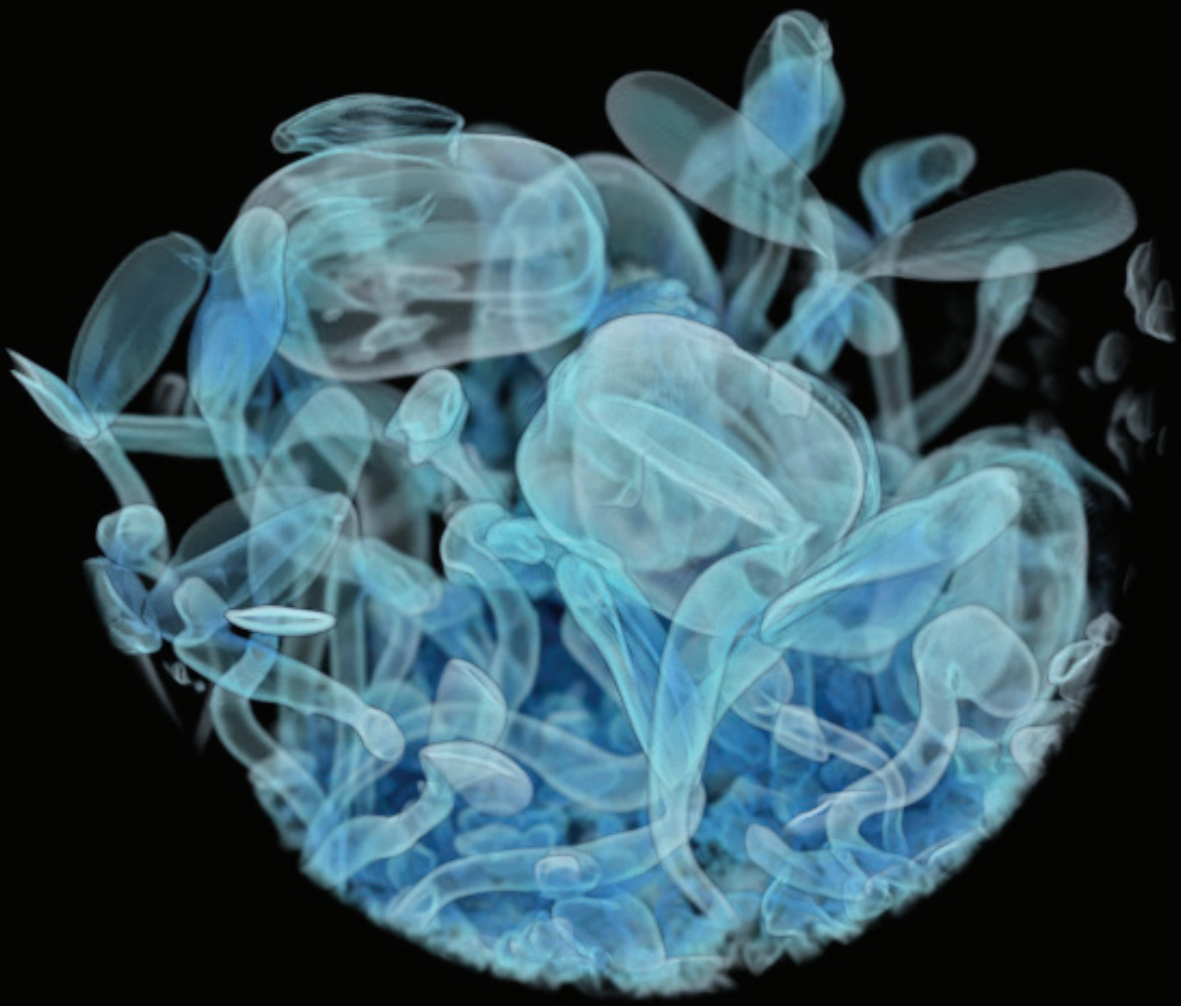
My reading of these concepts encouraged me to consider that perhaps through an immersive stereoscopic installation of virtual data, I might be able to situate an individual with the spatial and temporal event of the germinating seed, as a way to express or represent a kind of time that is made manifest in this changing world we inhabit. As mentioned earlier, I was inspired by Marder to title my final work *Out of Season*. In the perpetual state of germination, these seeds no longer adhere to natural rhythms. Germination time is compressed and sped up as the seeds repeatedly push their way into the virtual space outside of plant time, outside of seasonal patterns of life. They have become unseasonal.

The event of the germinating seed rotating quietly as a blue optical illusion is a metaphor to encourage its viewers to think about the future. In *Out of Season*, I am not mirroring a sensation of the viewer's experience back to themselves. Rather, I am creating a new opportunity of observing natural phenomena through a moment of wonder. In the process of continuous germination, the temporal event of the emergence of life is drawn into the present. Even though the germinating seeds are no longer material and exist only on a digital plane, compressed and accelerated in its prescribed timescale, the actual event of germination becomes a tangible experience within the gallery space via stereoscopic projection. Stepping into the 'fifth dimension' the viewer is free to make imaginative leaps between the originary event of the virtual germinating seeds, the future of the natural environment, or to wonder about their place in this vast yet finite cycle of time.

Fig. 6:13. *Out of Season*, 2016, (detail) 6 min stereoscopic projection installation.

134 Marder, "The sense of seeds," 97

135 *Ibid.*.



Conclusion

In my practice-led research *Grow: experiencing nature in the fifth dimension*, I created a new body of work *Out of Season*, for examination on 7th October, 2016. This work allows an audience to experience virtual germinating seeds through an immersive stereoscopic projection installation at the ANU School of Art Gallery. *Out of Season* has been created by germinating seeds for 4D Microcomputed X-ray Tomography and has been visualized in *Drishti*. In this work the germinating seed has become a visual analogy for ideas of time, growth and renewal in the context of current environmental issues and concepts such as the Anthropocene.

My research was framed by three main questions:

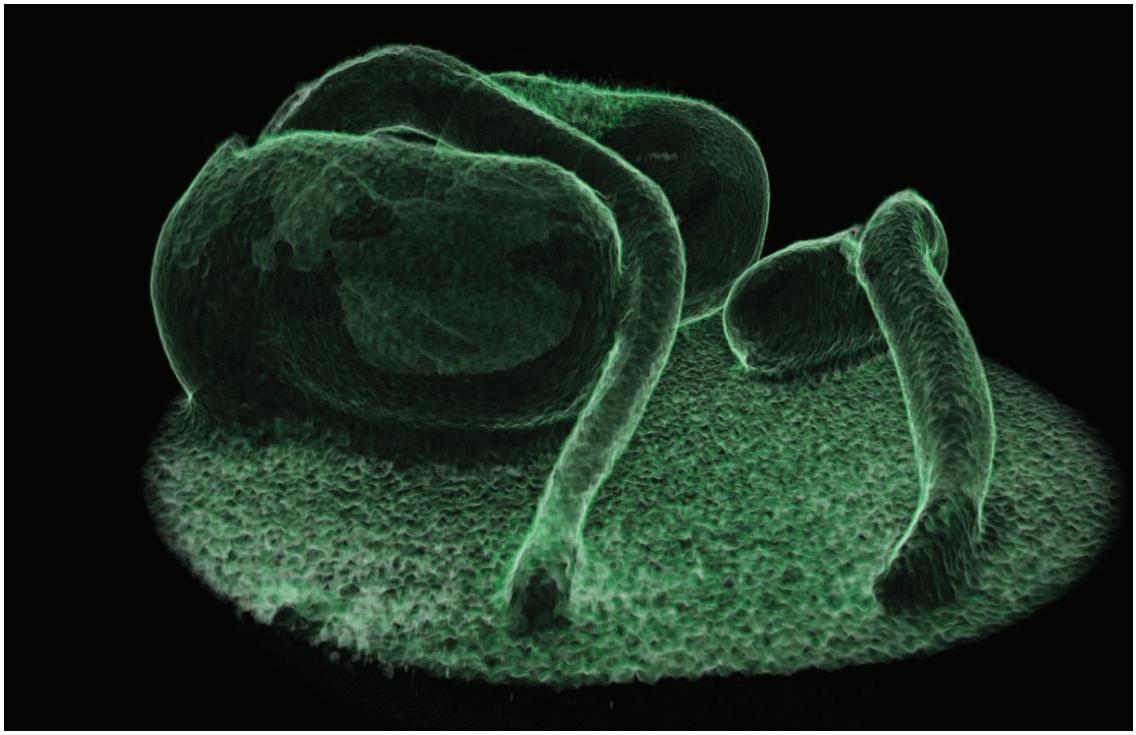
- How will I create works of art using the science of 4D Micro-CT?
- How can the resulting work connect to underlying environmental concerns?
- How is my work positioned in context of contemporary artistic practice?

In the first stages of this research I discovered how to acquire germinating seeds with time-resolved micro-X-ray Computed Tomography by experimenting and testing various techniques in the CT-Lab at the ANU Department of Applied Mathematics. I then visualized the volumetric seed data with the software Drishti, and developed new ways to make time-lapse animations of virtual germinating seeds that can be projected stereoscopically for exhibition.

Using the unique premise of my research to germinate seeds with 4D Micro-CT, I explored ideas about living in this present era of environmental uncertainty. I connected my practice with underlying environmental concerns by questioning how I might think ecologically in an era where the effect of 'the Anthropocene is actually *addressing us*.'[136] I examined the effectiveness of phenomenological methodologies in contemporary installation art to connect individuals meaningfully with concepts of nature.

This supported my proposal that an individual's subjective experience of nature in my work can be considered as an additional 'fifth dimension'. I based the concept of the 'fifth dimension' on the artist Ólafur Elíasson's intentions to heighten the sensory properties of

[136] Jill Bennett, "Living in the Anthropocene'," *Documenta 13: The Book of Books: catalogue 1/3,"* Hatje Cantz Verlaag, Germany, 2012, 347.



his work by transposing 'nature' into a constructed installation environment. Elíasson's installation *The Weather Project*, (2003), has been a significant point of reflection for me. My understanding of this work has been informed by essays written by Lesley Duxbury, and Sasha Engleman, who explore how this artist's practice of employing phenomenological methodologies can be considered an effective model for engaging individuals emotionally with ideas of climate change. I discovered these theories aligned with my own aims to create immersive stereoscopic projections for exhibition, so that an audience can experience the phenomenon of germinating seeds in the 'fifth dimension'.

To situate my practice within the broader context of an interdisciplinary enquiry, I considered specific works by the artists Stephanie Valentin and Maria Fernanda Cardoso. These artists employ scientific visualisation and microscopy as both a means and a metaphor. Analysing these works enabled me to draw out questions about my practice of using 4D micro-CT, compared to works of art that bring into focus phenomena which occur beyond the normal boundaries of human perception. To build on these ideas I examined contemporary scientific visualization of seeds produced by Dr Wolfgang Stuppy, and viewed my virtual models of germinating seeds in relation to the 19th century glass objects made by Leopold and Rudolf Blaschka.

The progressive development of my studio research to visualise my virtual datasets of germinating seeds led to the discovery of unpredicted visual elements such as mysterious bubbles and interactive surfaces. I was inspired to question the power of my work to captivate the viewer with the experience of wonder in seeing something for the first time. This opened up a whole new direction of inquiry into the concept of wonder and

first time experiences. Because my seeds reveal new things that allow us to continue to wonder about the mysteries of life, they draw us into the excitement of discovery. These perspectives on wonder have been important in further developing an understanding of how my 4D germinating seeds have the potential to extend the possibilities for different kinds of perceptive knowledge, such as the sense of mortality or hope for the future, in relation to the Anthropocene.

My two-week field trip as a resident at the Millennium Seed Bank was an essential influence on the ideas and direction of my research. Being physically located at the MSB allowed for a period of deep reflection about what the Anthropocene actually means. Contemplating the realities of global seed conservation helped me to position my work in my own time, in an era of environmental crisis and uncertainty. The frozen vaults of seeds at the MSB inspired me to think about seeds and their future viability — each seed embodying a potential future for survival. While at the MSB I made the connection that dormancy in a seed is a form of suspended time. This led me to further investigate the idea of time-scales in relation to the event of the germinating seed in my own practice.

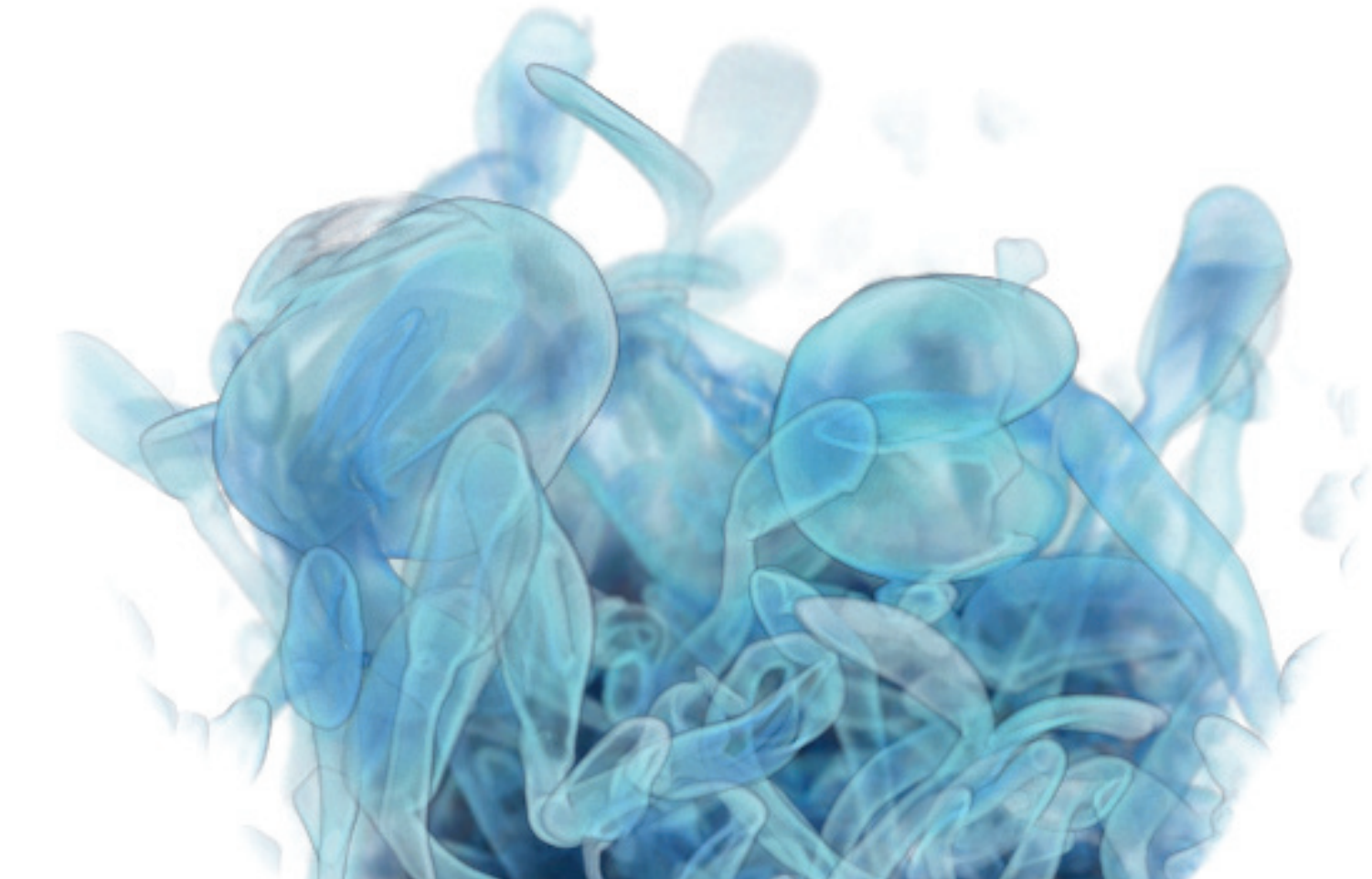
Testing how I could articulate these ideas about time I created several works which helped me further develop my understanding of how we experience time or temporality. A key example is *Constructed Landscape (2012),* a photographic study of my observations the National Arboretum in Canberra, motivated by my experiences at the Millennium Seed Bank, which explores the transient nature of experience. I further experimented with the representation of time by 3D printing objects derived from virtual datasets of germinating seeds. In creating a new stereoscopic installation for the exhibition Monster at CCAS in 2013, I also established that the concept of relativity of scale is not the main focal point of Grow, as this work relates instead to human time-scales.

In the context of my findings, Paul Klee's 1921 painting *Pflanzenwachstum* (Growth of plants), has proven to be important in how I came to recognise the concept of time in my own work as a reflection of the present. In contrast to Klee's painting, the perpetual germinating seeds in my work do not embody the natural rhythms and cycles of the seasons. Michael Marder's essay, 'The sense of seeds, or seminal events,' has also played a vital role in helping me conclude that my work expresses a different kind of time that is made manifest in this changing world we inhabit. Inspired by Marder I have titled my final work for examination *Out of Season*.

Throughout this practice led research I have experimented with and refined the virtual datasets of germinating seeds with *Drishti*. In *Out of Season*, the translucent blue sphere of seeds slowly rotates, pushing its shoots and leaves out into a virtual dimension. Projecting the virtual germinating seeds in a highly material and sensory form, my use of stereoscopic technology enhances the affect of wonder in nature by engaging

the viewer's sensory properties. Through this method of locating an individual as an active participant within the installation space, I have demonstrated the potential for this format to create a self-reflective experience that adds to the multi-dimensional nature of my work. By enhancing the virtual quality of the volumetric data of the germinating seeds through a simple optical illusion, it allows for an individual's experience of being grounded in a moment of self-reflection creates the additional 'fifth dimension'.

Unlike artists working at the turn of the 20th century, I live in a techno-scientific society in an era of rapid environmental change. This is evidenced in the rapid extinction of plant and animal species, the melting of polar ice caps, glaciers and permafrost in the arctic regions, and the rising ocean temperatures, which generate unstable weather and unpredictable seasons. While this new work offers no solution, hopefully it will inspire those who engage with it to reflect on our predicament, and perhaps participate in changes for a different kind of future than the one we are facing. Through my practice-led research *Grow: experiencing nature in the fifth dimension*, I have created a body of work that incorporates my use of frontier science and technology to pose new questions and to contribute to relevant contemporary art discourses and environmental concerns. *Out of Season* reflects the questions, concerns and themes relevant to my lifetime.



Bibliography

Books

Abbot, Edwin A., *Flatland: A Romance of Many Dimensions [by a Square],* 1884, Dover Thrift Editions, 1994.

Art Practice in a Digital Culture, Helen Gardiner, Charlie Gere, (eds), Ashgate, 2010.

Bachelard, Gaston *The Poetics of Space*, Beacon Press, 1969.

Baigrie, Brian S., *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science*, University of Toronto Press, 1996.

Brought to Light: Photography and the Invisible 1840-1900, Cory Keller, (ed). San Francisco Museum of Modern Art, 2008

Carroll, Sean B., *Endless Forms Most Beautiful: the New Science of Evo Devo and the Making of the Animal Kingdom*, Quercus, London, 2011.

Crary, Johathan, *Suspension of Perception: Attention, Spectacle, and Modern Culture*, The MIT Press, 1999.

Crary, Jonathan, *Techniques of the Observer*: *on vision and modernity in the nineteenth century*, MIT paperback edition, 1992, 16.

Dalrymple Henderson, Lynda, *The Fourth Dimension and non-Euclidian geometry in modern Art*. Princeton University Press, 1983.

Daston, Lorrain, Peter Galison, *Objectivity*, Zone books, New York, 2007.

Dawkins, Richard, *Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder*, Penguin Books, London, 2006.

Deleuze, Gilles, *Difference and Repetition*, (English translation Paul R. Patton) Columbia University Press, 1994.

Ede, Siân, *Art & Science*, I.B.Tauris & Co Ltd, London, NY, 2008.

Fisher, Philip, 'Wonder and the Sublime,' *Wonder: The Rainbow, and the Aesthetics of Rare Experiences*, Harvard University Press, 1998.

Gage, John, *Colour and meaning: art, science and symbolism*, Thames and Hudson, 1999.

Goethe, Johann Wolfgang von, *The Metamorphosis of Plants*, Introduction and photography by Gordon L. Miller, The MIT Press, 2009.

Grau, Oliver, *Virtual Art: From Illusion to Immersion*, MIT Press, Cambridge, 2003.

Henderson, Caspar, *The Book of Barely Imagined Beings: a 21st Century bestiary*, Granta, 2012.

Hinton, Charles H., *A new era of thought*, Published London, S. Sonnenschein & Co.1888. Digitised by Google, https://archive.org/stream/anewerathought00falkgoog#page/n36/mode/2up

In Paul Klee's enchanted garden, Bergen Art Museum, Henie Onstad Art Centre, Ostfildern, Hatje Cantz, 2008.

Jones, Stephen, *Synthetics: Aspects of Art and Technology in Australia*, 1956-75, The MIT Press, 2011.

Kessler, Robert, Wolfgang Stuppy, *Seeds, Time Capsules of Life*, Papadakis publishing, UK, 2nd Edition, 2014, 26.

Latour, Bruno and Steve Woolgar, *Laboratory Life: the Social Construction of Scientific Facts,* Sage Library of Social Research*, 1979.*

Marder, Michael, *Plant-Thinking: a philosophy of vegetal life*, Columbia University Press, 2013

Olafur Eliasson: Surroundings Surrounded, Essays on Space and Science, Peter Weibel, (ed), Neue Gallerie, Graz and MIT Press, Cambridge on the occasion of the exhibition, 2000.

Rabinbach, Anson, *The Human Motor: Energy, Fatigue, and the Origins of Modernity*, The University of California press, 1992.

Revelations: Experiments in Photography, Science Museum, Ben Burbridge, (ed), Media Space, London, 2015.

Spate, Virginia, *Colour of Time: Claude Monet*, Thames & Hudson, London, 1992

Take Your time: Olafur Eliasson, Madelaine Grynsztejn, (ed), exhibition catalogue San Francisco Museum of Modern Art, 2007

Textures of the Anthropocene: Grain, Vapor, Ray, Katrin Klingan, Ashkan Sepahvand, Christoph Rosol, Bernd M.Scherer, (eds), The MIT Press, 2014.

The Future of Environmental History: Needs and Opportunities, Edited by Kimberly Coulter, Christof Mauch, Rachel Carson Centre Perspectives, (2011/3).

The Holy Bible, The King James Version, Old Testament, "Ecclesiastes," (*Eccl. 3, Verse 1) Hendrickson Publishers Edition, 2011,* 325.

The Klee Universe, Scholz, Dieter Scholz, Christine Thomson, (eds), Staatliche Museen zu Berlin, Hatje Cantz, Verlag, Germany, 2008.

Thomas, Sue, *Technobiophilia: nature and cyberspace*, Bloomsbury, 2013

Thompson, Peter, *Seeds, Sex and Civilization: How the Hidden Life of Plants has Shaped Our World*, Thames & Hudson, 2010.

Time, Reality and Experience, edited Craig Callender, Cambridge University Press, 2002.

Tofts, Darren, Murray McKeich, *Memory Trade : A Prehistory of Cyberculture*, Interface, North Ryde, 1998.

Tucker, Jennifer, *Nature Exposed: Photography as Eyewitness in Victorian Science*. Baltimore: Johns Hopkins University Press, 2006.

Tuft, Edward R. *Visual Explanations: Images and Quantities, Evidence and Narrative*, Graphics Press LLC, Connecticut, 1997.

Williams, James, *Gilles Deleuze's philosophy of time: a critical introduction and guide* Edinburgh University Press, 2011

Wilson, Stephen, *Art + Science Now*, Thames & Hudson, New York, 2010.

Articles and Journal Essays

"Cultural History, Not Natural History," Ólafur Elíasson interviewed by Maria Morais, Oliver Koerner von Gustorf Translation: Andrea Scrima, Berlin *Deutche Bank online magazine*, http://www.db-artmag.com/archiv/06/e/magazin-eliassoninterview.

Adam, David, "Arctic permafrost leaking methane at record levels, figures show," Environment Correspondent, *The Guardian,* Thursday 14 January, 2010 www.guardian.co.uk

Barker, T.S., "The past and the present: Understanding David Claerbout's temporal aesthetics," *Time & Society,* November 2011, vol. 20, 3, 286-303. (accessed 15/10/14)

Bennett, Jill, "Living in the Anthropocene," *Documenta 13: The Book of Books: catalogue 1/3*, Hatje Cantz Verlaag, Germany, 2012, 346-347.

Best, Sue, "What is Affect? Considering the Affective Dimension of Contemporary Installation Art," *AAANZ Journal of Art*, vol.3, no.1, 2001, 207-225. (accessed 04/05/14)

Caro, T., J. Darwin, T. Forrester, C. Ledoux-Bloom, C. Wells, "Conservation in the Anthropocene," *Conservation Biology*, Volume 26, Issue 1, 2012, 185-188. (accessed 12/11/15)

Cavicchi, Elizabeth, "A witness account of solar microscope projections: collective acts integrating across personal and historical memory," *British Society for the History of Science*, 2008. DOI:10.1017/S0007087408000885 (accessed 20/01/11)

Chakrabarty, Dipesh, "The Climate of History: Four Theses," *Critical Inquiry* 35, The University of Chicago, 2008, 197-222. (accessed 06/10/11)

Cormak, Lucy., "Science meets art in Stephanie Valentin's *Closer* Exhibition," *The Sydney Morning Herald*, October 1, 2014. http://www.smh.com.au/entertainment/art-and-design/science-meets-art-in-stephanie-valentins-closer-exhibition-20141001-10oke1.html

Coutts-Smith Kenneth, "Art and Contemporary Science," *Brit J Aesthetics*, vol. 7 (2), 1967, 189-194.doi: 10.1093/bjaesthetics/7.2.189 (accessed 2/06/12)

Crutzen, Paul. J., "Geology of mankind," *Nature*, 415(6867), 2002, DOI:http://dx.doi.org/10.1038/415023a (accessed 04/05/14)

Davies, Char, "OSMOSE: Notes on being in Immersive virtual space," Digital Creativity, 9:2,65-74, 1998. DOI: 10.1080/14626269808567111 (accessed 5/08/1)

Davis, Douglas, "The Work of Art in the Age of Digital Reproduction (An Evolving Thesis: 1991-1995)," *Leonardo*, Vol. 28, No. 5, Third Annual New York Digital Salon, MIT Press, 1995, 381-386 (accessed 2/02/11)

Duxbury, Lesley, "A Change in the Climate: New Interpretations and Perceptions of Climate Change through Artistic Interventions and Representations," *Weather, Climate & Society*, vol. 2, 2010, 294-299. DOI: http://dx.doi.org/10.1175/2010WCAS1053.1 (accessed 10/05/11)

Duxbury, Lesley, "Out of Place: Close Observations of the Local Kind," *PAN: Philosophy Activism Nature*, no. 5, 2008, 41-46. (accessed 10/05/11)

Engelmann, Sasha, "Breaking the frame: Ólafur Elíasson's art, Merleau-Ponty's phenomenology and the rhetoric of eco-activism," *Stanford Undergraduate Journal for Excellence in Writing,* 2008, http://www.artandeducation.net/paper/breaking-the-frame-olafur-eliasson's-art-merleau-ponty's-phenomenology-and-the-rhetoric-of-eco-activism/ (accessed 10/05/11)

Fiege, Mark, "The Atomic Scientists, the Sense of Wonder, and the Bomb," *Environmental History*, Vol 12, 2007, 578-613. (http://www.jstor.org/stable/25473133)

Henderson, Casper, "The Sixth Extinction, Elizabeth Kolbert – Review," *The Guardian*, (Friday, February 14, 2014) http://www.theguardian.com/books/2014/feb/14/sixth-extinction-unnatural-history-kolbert-review

http://grail.cs.washington.edu/projects/timelapse/TimelapseMiningSIGGRAPH15.pdf

Interview with Ólafur Elíasson, Museum of Modern Art, MoMa, *Red Studio online education program Talk to me*, http://redstudio.moma.org/talktome/eliasson/?URL=8, retrieved 11 July 2011.

Joseph, Laurence E., "James Lovelock, Gaia's grand old man," *Salon*, Friday August 18, 2000. http://www.salon.com/2000/08/17/lovelock/

Keller, Cory "Sight Unseen: picturing the invisible," *Brought to Light, photography and the invisible 1840 to 1900*, San Francisco Museum of Art, 2008, 29.

Krogh Jenson, Marion, "mapping virtual materiality," Editer, Peter Weibel, *Olafur Eliasson: Surroundings Surrounded, Essays on Space and Science*, Neue Gallerie, Graz and MIT Press, Cambridge on the occasion of the exhibition, 2000.

Kulvicki, John, "Heavenly Sight and the Nature of Seeing-In," *The Journal of Aesthetics and Art Criticism*, Vol. 67, No. 4, Fall, 2009, 387-397, Published by Wiley, The American Society for Aesthetics, URL: http://www.jstor.org/stable/25622100 (accessed (13/08/14)

Long, J.A., Young, G.C., Holland, T., Senden, T.J. & Fitzgerald, E.M., "An exceptional Devonian fish from Australia sheds light on tetrapod origins," *Nature* 444 (7116): 2006, 199–202. DOI:10.1038/nature05243 (accessed 5/08/11)

Loss Woodruff, Lorande, "Hooke's Micrographia," *The American Naturalist*, Vol. 53, No. 626, May - Jun., 1919, 247-264), Published by: The University of Chicago Press for The American Society of Naturalists URL: http://www.jstor.org/stable/2456002 - (accessed 2/04/11)

Lovelock, James., "Nuclear Power is the only green solution," *The independent*, 24 May 2004) http://www.jameslovelock.org/page11.html

Marder, Michael, "The pulse of phenomenology," *Parrhesia*, Number 14, 2012, 16-22.

Marder, Michael, "The sense of seeds, or Seminal Events," *Environmental Philosophy*, Vol. 12, Issue 1, Spring 2015, 87-97. DO1:10.5840/envirophil201542920 (accessed 10/02/16) The author sent me the unpublished version of his paper via email, October, 2014.

Matthews, Patricia, "Scientific Knowledge and the Aesthetic Appreciation of Nature,' *The Journal of Aesthetics and Art Criticism*, 60:1 Winter 2002, 37-48. DOI:10.1111/1540-6245.00050 (accessed 2/06/12)

Oddie, Graham, "Truthlikeness", The Stanford Encyclopedia of Philosophy (Spring 2016 Edition), Edward N. Zalta (ed.), URL: http://plato.stanford.edu/archives/spr2016/entries/truthlikeness/, (assessed 22/8/16)

Oliver, Marc, "Binding the book of nature: microscopy as literature," *History of European Ideas*, Vol.31, 2005, 173-191. DOI: 10.1016/j.hiteuroideas.2003.11.005 - accessed 5/03/11

Parke, Margaret, "The glass flowers of Harvard's Botanical Museum", *Endeavour,* Volume 7, Issue 3, 1983, 116-122. DOI:10.1016/0160-9327(83)90003-0 (accessed 10/05/12)

Pattbert, Philipp, "Conquest, Domination and Control: Europe's Mastery of Nature in Historic Perspective," *Journal of Political Ecology*, vol. 14, 2007. http://jpe.library.arizona.edu/volume_14/pattberg.pdf (accessed 6/09/13)

Pimm, Stuart L. & Peter Raven, "Biodiversity: Extinction by numbers," *Nature,* 403, 2000, 843-845. DOI:10.1038/35002708 (accessed 5/12/14)

Ricardo Martin-Brualla, David Gallup & Steve M. Seitz, "Time-lapse Mining from Internet Photos, *ACM SIGGRAPH 2015*, (accessed 10/05/16)

Schaub, Miriam, "'The Logic of Light: Technology and the Humean Turn," *Thyssen-Bornemisza Art Contemporary: The Collection Book*. Cologne: Walther König Verlag, 2009, 138-141. (accessed 12/03/11)

Schellenberg, J. L. (2014) "The End is not near: why do we assume the future will be short," *Aeon Magazine*, 10 February 2014, http://aeon.co/magazine/philosophy/why-do-we-assume-the-future-will-be-short/

Schmidt, Dennis J., "Klee's Gardens," *Research in Phenomenlology, Vol.* 43, Koninklijke Brill NV, Leiden, 2013. DOI:10.1163/15691640-12341266. (accessed 24/03/14)

Smith, David Woodruff, "Phenomenology", *The Stanford Encyclopedia of Philosophy* (Winter 2013 Edition), Edward N. Zalta (ed.), URL: http://plato.stanford.edu/archives/win2013/entries/phenomenology/. (assessed 22/8/16)

Steffen, Will, Jacques Grinevald, Paul Crutzen, John McNeill. "The Anthropocene: conceptual and historical perspectives," *The Royal Society*, vol.369, no.1938, 2011, 842-867. DOI: 10.1098/rsta.2010.0327 (accessed 5/12/14)

Steffen, Will, Paul J. Crutzen, John R. McNeill, "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature." *A Journal of the Human Environment*, Vol. 36(8), 2007. 614-621. DOI:http://dx.doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2 (accessed 5/12/14)

Thomas, Sue., "Can we get all the nature we need from the digital world," *Aeon Magazine,* 2013. http://www.aeonmagazine.com/nature-and-cosmos/can-we-get-all-the-nature-we-need-from-the-digital-world/

Thornton, Stephen, "Karl Popper", *The Stanford Encyclopedia of Philosophy* (Winter 2015 Edition), Edward N. Zalta (ed.), URL: http://plato.stanford.edu/archives/win2015/entries/popper/. (assessed 22/8/16)

Tremlett, Giles, "Spain's Greenhouse effect: the shimmering sea of polythene consuming the land." *The Guardian*, Wednesday 21 September, 2005. http://www.theguardian.com/world/2005/sep/21/spain.gilestremlett

Vallega, Alejandro A., "Paul Klee's Originary Painting," *Research in Phenomenology* 43, 2003, 462-472. DOI:10.1163/15691640-12341270 (accessed 24/03/14)

Williams, Mark, Zalasiewicz, Alan Haywood, Mike Ellis, "The Anthropocene: a new epoch of geological time?" *Philosophical Transactions*, The Royal Society, Vol. 369, no. 1938, 2013. DOI:10.1098/rsta.2010.0339 (accessed 5/12/14)

Zalasiewicz, Jan, *et al*., "Are we now living in the Anthropocene?" *GSA Today*, V.18, no.2, 2008. DOI: 10.1130/GSAT01802A.1 (accessed 8/06/12)

Other references

'Anthropocene', Subcommission on Quaternary Stratigraphy: http://quaternary.stratigraphy.org/definitions/

"verisimilitude, n.". OED Online. June 2016. Oxford University Press. http://www.oed.com.virtual.anu.edu.au/view/Entry/222523?redirectedFrom=Verisimilitude (accessed 22/08/2016).

"wonder, n.". OED Online. June 2016. Oxford University Press. http://www.oed.com.virtual.anu.edu.au/view/Entry/229936?rskey=pLaQXh&result=1 (accessed 22/08/2016).

Documentaries

Dr John Nash Ott, *Exploring the Spectrum*, The Effects of Natural and Artificial Light on Living Organisms. A Documentary About the Work of Dr. John Nash Ott, Filmed and Directed by John Nash Ott, DVD released 2008. Natural Energy Works, http://www.orgonelab.org/cart/xspectrum.htm.

Professor Maria Fernanda Cardoso and the Museum of Copulatory Organs, ABC Arts Documentary, 2012, http://www.abc.net.au/arts/artists/maria-fernanda-cardoso-the-museum-of-copulatory-organs/

The Kingdom of Plants, David Attenborough, Nature Documentary, Sky Atlantic, 2012.

The Life of Plants, David Attenborough, Nature Documentary, BBC Natural History Unit, Turner Broadcasting, 1995.

Interviews

John Siemen, Australian Plantbank, Royal Botanic Gardens and Domain Trust, Mt Annan, NSW, 30 June 2011.

Dr Wolfgang Stuppy, Millennium Seed Bank, Royal Botanic Gardens Kew, Wakehurst Place, West Sussex UK, 5-9 May 2012.

Visual resources

Australian Plantbank, Royal Botanic Gardens and Domain Trust, Mt Annan, NSW, 30 June 2011, & 14 April 2014.

Anthony McCall: Five Minutes of Pure Sculpture, Hamburger Bahnhof, Museum für Gegenwart, Berlin, (viewed 7 August 2012).

*Damien Hirs*t, Tate Modern, London, (accessed 7 July 2013).

David Claerbout: the time that remains, Parasol Unit: Foundation for Contemporary Art, Wharf Road, London, (viewed 1 June, 2012).

Hooke, Robert, *Micrographia: or, Some physiological descriptions of minute bodies made by magnifying glasses.* London: J. Martyn and J. Allestry, 1665. (first edition), (accessed Natural History Museum Library, London, 20 May 2012, and 4 September 2013)

James Turrell: A retrospective, National Gallery of Australia, Canberra, (viewed 31 December 2015).

Light Show, Museum of Contemporary Art, Sydney, (viewed 12 June 2015).

Lynette Wallworth, *Coral – Rekindling Venus*, Peter Harrison Planetarium Royal Observatory, Greenwich (viewed 5 July 2012).

Malevich, Tate Modern, London, (viewed 17 July 2014).

Millennium Seed Bank, Royal Botanic Gardens Kew, Wakehurst Place, West Sussex UK, 5-9 May 2012.

Revelations: Experiments in Photography, Science Museum, London, (viewed 2 June, 2015).
Rudolf and Leopold Blaschka Collection, Natural History Museum, London, (viewed 18 July, 2012).
Santos Museum of Economic Botany, (est 1881), South Australia Botanic Gardens, (visited 30 September, 2014).
Seduced by Art: Photography Past and Present, National Gallery, London, (viewed 3 January 2013).
Take Your Time: Olafur Eliasson, Museum of Contemporary Art Australia, Sydney, (viewed 10 March 2010).
The Bloomburg Commission: Giuseppe Penone: Spacio di Luce, Whitechapel Gallery, London, (viewed 4 January 2013).
The Sir Hans Sloane Herbarium, Natural History Museum, London, (accessed 12 May, 2015).

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(Fig. 1:7. P.17 (Detail from the *Gogonasus* fossil specimen voluntric dataset imaged in Drishti. Professor Tim Senden (ANU) and Dr John Long, (Museum Victoria), (2006). Image courtesy T. Senden, A. Limaye, Vizlab, ANU, NCI.

(Fig. 2:4. p. 26) Costa del Polythene, a sea of plastic, Almería, Spain. Over 200 square km of greenhouses, (February 2004). Photo by NASA, Earth Observing System (EOS), Spacecraft: Terra, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Image credit: NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

(Fig. 2:5. p. 29) Olafur Eliasson, *The Weather Project*, (2003), monofrequency lights, projection foil, haze machines, mirror foil, aluminium, and scaffolding, 26.7 m x 22.3 m x 155.4 m, installation in Turbine Hall, Tate Modern, London, photo: Studio Olafur Eliasson © Olafur Eliasson 2003. http://www.olafureliasson.net/works/the_weather_project.html

(Fig. 2:6. p. 30) Olafur Eliasson, *The Weather Project*, (2003), monofrequency lights, projection foil, haze machines, mirror foil, aluminium, and scaffolding,
26.7 m x 22.3 m x 155.4 m, installation in Turbine Hall, Tate Modern, London Photo: Studio Olafur Eliasson © Olafur Eliasson 2000. http://www.olafureliasson.net/works/the_weather_project.html

(Fig. 2:7. p. 32) Ólafur Elíasson, *Beauty*, (1993), spotlight, water, nozzles and hose, dimensions variable. Collection of the Museum of Contemporary Art, Los Angeles, Installation view at Museum of Contemporary Art (MCA), Sydney, documented during my visit to the exhibition *Take Your Time: Ólafur Elíasson*, (2010).

(Fig. 2:8. p. 33) Ólafur Elíasson, *Fog assembly*, (2016) Palace of Versailles, 2016, photo, Anders Sune Berg. http://olafureliasson.net/archive/artwork/WEK110139/fog-assembly#slideshow.

(Fig. 2:9. p. 35) Charles Howard Hinton "The genesis of a cube," *A new era of thought* published London, S. Sonnenschein & co.1888, 110. Digitised by Google, https://archive.org/stream/anewerathought00falkgoog#page/n36/mode/2up

(Fig. 2:10. p. 37) Kazimir Malevich *Black Square* 1915, oil on linen, 79.5 x 75.9 cm, © State Tretyakov Gallery, Moscow, Tate Modern. http://www.tate.org.uk/context-comment/articles/five-ways-look-Malevich-Black-Square

(Fig. 2:11. p. 38) Eadweard Muybridge *Untitled (Woman Walking Down a Plank*) (detail), 1887, and Marcel Duchamp *Nude Descending a Staircase (No. 2),* 1912, © Artists Rights Society (ARS), New York/ADAGP, Paris/Estate of Marcel Duchamp. Philidelphia Museum of Art. http://philamuseum.tumblr.com/post/47538803718/happy-birthday-to-eadweard-muybridge-18301904

(Fig. 2:12. p. 39) Paul Klee, *Pflanzenwachstum*, 1921 Oil on Canvas, 54 x 40 cm, Centre Pompidou, https://www.centrepompidou.fr/cpv/resource/ca9q6r/rxA8dRr

(Fig. 3:8. p. 48) Stephanie Valentin, *Zinnia 2*, 2002, from *Pollinate*, (etched pollen grain - magnification 5,000x) Gelatin silver print, 18 x 21cm, edition of 7, Stills Gallery. http://www.stillsgallery.com.au/artists/valentin/index.php?obj_id=folio&image=1&nav=3

(Fig. 3:8. p. 48) Stephanie Valentin , *polygala* (subdue), 2002, from *Pollinate*, (etched pollen grain - magnification 4,00x), Gelatin silver print18 x 21cm, edition of 7, Stills Gallery, http://www.stillsgallery.com.au/artists/valentin/index.php?obj_id=folio&image=5&nav=3

(Fig. 3:10. p.50) William Henry Fox Talbot, *Photomicrograph of Moth Wings*, (1840),
Calotype negative, 11.3 x 15.4 cm, National Media Museum, Bradford, England.
Brought to Light: Photography and the Invisible 1840-1900, Cory Keller, (ed).
San Francisco Museum of Modern Art, 2008, [plate 1]

(Fig. 3:11. p.51) Jean Bernard Léon Faucult, Ferments of sweet urine (1840),

daguerreotype, 9.6 x 13cm, Société Française de Photographie, Paris. *Brought to Light: Photography and the Invisible 1840-1900,* Cory Keller, (ed).
San Francisco Museum of Modern Art, 2008, [plate 15]

(Fig. 3:12. p. 52) (Left) Maria Fernanda Cardoso, *Intromittent organs of the Allabunus distincta harvestman,* (2008-2009), resin, glass, metal. Museum of Copulatory Organs (MoCO), 2012. http://mariafernandacardoso.com/category/animal-art

(Fig. 3:13. p. 53) (Right) Maria Fernanda Cardoso, *Intromittent organs of the Allabunus distincta harvestman*, (2008-2009), (Detail) resin, glass, metal. Museum of Copulatory Organs (MoCO), 2012. http://mariafernandacardoso.com/category/animal-art

(Fig. 3:13. p. 54) Venus's Flower Basket, *Euplectella Aspergillum*, or Deep Sea Glass Sponge (c. 1850), Natural History Museum, London.

(Fig. 3:12. p. 54) Deep Sea Glass Sponge, *Euplectella Aspergillum* (c. 1890), Photographer: C Bento © Australian Museum, Sydney. http://australianmuseum.net.au/invertebrates-collection-deepsea-glass-sponge

(Fig. 3:13. p. 56) Rob Kesseler, Wolfgang Stuppy, *Lamourouxia viscosa*, (2006), (Mexico), honeycomb structure found in wind-dispersed seeds, 1.2 mm. Image courtesy Wolfgang Stuppy. Can be found in Robert Kessler, Wolfgang Stuppy, *Seeds, Time Capsules of Life*, Papadakis publishing, UK, 2nd Edition, 2014, 18.

(Fig. 3:14. p.5) Rob Kesseler, Wolfgang Stuppy, *Nyphoides peltata, (*2006), (Europe), bristly hairs allow the seed to float on water, and disperse by attaching to feathers of waterbirds, 0.5 mm. Image courtesy Wolfgang Stuppy. Can be found in Robert Kessler, Wolfgang Stuppy, *Seeds, Time Capsules of Life*, Papadakis publishing, UK, 2nd Edition, 2014, 130-131.

(Fig. 3:14. p. 58) A Blaschka glass model of the radiolarian *Aulosphaera elegantissima Haeckel*, (1862). The central mass of cytoplasm, the axiopoda and the spherical silica shell are magnified about 500 times and reproduced in glass. Natural History Museum, London. *Radiolarian microfossils proving popular for exhibitions,* posted by Giles Miller (Jul 18, 2012 4:56:04 PM) http://www.nhm.ac.uk/natureplus/blogs/micropalaeo/2012/07/18/beautiful-radiolarians-from-barbados

(Fig. 3:15. p. 59) A Blaschka glass model of the *Clathrulina elegans,* one of the *Heliozoa,* Natural History Muesum, London, (2012).

(Fig. 5.2. p.86) Etienne-Jules Marey, *Geometric Chronophotograph of the man in the black suit,* (1883), Aaron Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity*, University of California, 1992, 15.

(Fig.5:3. p.87) Dr John Nash Ott, detail from a time-lapse of a pumpkin developing (1950),
Exploring the Spectrum, The Effects of Natural and Artificial Light on Living Organisms. Filmed and Directed by John Nash Ott, DVD (2008). Natural Energy Works. http://www.orgonelab.org/cart/xspectrum.htm.

Research outcomes

Published papers

Seccombe, Erica, "Relocating the real: experiencing nature in the fifth dimension," *AAANZ 'Inter-discipline' conference proceedings*, December 2014 (peer reviewed) http://aaanz.info/aaanz-home/conferences/aaanz-inter-discipline-proceedings

Seccombe, Erica, "Grow: an investigation of 4D Micro-CT," *SPECTRA 2012* conference proceedings, CSIRO Discovery Centre.

Seccombe, Erica. "Grow: visualising nature at nanoscale," *EVA LONDON 2012 - Electronic Visualisation and the arts (*London, UK, 10 - 12 July 2012) ISBN 978-1-780171-59-3, Editers, Dr Stuart Dunn, Prof. Jonathan P. Bowen, Dr Kia Ng. (Peer reviewed)

Exhibitions

'Grow,' 2014, *Light Speculation*, The Carlton Connect Initiative, The University of Melbourne, curated by Dr Renee Beale, 23 July – 8 September 2015.

'Grow',' 2013 *Synapse a Selection*, Powerhouse Museum, Sydney, 8 June- 14 July 2013

'Virtual Life,' 2015, (awarded first prize), and 'Printed Time,' 2014 Paramour Prize: Art and Innovation, Casula Powerhouse Art Centre, NSW, 31 Janruary - 1 February 2015.

"Printed Time,' 2014, *Aesthetics of Manufacture*, Sheffield Design Week, Butcher Works Galley, UK, curated by Carle Baugh, Sheffield, UK. 1-15 June 2015.

'Printed Time,' Dominik Mersche Gallery, Rushcutters Bay, Sydney, 8-31 May 2014

'Constructed Landscape,' 2012, and 'Vault Door,' 2012, *Crossing the Rubicon*, with Ellis Hutch, ANCA Studios & Gallery, Dickson, Canberra, 24 October – 4 November 2012.

'Monster', 2013 *Science Fiction*, Canberra Contemporary Art Space, Supported by the Centenary of Canberra. 16 August – 16 September, 2013

Academic and pubic presentations

OzViz, University of Technology, Sydney, 2 December, 2015

TED X Canberra. Erica Seccombe, *Experiencing Nature in the Fifth Dimension*, 2014, Video reference https://www.youtube.com/watch?v=_8-OGyAILxk

Tomography for Scientific Advancement, (ToScA), Natural History Museum, London, 1-3 September 2014. http://www.nhm.ac.uk/our-science/departments-and-staff/core-research-labs/imaging-and-analysis-centre/tosca.html#sthash.osb1kRnk.dpuf

Environmental Humanities Conference: Affective Habitus: new environmental studies in botany, zoology and emotions, 20 June 2014, Sir Roland Wilson Building, ANU. The Fifth Biennial Conference of The Association for the Study of Literature, Environment and Culture, Australia and New Zealand (ASLEC-ANZ) –an Environmental Humanities collaboration with the ARC Centre of Excellence for the History of Emotions, and Minding Animals International. http://hrc.anu.edu.au/affectivehabitus.

AAANZ Conference 2013 – Inter-Discipline. Panel "Art, Environment, Interdisciplinarity: New Perspectives in Australian Art Practice," Chair, Chris McAuliffe & Jolanta Nowak, University of Melbourne, speakers, Erica Seccombe, Malcolm Bywaters, Amanda Stuart, Janine Burke, 7-9 December, 2013.

International Symposium of Electronic Arts, (ISEA) Sydney 2013, Conference, Panel discussion, 'Sensation meaning and affect in art/science collaborations'. with Prof. Sue Best, A.Prof Barbara Rauch, Elizabeth Eastlake, Chris Henchke, 10-13 June 2013.

Postgraduate Photography Symposium, Museum of Contemporary Art, MCA's Centre for Creative Learning, 31 August, 2012.

EVA LONDON 2012 - *Electronic Visualisation and the arts*, 10 July - 12 July, 2012

Understanding Interdisciplinarity: Theory and Practice, Sheffield Hallam University, UK, 12 - 14 June, 2012.

Animating Time-space Symposium Raglan, New Zealand, The University of Waikato, 30 Sept - 2 October, 2011.

Glossary of key terms

3D micro-X-ray Computed Tomography, (3D micro-CT), records a fully three-dimensional map of X-ray opacity throughout the entire volume of an object with microscopic resolution. Please see the introductory chapter, p.3 and chapter one for a full description in context of my research.

4D 3D micro-X-ray Computed Tomography, (4D micro-CT), records a fully three-dimensional map of X-ray opacity throughout the entire volume of an object, with microscopic resolution and includes the additional movements within the data over a period of time, hence 3D + time = 4D. Please refer to chapter one, see p.4 for an indepth explanation of this term in context of my research.

The Anthropocene is considered by scientists to be the new geological epoch encapsulating the quantitative shift in the relationship between humans and the global environment, and the role human activity has had on re-shaping the Earth's geology and ecology. The term which combines the Greek word for human, 'anthropos,' with the suffix 'cene', meaning new, was first published as a concept by Nobel Laureate Professor Paul Crutzen in 2000. Please refer to Chapter two for a full explanation of this term in context of my research.

Computer generated imaging, CGI, generally refers to 2D or 3D computer graphics which simulate images of objects or landscapes in films, games, fine art and virtual environments. Typically 3D images are created from computer algorithms which create texture mapped surfaces through fractals or triangular mesh frames. My reference to this terminology in this Exegesis is to explain that I am not employing CGI, but rendering volumetric datasets (virtual data) through software that uses scientific analysis of algorithms that detects material density rather than surface geometries. See chapter one for a full explanation of my use of volumetric data.

Drishti is the open source volume exploration software I am using for the purpose of this practice-led research. Please see chapter one p.18 for a more indepth explanation of my use of this *Drishti* in context of this research. Designed by Ajay Limaye at the National Computational Infrastructure's VizLab. The central idea of Drishti is that scientists can use it to explore and present volumetric datasets without extensive training. Drishti has been developed with its end use in mind: ie. visualising volumetric data, such as tomography data, electron-microscopy data. Drishti stands for vision or insight in Sanskrit, an Indian language. Drishti works on GPUs with OpenGL 2.0 capability. For futher reference see: Citation Ajay Limaye "Drishti: a volume exploration and presentation tool", Proc. SPIE 8506, Developments in X-Ray Tomography VIII, 85060X (October 17, 2012); doi:10.1117/12.935640; http://dx.doi.org/10.1117/12.935640

Fifth dimension –

In physics a space with five dimensions is interpreted as a physical space with one more than the typical three spatial dimensions and the additional dimension of time. In the early 20th century the fifth dimension was considered a theoretical construct, but indirect recorded evidence of its existence is now explored in contemporary molecular physics through particle acceleration in research in facilities such as the Large Hadron Collider. For example the fifth dimension could be measured as the fundamental force of gravity or electromagnetism.

In my research I refer to the 'fifth dimension' in my practice as the inclusion of an individual's subjective experience of art, and I support my argument by referring specifically to the artist Ólafur Elíasson's interpretation of this concept. For further explanation of this term context of my research please see chapter one and chapter two, and my findings based on this concept in relation to my own art work are summarised in the conclusion. To define my use of the 'fifth dimension' as a type of experience rather than scientific evidence, I have used single inverted commas in all instances except where referenced in the title of this research paper.

Fourth dimension –

In physics the fourth dimension is a term that explores the qualities of space including time. In physics, this combination of space and time, spacetime is a mathematical model combining space and time into a single interwoven continuum. In Euclidean geometry, flat space consists of three dimensions, and time as consisting of a single extra dimension, the 'fourth dimension'. This perspective was employed from 300 BCE until non-Euclidean geometry such as hyperbolic space began to be further explored at the turn of the 20th Century when physicists began combining space and time into a single manifold. Non-Euclidean geometry enabled the development of new physical theories in order to describe the workings of the universe at both the super galactic and subatomic levels. I explain how this term is understood in relation to my practice-led research in chapter two, p.44-35.

In my research I refer to the fourth dimension as the inclusion of time in 3D or 4D Micro-CT. For further explanation in context of my research see chapter one and chapter two.

Virtual or virtual reality (VR) are terms typically used when referring to immersive or 3D interactive CGI. In my research I am instead using the term 'virtual' in relation to volumetric data - in that I am fully tranposing a 3D object into a digital platform through the use of Micro-CT rather than constructing it though mesh framed CGI. Using the word 'virtual' to describe volumetric data is to distinguish it from the 'actual' or original sample it was taken from. It follows the derivation from the Latin *virtus*, or *virtue*, as in displaying the ideal or true qualities of what is real. Please see the introduction, p.4 for a full explanation.

Volumetric datasets are made up of voxels. A voxel (volume 'x' element) represents a point or single unit in a 3D grid in the same way a pixel (picture 'x' element) represents a unit within 2D image, or picture. It is important to note that voxels are not the same as texels, which are texture mapping elements used more commonly in CGI. Please see chapter one, p.17 for further explanation.