Neo-gemstones®

An Alchemical Jeweller's Exploration of Lab-grown Crystals and Related Technologies, Proposing Innovations Whilst Challenging Context, Terminology, and Underlying Assumptions.

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A thesis submitted in partial fulfilment of the requirements of the University of the West of England, Bristol for the degree of Doctor of Philosophy

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Figure 1.1. Ruby seeds harvested from the inside of a crucible following exposure to a growth environment and process.

Abstract

With crystal growing techniques having been around since the 19th century, man-made crystals now drive innovations in various industries. However, this has not fully translated into the jewellery industry, where efforts to de-value them have limited scientific interest. A historical and contemporary review explores why innovations in man-made crystal materials within a jewellery context remain sparse. An investigation into the culture and context surrounding man-made crystals explores the differences between these crystals and their mined counterparts, with findings visualised through Critical Design. 'Neo-gemstone(s)' is proposed as alternative terminology for labelling novel man-made crystal materials in response to the identified need for the re-framing and re-naming of enhanced and designed crystal materials when used in a contemporary jewellery context. This thesis, furthermore, documents the creative potential of incorporating lab-grown gemstones through three case studies: using urban mined lab-grown waste gemstones; collaborating with scientists to develop and use novel crystals with unique properties, such as phosphorescence; and incorporating crystal growth technologies directly into a Neo-alchemical jeweller's practice. These studies document the implications, possibilities, and limitations of using man-made crystals in jewellery. This alchemical exploration of lab-grown crystals and related technologies signifies innovations while challenging existing contexts, terminology, and assumptions, providing a comprehensive insight into the multiplicitous approaches possible within a contemporary jewellery practice.

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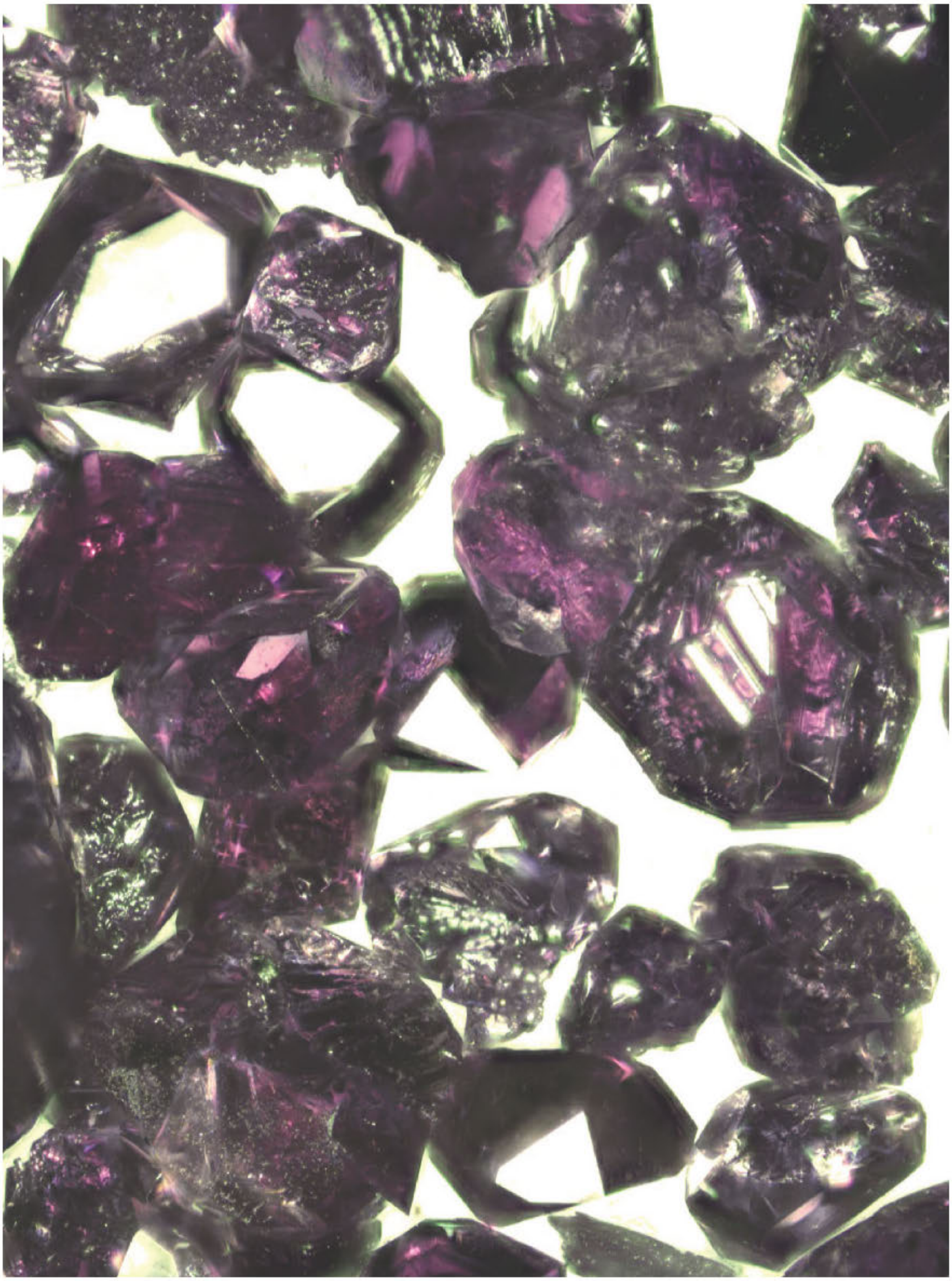

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Figure 1.2. Microscope image of ruby seed harvested from the inside of the crucible following exposure to a growth environment and process.

Glossary of Terms and Abbreviations

Agential Realism Theoretical framework developed by philosopher and physicist Karen Barad (Barad, 2007).

Artefact Objects with cultural, historical, or practical significance. Theories like 'Actor Network Theory' (Latour, 2005) and 'Phenomenology' (Merleau-Ponty, 2011) distinguish artefacts from natural objects due to their intentional creation and cultural meanings. In Agential Realism (Barad, 2007), the distinction between natural objects and artefacts is not a fundamental or pre-existing one. Objects are viewed as dynamic, entangled participants in the ongoing intra-active processes that constitute reality. They are not passive but active agents whose properties and significances are continually produced and reconfigured through material-discursive practices. This perspective challenges traditional views of objects as static and highlights the complex, relational, and ethical dimensions of their existence. In this thesis the term 'artefact' is used to signpost the objects with which the author has intra-acted, and which can be used by viewers to re-engage with these intra-actions.

Chemical Vapour Deposition (CVD) A technique used to grow diamonds. Growth occurs in a heated mixture of a hydrocarbon gas (such as methane) and hydrogen within a vacuum chamber. Activation of the gas by an energy source (a microwave plasma) breaks apart the gas molecules to release carbon atoms, which are drawn towards the cooler substrate (typically flat, square-shaped seed plates) positioned in the chamber (Eaton-Magaña and Shigley, 2016). The technique has become increasingly popular since it requires much lower temperatures (700–1300°C) and pressure (less than 1 atmosphere) than the High Temperature High Pressure technique.

Contemporary jewellery "*Much used term for modern jewellery from the fifties onwards, made by highly creative individual artists and designers [...]. It is in fact a misnomer, because every piece of jewellery was contemporary when it was made, unless it is a fake or counterfeit intended to look much older than it really is.*" (Unger, 2017, 614) In this thesis, the term contemporary jewellery is used as a blanket term for jewellery made in a contemporary context. As a Neo-alchemist, looking to cross boundaries, not establish them, it is beyond the scope of this thesis to delineate definitions for the various types of jewellery that exist. For such delineations, please see den Beste (2011, pp. 7-15), but also Unger and Van Leeuwen (2017), Lindemann et al. (2011) Cheung et al. (2006) and Astfalck et al. (2005).

Corundum Term to describe aluminium oxides. The varieties are: ruby (red), sapphire (colourless, blue, pink, orange, yellow, green and purple).

Critical Design Term introduced by Anthony Dunne (2005) to refer to a type of design that is critical and speculative, poses questions, and tells stories. Critical design pieces demonstrate that an object, including a piece of jewellery, can provoke thought and that design can be expressive (Gaspar, 2013).

Crystal This word has Greek roots and used to mean clear ice. It is still today called upon for a range of different uses, from signifying cut glass, to a clear ball to predict the future, to a gem in a piece of jewellery. To physicists and chemists however, a crystal is a solid material with atoms arranged in an orderly way, in line with its lattice structure, which gives crystals their unique properties.

Cubic Zirconia (CZ) The cubic crystalline form of Zirconium dioxide (ZrO_2).

Diffractive methodology See Section 2 titled *Diffractions: Differences, contingencies and Entanglements that matter* of Chapter 1 in the book *Meeting the Universe Halfway* by Karen Barad (2007, pp.71–96).

Do It Yourself (DIY) A concept that has been (re-)invented multiple times throughout the 20th and 21st centuries (Cramer, 2022). It was originally used to describe home improvements in America, but soon became more widespread in use to delineate a material practice where someone without professional training is working with techniques in a makeshift way. Today's DIY culture stems from self-built communities as could be found in the Arts and Crafts movement and was expanded as being counter-cultural when it became popular to describe home computing and hacking. Various subcultural uses of DIY turned it *"from merely a poetics (in the literal sense of poiesis as 'making') into a simultaneous poetics, aesthetics and – to some degrees – ethos and politics"* (Cramer, 2022). In this thesis DIY refers to making without being an expert, in a context where delineations between disciplines and labels such as artist and scientist become blurred.

Doublet Used in the jewellery field to describe a composite gemstone assembled from two parts.

Gemstone In the dictionary one can read: *"a jewel (= precious stone), especially when cut into a regular shape"* (Cambridge Dictionary, 2024a). In gemmology there are a variety of different definitions for the term, see Chapter 2, Section 2.

Grit crystal particles used in the production of abrasive tools, such as diamond saw blades. Crystal grit is applied to tools to enable the cutting of hard materials, such as stone or concrete.

Imitation Term used to describe materials which imitate a gemstone. These materials are not, however, the same in composition, structure or physical constants (Read, 1982). In gemmology imitation is used synonymously with simulant.

Inclusion Generally refers to a feature contained within a gemstone. A pre-existing or protogenetic inclusion is formed from a material which was present before the host crystal grew around it. A contemporary syngenetic inclusion is a substance which formed as the crystal grew. A post-contemporary or epigenetic inclusion occurred after the growth of the crystal has been completed (Read, 1982).

Intra-action As Barad (2007, p.33) states: *"The neologism 'intra-action' signifies the mutual constitution of entangled agencies. That is, in contrast to the usual 'interaction,' which assumes that there are separate individual agencies that precede their interaction, the notion of intra-action recognizes that distinct agencies do not precede, but rather emerge through, their intra-action".*

Jewellery artist In this thesis a jewellery artists is considered to be a maker of contemporary jewellery who is aptly aware of the developments of the practice since the 1950's when materials, function and the social context around the value of jewellery became subject of artistic interrogation. *"Jewellery as a fine art practice could not exist without its historical and traditional roots in materials and processes, adornment and ornamentation. A generation of jewellery artists are practicing now who have not only been trained with the tight parameters of a skills-oriented craft, but have also been educated by studio crafts people, who themselves revolutionised jewellery design in the 1960s and 70s. [...] Now, informed by current visual culture and the history and theory of modern art, new artistic strategies and enquiries are being formulated."* (Astfalck, 2005, p.19)

Lab-grown gemstone Term now prescribed to describe all gemstones created in a lab. In this thesis, the term is used interchangeably with man-made gemstone. See Chapter 2, Section 3, for a discussion on terminology.

Lattice Structure Term to describe the structure formed by the regular three-dimensional arrangement of atoms and molecules in a crystal (Read, 1982).

Macrocosm – Microcosm From the Greek μακρο (macro) and μικρο (micro), referencing great and small order (kosmos). Ancient alchemists believed that all components of the cosmos exist in relation to each other, and humans are a small component (microcosm) of the rest of the universe (macrocosm) (Dupre, 2014a), a belief that seems to align with our contemporary understanding of the world as expanded through the study of quantum physics. In this thesis, these terms are used in alignment with their original ancient alchemical usage and are used to shed light on arrangements and ornamentations.

Man-made gemstone Term used interchangeably with lab-grown gemstone to describe gemstones produced in a lab.

Materia Prima In alchemical literature, Materia Prima refers to formless primary matter from which the elements (air, earth, fire and water) developed (Dupre, 2014a). In this thesis, which borrows terms from alchemical practice, Materia Prima refers to both the various chemical elements that make up a formula, as well as the elements that make up a jewellery artefact.

Mined gemstone Term used in this thesis to describe all gemstones that have not been produced in a lab or were made by humans.

Neo-alchemist Term used in this thesis to describe a modern day alchemist, someone applying alchemical principles in a modern-day context, using contemporary tools, theories and capabilities.

Neo-gemstone(s) Whilst searching for a term to replace the prefixes used to describe lab-grown gemstones, Dr Hall, in response to the quest for a 'new' term, identified Neo-gemstones as a possible alternative. Neo, with its etymology linking back to the Greek 'néos' meaning young, fresh and new, is used in a range of fields to describe *"a different period or form of"* the *"new and abnormal"*, and even *"a new chemical compound isomeric with or otherwise related to (such) a compound"* (Cambridge Dictionary, 2024b). The term proved to be the most suitable and is used throughout this thesis to describe gemstones that have been grown in new ways or with varying chemical compositions, thereby extending beyond their appearance in nature or the use of natural stones.

Ouroboros Represented by a snake eating its own tail, in ancient alchemical texts this stands for cycles between, for example, solidification and dissolution, but also dying and rebirth (Dupre, 2014a). In this thesis, the term will be used to refer to both cyclical processes and thinking.

Phosphorescence A specific type of photoluminescence related to the ability of certain materials to emit light after they have absorbed photons. Unlike fluorescence, which occurs almost instantaneously, phosphorescence involves a delay between the absorption of light energy and its re-emission. In common language materials exhibiting phosphorescence are also referred to as 'glow in the dark' materials. In scientific literature the term 'persistent luminescence' is also used. In this thesis, all three are interchangeable.

Polycrystalline crystals A formation of many crystals, which each have a different orientation.

Quintessence Following Aristotle's view of nature, this was the fifth heavenly element (supplementing air, earth, fire and water) or spirit. In ancient alchemical literature everything was considered to have a core under this name, which combined all qualities, and can be distilled and therefore known (Dupre, 2014a). Whilst conducting research, several interviewees referenced the soul of crystals and gemstones, in this thesis, the term is used interchangeably with soul, and refers to the spirit/soul of both materials, tools, artefacts and people.

Ruby (Al_2O_3:Cr) The jewellery field's term for chromium doped aluminium oxide (Al_2O_3) (Figure 1.1 on page 2 and Figure 1.2 on page 6), also referred to as corundum.

Sapphire (Al_2O_3) The jewellery field's term for transparent undoped aluminium oxide (Al_2O_3) and all colours achieved beyond red chromium doped aluminium oxide (ruby). This includes aluminium oxide, also referred to as corundum, doped with pure or mixtures of iron (blue or yellow), titanium (blue or green), cobalt, lead, chromium, vanadium (purple or green), for example (Dubinsky, Stone-Sundberg and Emmet, 2020).

Simulant Term used in gemmology to describe a material that resembles another (usually more costly) material (Arem, 1977).

Solve et Coagula In alchemical literature, this term refers to the repeated dissolution and solidification of a substance or the repeated separation and combination of matter and form (Dupre, 2014a). In this thesis, the term is used to describe these two processes in relation to the growth of gemstones and to the creation of artefacts.

Synthetic gemstone The term, commonly used in the press and gemmological literature to describe gemstones made from man-made crystal materials, is not considered adequate by the author of this thesis (see Chapter 2, Section 3) and is therefore not used to describe these stones.

Tinkering A term borrowed from Human-Computer Interaction (HCI) that points to hacking and manipulating physical interaction materials in a naive, playful and creative way (Cermak-Sassenrath and Møllenbach, 2014; Sundström and Höök, 2010; Brown and Sarkar, 2008; Buxton, 2007; Zimmerman, Forlizzi and Evenson, 2007). Tinkering is an approach characterised by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities (Resnick and Rosenbaum, 2013). Tinkering is a seemingly undirected process; it is driven by curiosity and playfulness; problems and challenges are self-defined, in which iterations of prototyping, observing, reflecting, defining a new challenge and failing all play a role (Mader and Dertien, 2016).

Transmutation Derived from the Latin 'transmutare'. In the alchemical literature, the production of bronze, brass, glass, and other materials is considered a transmutational process, along with the production of gold, a key pursuit of alchemists (Dupre, 2014a). Transmutation in this thesis will therefore refer to the transmutational process of growing gemstones.

Triplet Used in the jewellery field to describe a composite gemstone assembled from three parts, or when a coloured transparent cement is sandwiched between two transparent parts (Nassau, 1980).

Urban mining This is a relatively recent term, although its underlying concept has been in development for the last two decades (Xavier, Ottoni and Leonardo, 2023). As part of the research project, the term was first discussed with Julia Wild, who supported the development and execution of the 'Bling It' project (see Chapter 3) to communicate the activity the project aimed to instigate. Therefore, in this thesis, the term is used to describe the retrieval of waste gemstone materials (mining) from a company (urban environment) that no longer has any use for the materials in their setting.

Waste Referred to in the dictionary as *"unwanted matter or material of any type, especially what is left after useful substances or parts have been removed"* (Cambridge Dictionary, 2024c).

YAG Yttrium Aluminium Garnet. Colourless YAG ($Y_3Al_5O_{12}$) became available as a diamond imitation in the late 1960s (Nassau, 1980). It has a refractive index of 1.83, dispersion of 0.028, minor brittleness, and hardness of 8¼. Since the influx of Cubic Zirconia in 1977, it is rarely used as a diamond imitation in the jewellery industry today. However, YAG is still produced in large quantities for the laser industry.

4 Cs In diamond certificates, diamonds are assessed on Colour, Clarity, Cut and Carat (weight). The absence of colour is graded on a D-to-Z scale ranging from colourless ('D' being the most valuable), to light yellow or brown ('Z' is the least valuable). Colour is usually established by comparing the diamond with a Master Colour Comparison Set. The relative absence of inclusions and blemishes is referred to as the clarity grade, ranging from Flawless to Included, based on size, nature, number, position, and relief of characteristics visible under 10x magnification. Cut grade incorporates the aspects of face-up appearance, design, and craftsmanship, and is graded on a scale from Excellent to Poor. The weight given in Carats is recorded on certificates to the nearest hundredth of a carat, where one carat is equal to one-fifth of a gram.

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Figure 1.3. Author at the Centre for Print Research. Photography by Kate Rutsch for the University of the West of England.

Chapter 1. Introduction

1.1. Researcher's Rationale

To provide an insight into the formulation of the aims, objectives, and choice of methods and approaches to the research presented in this thesis, it is useful to comment on the author's background and underpinning motivations for undertaking the study. As a contemporary jeweller, educator and self-proclaimed alchemist, the author has experience in the production of jewellery designs for commercial and artistic purposes, including several projects that crossed art and science, and has worked for and in jewellery education institutions. After six years of both operating within the jewellery industry and overseeing and developing a curriculum for the jewellers of the future, the research presented itself as an opportunity to respond to the gap in knowledge that was identifiable on the subject.

Jewellers have used crystals for the creation of jewellery for centuries (Philips, 2012), utilising tools to adjust and enhance stones found or extracted from the earth. Today, however, some significant innovations in the materials and processes naturally associated with jewellery have been achieved to serve other sectors. Bespoke man-made crystals are revolutionising technology and engineering: for instance, diamonds grown microscopically on sheets to optimise conductivity (American Institute of Physics, 2017) are present in high-performing microchips, and the laser industry has seen major improvements due to the introduction of synthetic sapphire components developed to specifications (Stone-Sundberg, 2013).

However, in the jewellery industry, where crystals are used in great numbers, there has been limited innovation in the use of bespoke lab-grown materials. Although the technology to produce lab-grown crystals of gemstone quality has been around for decades (Arem, 1973), it has mainly been used to imitate mined stones. The industry has remained fearful of a significant disruption by these 'fakes' (Pyne, 2019). Companies that have been at the forefront of supporting the invention of lab-grown gem materials have been subject to lawsuits (Chatham, 2017), and large corporations are setting up product lines (Biesheuvel and Burden, 2018) with the aim of segmenting the position of some of these man-made materials as inferior to their 'natural' counterparts.

1.4

Figure 1.4. Centre for Print Research Postcard, created by the author.

Even though more lab-grown gemstones are entering the market, there is still limited attention dedicated to exploring the possibilities for innovation these new materials provide in a jewellery context. This is in contrast to their traceability and potentially beneficial sustainability credentials (Martin, 2011), compared to mined gemstones (Van Der Wal and Haan, 2010).

The limited innovation in this area can also be attributed to jewellers' lack of understanding of the chemistry and physics required for crystal growth. Whereas in the past European alchemical ateliers regularly housed all the arts of fire, including goldsmithing and sciences, today it is rare for jewellery artists and chemists to collaborate. The divide between art and science is well-debated and, even though there are initiatives to bridge the gap between the two, often still entirely independently running disciplines, no return to the alchemical laboratory is in sight. During their training, neither jewellers nor chemists gain insights into aspects relevant to them that are encompassed in the other discipline. For jewellery artists, this means they receive little instruction in the relevant chemistry and physics; for chemists, this means that little to no time is dedicated to developing creativity.

To date, the polarisation of the personae of scientist and artist, one expected to be methodological in tracing 'facts ', the other to be imaginative in dealing with 'artifacts', prevails (Daston, 2005). Frustrated by the jewellery industry's lack of knowledge of the subject, and determined to investigate the opportunities these materials provide to jeweller artists, the author saw the doctoral research opportunity as part of her Crafts Council Research Fellow role at the multidisciplinary Centre for Print Research (Figure 1.3 and Figure 1.4) as the ideal springboard and context for the research detailed in this thesis. The research aimed to be an exemplar of the return of artistic imagination and artefact creation to the chemistry lab and demonstrate that there is opportunity for innovation when applying a disregarded alchemical methodology, bringing together methods of both the discipline of art and science.

1.5

Figure 1.5. *What is 'fake' today, might be 'real' tomorrow*. Digital artwork.

1.2. Research Questions, Aim and Objectives

The doctoral research project was structured to respond to the following research questions:

1. What creative opportunities does the incorporation of man-made crystal materials and/or related crystal growth processes provide jewellery artists when creating jewellery?

2. With the technology and resulting materials having been around since the late 19th century, why are innovations with man-made crystal materials within a jewellery context sparse?

The underpinning aim of this research project was therefore to complete a practice-based study on man-made crystals through the lens of contemporary jewellery, by conducting an alchemical exploration of lab-grown crystals and related technologies in order to propose innovations while challenging the current context, terminology, and underlying assumptions. This would enable the determination of implications, possibilities, and limits in utilising man-made crystals for the development of jewellery, situating their highly debated usage in a historical and contemporary context (1900-2024) and proposing an alternative terminology for their labelling in a jewellery context.

The following objectives were established to achieve the aim of the research project:

1. To complete a contextual review and interviews with key sector experts to investigate the culture and context surrounding man-made crystals, exploring the differences between man-made crystals and their mined counterparts used in the production of jewellery, visualising findings through Critical Design (Malpass, 2017; Gaspar, 2013).

2. To investigate the terminology used to reference man-made crystals in order to identify the need for the re-framing and re-naming of enhanced and designed crystal materials when used in a contemporary jewellery context.

3. To conduct three case studies through which man-made crystals are researched and used in the experimental production and planned creation of jewellery designs, to explore their potential design implications, possibilities and limitations.

4. To evaluate the feasibility and practicality of incorporating the researched man-made crystals and related processes into a contemporary jewellery practice.

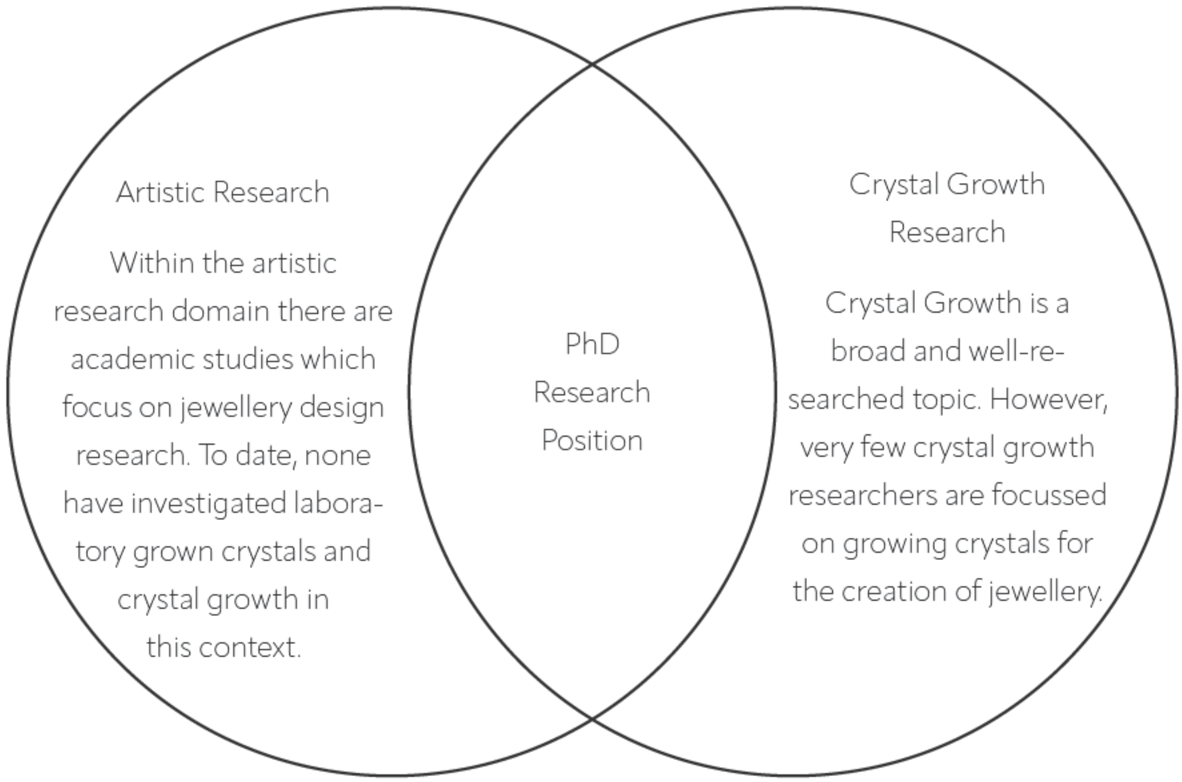


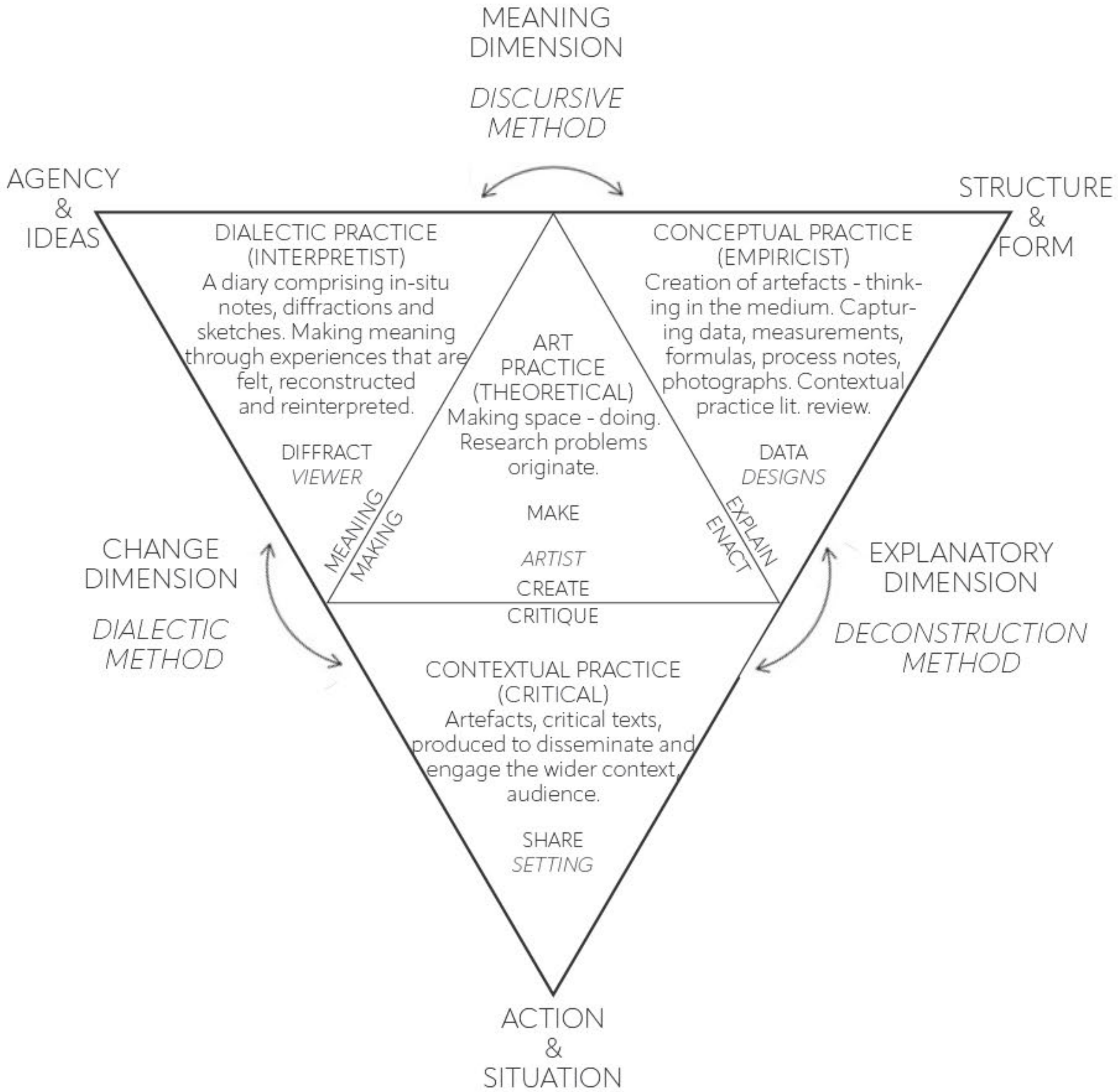
Figure 1.6. Venn diagram of PhD research position.

1.3. Research Methodology

"The conceptual clarity of classical physics has been swept away by quanta. Reality is decidedly not how it is described by classical physics. This was an abrupt awakening from the pleasant sleep in which we had been cradled by the illusion of Newton's success. But it was a reawakening that connects us back to the beating heart of scientific thinking, which is not made up of acquired certainties: it is thinking constantly in motion, the power of which is precisely the capacity to always question everything and begin over again, to be fearless of subverting the order of the world in the search for a more efficient one, only to then put a further question mark over everything, to subvert it all over again."
(Rovelli, 2022, p.66)

It could be argued that our understanding of gemstone crystal growth, both in nature and in the laboratory, has evolved to such an extent that endeavours to build upon this knowledge in the scientific realm is where a contemporary scholar's focus should sit. However, it is important to point out that the knowledge acquired on the subject to date has mainly remained in the scientific realm and has persisted in being largely inaccessible to artistic interrogation or exploration, resulting in a vacuum of understanding. This artistic practice-based research project has been developed to be a first attempt to bridge this gap (Figure 1.6) and, as encouraged by our most recent understanding of scientific enquiry, attempted to fearlessly question everything in relation to the growth of crystals for jewellery all over again – this time from a jeweller's perspective.

Whilst acknowledging that no certainties can ever fully be assured, in order to achieve the aforementioned research aim and objectives, and arrive at a suitably substantiated intermediate answer to the instigating research question, the research project was designed in alignment with the practice-led research framework documented by Graeme Sullivan in *Art Practice as Research: Inquiry in Visual Arts* (2010) and in Chapter 2 of *Practice-led Research, Research-led Practice in the Creative Arts* (Smith and Dean, 2009). The framework was developed to conceptualise art practice as research by "*considering the relationship between the theories and practices that inform how art can assume its potential as a creative and critical form of human inquiry.*" (Sullivan, 2010).



1.7

Figure 1.7. 'Practice-led research framework of practices' as documented in the text ***Making Space*** by Graeme Sullivan published in ***Art Practice as Research: Inquiry in Visual Arts*** (2010) and in Chapter 2 of ***Practice-led Research, Research-led Practice in the Creative Arts*** (Smith and Dean, 2009). Here recreated with inclusion of methods applied as part of the PhD research.

A framework that can be adapted to suit different purposes, emphases, and scales, yet retain a dynamic relationship between the parts and the whole, will guard against the tendency to codify research.
(Sullivan, 2005, p.93)

The framework, which was not designed to codify research practice, but to instead accommodate a broad range of content interests within the visual arts, was aligned with the scale and emphasis of the research aim and objectives underpinning the project. It was recreated in Figure 1.7, summarising the most relevant features of the framework and the planned methods of enquiry of the research.

ART PRACTICE

"When seen in relation to the surrounding areas, different perspectives and practices may emerge as inquiry twists and turns towards various sources in the exploration of forms, purposes and actions."
(Sullivan, 2009, p.49).

The central triangle, which shares conceptual edges with the three adjoining triangles representing other research practices in the diagram, is the 'making space'. The questioning of existing knowledge by the artist, through a hands-on exploration, was at the core of this artistic research project and central to theorising the practice as research. The processes employed were directed by personal artistic interest and insight, and were informed by knowledge of the practice (jewellery). While the research was grounded in the studio experience, throughout the project, the research moved eclectically across the permeable barriers.

CONCEPTUAL PRACTICE

"[...] evidence is derived from experience of social reality and is collected in many forms and analyzed using a range of related methods and techniques."
(Sullivan, 2005, p.97)

The conceptual practice encompassed visualising thoughts through form-giving, resulting in the creation of artefacts (ranging from samples and tests to pieces of jewellery), by 'thinking in the medium' (Sullivan, 2010). In alignment with empiricist traditions, three case studies (Gillham, 2000) (Table 1.1 on page 34) in which man-made crystal materials and, where applicable, aligned processes, were used in the production of such artefacts. Each case study was documented through the capturing of data (e.g. measurements/formulas), taking of process notes and photographs. In order to support a critique of existing knowledge, find problems and identify the 'What?' and 'Why?' (Sullivan, 2010), a literature review (which proved to provide limited and static insight due to the nature of the study) was supplemented with additional data-creation methods (interviews, survey, workshop, guided tours at companies, along with relevant fair, museum and site visits) that aligned with the investigation of dynamic systems. The latter also includes data created through collaborations with professionals and companies.

Case Study 1 (Chapter 3)			
In order to exemplify how non-utilised gemstone materials (in particular industrial waste materials) could be incorporated into jewellery, Case Study 1 concerned the identification of artistically interesting yet currently non-utilised man-made gemstone materials. Following this scoping activity, which included a visit to several companies (including the UK diamond growing company Bring Diamonds), the author incorporated the acquired waste materials into contemporary pieces of jewellery and diffracted on the concept of waste and its influence on creative practice. Furthermore, during the Mary Somerville funded research visit to Idar-Oberstein, a workshop was organised for nine participants (Figure 1.8 on page 38), where waste materials retrieved through an urban mining experience at Effgen enabled participants to incorporate both materials and associated industrial processes for the creation of new work.			
Data:	10 guided company visit observations notes	9 unguided company visit observation notes	4 museum visit notes
	4 fair observations	3 lecture notes	'Bling It' workshop data
	51 survey responses	Literature review	Process notes
	Artefacts	Measurements	Photographs

Case Study 2 (Chapter 4)			
Case Study 2 involved two collaborations with crystal growing institutions, one from industry (BREVALOR– Switzerland), and one academic crystal growth department based in Bristol University, exploring whether these collaborations between art (jewellery) and science (crystal growth) could result in innovative man-made crystal materials and artefacts that would be interesting for the production of jewellery artefacts. In collaboration with BREVALOR, BRG Types 1 and 2 and BRB Type 1 (each glow in the dark gemstone materials not previously used in jewellery) were grown and manufactured for application. In collaboration with Dr Hall, Dr Potticary and PhD candidate M. Whitehurst, low-temperature growth of corundum was explored, which they are now furthering through the development of novel formulations for the creation of new crystal colours, opening up avenues of exploration for the production of glazes and enamels.			
Data:	Email communication	Meeting minutes	Models
	Design briefs	Process notes	Samples
	artefacts	measurements	photographs

Case Study 3 (Chapter 5)			
The final case study explored the DIY growth of crystals. The solution growth method was documented using the growth of salt, sugar and alum. Learnings were later applied to the low-temperature growth of ruby, which was incorporated into the jewellery design process. Linking to bio-design/art methodologies, five hypotheses derived from the characteristics and advantages of Growing Design were tested to explore the design opportunities the method provides designers when: (1) growing around shapes, (2) in-situ in designs, (3) when utilising the grow-ability of the process as a feature, (4) inviting polycrystalline configurations or (5) inviting spontaneous nucleation.			
Data:	Literature review	Design of experiments	Health and safety data
	Models	Process notes	Samples
	Artefacts	Measurements	Photographs

Table 1.1

Table 1.1. Overview of case studies.

DIALECTIC PRACTICE

"Entanglement is therefore far from being a rare phenomenon that occurs only in particular situations: it is what happens generically in an interaction, when this interaction is considered in relation to a system external to it. From an external perspective, any manifestation of one object to another, which is to say any property, is a correlation; it is an entanglement between object and another. Entanglement, in some sense, is none other than the external perspective on the very relations that weave reality: the manifestation of one object to another, in the course of an interaction, in which the properties of the objects become actual."
(Rovelli, 2022, p.88)

"The conclusion is revolutionary. It leaps beyond the idea that the world is made up of a substance that has attributes and forces us to think about everything in terms of relations."
(Rovelli, 2022, p.120)

The dialectic practice: following the collection of data, an intertextual analysis (Yin, 2018) was conducted, firstly on the books, articles, newspaper clippings and other documents sourced from publicly available sources and those obtained through visiting the private archive of D. Jerusalem. The literature review also consisted of reviewing relevant documentaries, media footage and social media content from brands and industry institutions. This data was supplemented with data that supports the creation of dynamic systems (Sullivan, 2010), which included a survey (Appendix 6) and interviews with 12 key industry experts (Appendix 4), both qualitative methods of data collection which were used in order to document the, often unwritten, ideas and beliefs held by industry professionals in relation to the materials at the heart of the enquiry. Applying discursive methods, incorporating an empiricist focus on structure (conceptual practice) and the interpretivist emphasis on agency, patterns and inconsistencies in the data were sought out and a process of 'making sense of the data' (Sullivan, 2010) undertaken. All the collected data was used to build a picture of the context around the enquiry, to influence the designs and making practice and to guide its findings.

Such dialectic practice results in the making of meaning through experiences that are felt, lived, reconstructed and reinterpreted (Sullivan, 2009). A reflective diary comprising in-situ notes, reflections and sketches was kept to capture the uniquely human process of making meanings and their impact, with the aim of intently documenting the possibilities and limitations of using these crystals, and the processes with which they were developed. Following the methodology described by Skains (2018) a post-textual examination was conducted on both the created artefacts and the diary at the end of each case study, and then again during the writing up of this thesis, in order to offset the limitations of reflective analysis and self-observation.

Method	Participant(s)	Date(s)	Reach
Survey	Global jewellery community	31 January see Appendix 6	51
Monthly meetings	D. Rytz	Various see appendix 8	1
Six-monthly meetings	Dr Hall, Dr Potticary and M. Whitehurst	Various see appendix 8	3
Guided company visits	9 German companies, 1 UK company	Various see Appendix 5	10
Conference presentations	Artistic research community	Various see Appendix 1	>100
Lectures	Art education community	Various see Appendix 1	>100
Industry round table event	German industry	6 October 2021	15
Presentations/exhibitions at industry fairs	Global jewellery community	See Appendix 1	>100

Table 1.2

Table 1.2. Outreach research methods overview.

Furthermore, as the interpretivist tradition emphasises meta-cognition, and reflective processes are considered dialogic (Sullivan, 2010) the research project was designed to include two longer residencies (of two months each) and several smaller research visits to Idar-Oberstein in Germany, in order to engage with the largest stone cutting and dealing community in Europe. To supplement individual open dialogue and attempts at drawing together all the information, and to answer 'How?' and 'What might be?' within the research project, understandings were communicated at a community level, and with the research community, opening the reflexive dialogue up to debate and discussion. Several communication methods were employed to engage with experts individually and the community in general throughout the research project (Table 1.2 on page 36).

This thesis documents the findings of the contextual review (Chapter 2) and case studies (Chapters 3, 4 and 5). Following the prescribed format underpinning good case study research as documented by Gillham (2000) care is given to document each case study's alignment with the aim of the research and how it influenced the research in response. Each case study chapter concludes with an evaluation, documentation of the emergent theorising, and an explanation of the issues being dealt with (Gillham, 2000). The last chapter (Chapter 6) provides an overarching summary of the conclusions drawn from the research and recommendations for future research.

CONTEXTUAL PRACTICE

"The broad purpose of critical forms of inquiry is the enactment of social change."
(Sullivan, 2005, p.97)

Furthermore, as part of the contextual practice, and a desire as an artist/designer to bring about social change, artefacts and critical texts were produced (Appendix 10) to pose as a critical form of enquiry, which aimed to visualise the findings deemed important to highlight in order to question and perhaps influence problems identified in the research project. Engaging in a cycle of creating-critiquing, the cognitive process of 'thinking in a setting' makes use of debates and desires that are local in focus but global in reach (Smith and Dean, 2009). Chapter 2 documents the key considerations that aligned with the contextual practice of this study, revolving around questioning the inferior status that man-made crystal materials are assigned in gemmological circles, in trade and (increasingly fewer) general press reports. Additionally, the confusing, wide-ranging and, in some cases, devaluing terminology used to describe these materials in a jewellery context was revealed as a problematic aspect of the setting, driving a response to propose change. Utilising the interactive nature of aesthetic expression and the debate and dialogue resulting from the published text (Appendix 10), artistic attempts were shared as part of exhibitions, presentations and lectures, in the hope of bringing about political, cultural and educational change (Appendix 1).

1.8

Figure 1.8. Author working with the participants of the 'Bling It' project at the University of Applied Sciences Trier/Idar-Oberstein. Photography by Gina Müller for the University of Applied Sciences Trier/Idar-Oberstein. Image used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein.

1.4. Ethics

Following ethical approval obtained from the UWE Ethics Board, all interview participants, industry and academic collaborators and workshop participants gave written permission for their information to be used throughout the study. Prior to any interview, activity, or workshop, details were shared about the research project (Appendix 2). A copy of UWE's privacy notice and participant consent form were also provided ahead of any activity to obtain written consent and protect both parties. Where possible, permission has been sought for the images included in the thesis, any images that have not been granted permission for inclusion will be redacted in the final published thesis. Where images were not taken by the author, the photographer is credited in the captions.

Chapter 2	Objectives met:
This chapter explores the historical and contemporary context of lab-grown crystals. Tracing first historical developments and the response of the jewellery industry, it then proceeds to discuss man-made gemstones in today's complex jewellery landscape, addressing terminology, value, authenticity, and artificiality. The term 'Neo-gemstone' is introduced and examined as an alternative to common descriptors. Findings are supported by data from an open survey, interviews, company visits, and other research visits, as well as openly accessible data. The chapter aims to consider jewellery professionals' views and sentiments. The chapter references critical design pieces to highlight identified challenges and implications.	Complete a contextual review and interviews with key sector experts to investigate the culture and context surrounding man-made materials. Investigate the terminology used to reference man-made crystals.

Chapter 3	Objectives met:
Case Study 1, designed to test the suitability of currently non-utilised man-made gemstone materials, revolved around the identification of industrial waste. Following a visit to Bring Diamonds, the author, as a jewellery artist, incorporated the waste materials acquired into contemporary pieces of jewellery, through which a review of their properties and the outcomes was conducted. During the Mary Somerville-funded research visit to Idar-Oberstein, a workshop was organised for nine participants, where waste materials retrieved through an urban mining experience at Effgen were used, enabling participants to incorporate both materials and associated industrial processes in their creation of new work.	Use case studies through which man-made crystals are used in the experimental production and planned creation of jewellery designs to explore potential design implications, possibilities, and limitations. Evaluate the possibility and practicality of incorporating researched man-made crystals into a contemporary jewellery practice.
Chapter 4	
Chapter 4 documents Case Study 2 – two collaborative studies with crystal growers, one from industry (BREVALOR– Switzerland) and one with an academic crystal growth department based in Bristol University, exploring whether the collaboration between art (jewellery) and science (crystal growth) could result in innovative man-made crystal materials that would be interesting for the production of jewellery. In collaboration with BREVALOR, BRG types 1 and 2 and BRB type 1 were grown and manufactured for the application in jewellery. In collaboration with Dr Simon Hall, Dr Jason Potticary and PhD candidate Michaela Whitehurst at the University of Bristol novel formulations were tested for the creation of new crystal colours.	
Chapter 5	
The final case study, documented in Chapter 5, describes the DIY growth of crystals. The solution growth method, first documented to grow salt, sugar and alum, and later applied to the flux growth of ruby, was incorporated into the jewellery design process, and considered as methodology in the context of the author's jewellery practice.	

Chapter 6	Aim met:
While reviewing and responding to what this research set out to do, the final chapter summarises the key findings from the previous chapters, noting the contribution to knowledge of the research and thesis. Furthermore, areas for further research and exploration are signposted.	Determine the design implications, possibilities, and limits of utilising man-made crystals in the development of jewellery designs.

Table 1.3

Table 1.3. Thesis chapter overview.

1.5. Structure

The thesis will guide the reader through the findings of the research project. The thesis is structured into an introductory chapter (Chapter 1), covering the researcher's rationale for the research project, the research questions, aims and objectives, a section on ethics and the current section documenting the structure and approach to the research. The introduction chapter is followed by a chapter documenting the context surrounding man-made crystals (Chapter 2), and three chapters (Chapters 3-5) documenting the practice and three case studies conducted as part of the research project. Table 1.3 gives an overview of the chapters and their alignment with objectives and aims.

1.9

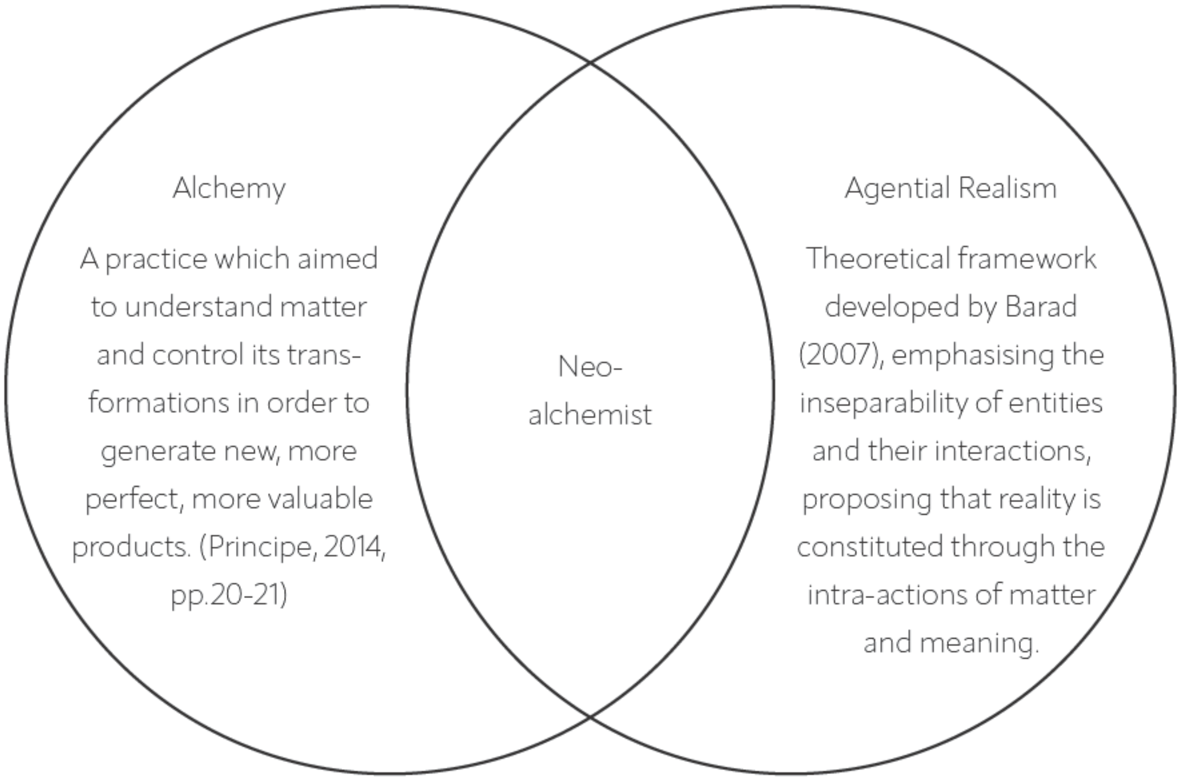
Figure 1.9. Desk used to conduct reading, writing and research by the author.

1.6. Alchemical Approach

"Alchemists sought knowledge and explored the world in two very different places: in books and laboratories. In books they sought written hints to guide their practice, clues to secrets known by their predecessors, recipes for useful materials and notions about the nature of matter and how to control and transform it. In laboratories, they struggled to put into practise what they had read and interpreted, or they struck out along new avenues to uncover the secrets of nature and produce new materials."
(Principe, 2014, p.60)

Since originating in Graeco-Roman Egypt during the 2nd century AD, alchemy and its numerous practicing alchemists (including famous figures like Isaac Newton and Robert Boyle) laid the foundations for modern science, most notably chemistry, in three Western cultures. Even though popular ideas about the subject still associate it mainly with witchcraft, spirituality and fraud, there has been scholarship to rewrite its history and correct this misconception (Dupre, 2014a). Expanding far beyond the quest for re-creating gold, alchemical practitioners focussed on the creation of medications, pigments, dyes, alloys, as well as the recreation of gemstones. Those practicing alchemy had diverse backgrounds and included university professors, noblemen, physicians, brewers and also gold- and silversmiths. Alchemical laboratories were known to house multiple disciplines. Two famous examples from the 16th century were the 'fondaria' at the Ufizzi and the 'Casino di San Marco' in Italy where, amongst other activities, the imitation of precious gemstones and goldsmithing occurred under the same alchemical moniker and in relative close proximity.

Whilst today it is rare to find a silversmith, goldsmith, or jeweller in a crystal growth chemistry lab and, vice versa, a crystal grower in a jeweller's workshop, and collaboration between the two disciplines seems infrequent in occurrence, applying an alchemical methodology, which includes both reading/researching and hands-on experimenting (Figure 1.9 and Figure 1.11 on page 46) in order to acquire new knowledge, became an endeavour as part of the research. Art and alchemy (as pre-cursor to modern chemistry) have a tradition as manual crafts (Dupre, 2014b). Alchemists and artists engaged in hands-on explorations of their subject, conducting experiments and creating 'artefacts', not just 'facts'.



1.10

Figure 1.10. Venn diagram of Neo-alchemist position as proposed in this thesis.

Lying at the basis of the polarisation of the personae of scientists and artists in the early 17th century (one deemed to be methodological in tracing 'facts', the other to be imaginative in dealing with 'artefacts'), the common etymology behind both words started to be ignored, yet both interestingly derive in Latin and European vernaculars from making and doing (facere, faire, fatto) (Daston, 2005). In order to overcome the basis for limited innovations in the subject in a jewellery context to date, a turn to either the creation of artefacts in collaboration with scientists, or applying an alchemical approach to the application of crystal growth experiments was required.

This also aligns with modern-day philosophies that have emerged as a result of quantum physics. Agential Realism, as proposed by Karen Barad (2007, p.26) is *"an epistemological-ontological-ethical framework that provides an understanding of the role of human and nonhuman, material and discursive, and natural and cultural factors in scientific and other social-material practices, thereby moving such considerations beyond the well-worn debates that pit constructivism against realism, agency against structure, and idealism against materialism. Indeed, the new philosophical framework that I propose entails a rethinking of fundamental concepts that support such binary thinking, including the notions of matter, discourse, causality, agency, power, identity, embodiment, objectivity, space, and time".* Building on Barad's writings, it is proposed a Neo-alchemist, whilst no expert on the subject, would be inspired by the ideas presented as part of Agential Realism. Underpinnings of such theories align with alchemical sentiments around the necessity to have hand-on engagement with experiments in order to acquire knowledge. Challenging the nature-culture dichotomy, humans are considered part of the nature that is sought to be understood (Barad, 2007).

"Diffraction is not a set pattern, but rather an iterative (re)configuring of patterns of differentiating-entangling. As such, there is no moving beyond, no leaving the 'old' behind. There is no absolute boundary between here-now and there-then. There is nothing that is new; there is nothing that is not new. Matter itself is diffracted, dispersed, threaded through with materializing and sedimented effects of iterative reconfigurings of spacetimemattering, traces of what might yet (have) happen(ed)."
(Barad, 2014, p. 168)

The framework also offers the concept of diffracting (Barad, 2014), to replace reflecting, which holds the world at a distance. Considering knowing as a material engagement that participates in (re)configuring the world, a Neo-alchemist agrees that making knowledge is not merely about making facts, but about making worldly configurations through materially engaging as part of the world and in giving it specific material form (Barad, 2007). It is for this reason that diffraction is used as an alternative to reflection in sections titled ouroboros. Represented by a snake eating its own tail, ouroboros in ancient alchemical texts stands for cycles between solidification and dissolution, as well as dying and rebirth (Dupre, 2014a). In this thesis, the term is used to refer to both cyclical processes in experimentation and thinking which aligns with diffraction.

1.11

Figure 1.11. Author in the lab/studio at the Centre for Print Research. Photography by Kate Rutsch for the University of the West of England. Image used with kind permission of the University of the West of England.

Furthermore, in alignment with alchemical practices, where reading and experimenting go hand in hand, the interweaving of quotes and positioning of images in juxtaposition to text, is also tested as a diffraction method and experiment. Pulling readers back in time, scaling up or down, bouncing the gaze or evoking an imaginary material engagement, the text is balanced with reading and non-reading, the author's voice and the voices of others, evoking the diffraction patterns of light and dark. It is for this reason recommended that a reader engaging with this text on a digital device should use the double-page spread function to allow these diffractions to materialise across pages. Diffraction challenges linearity which, albeit present in the thesis in some sense (particularly due to the format requirements set for this thesis by the university and overarching regulatory bodies), has been attempted to be bent, twisted and turned within the confines of the structure. Whilst it is outside the scope of this thesis to offer a full overview of Agential Realism and other aligned philosophies, as a true Neo-alchemist, the author attempted to be unencumbered by disciplinary boundaries, and aimed to be experimental in approach, and this thesis will therefore engage with some of the shifts in thinking these philosophies propose.

This thesis, itself a written accompaniment to the artefacts at the centre of the investigation, aims to provide the reader with an insight into the collaborations and the alchemical methodology underpinning the research. Departing from alchemical traditions, which saw incomprehensible pictures and texts requiring decoding and translation, this thesis has been written to be comprehensible, with limited references to alchemical codes, only where methodologically justified, in line with a key desire to promote the methodology for broader adaptation. However, this thesis clearly does not aspire to be a modern version of a scientific text and, even though processes and scientific collaborations are reported on, the unreproducible nature of the experiments, and the limitations on reporting in relation to Non-Disclosure Agreements does align naturally with the culture of alchemical secrecy.

1.12

Figure 1.12. Author visiting discontinued mine in Idar-Oberstein, Germany.

1.7. Research Positionality

"The real nature of matter was unknown to the alchemist: he knew it only in hints. In seeking to explore it he projected the unconscious into the darkness of matter in order to illuminate it. In order to explain the mystery of matter he projected yet another mystery – his own psychic background – into what was to be explained: Obscurum per obscurius, ignotum per ignotius! This procedure was not, of course, intentional; it was an involuntary occurrence."
(Jung, 1968, p.336)

In this research project the author was an active interpreter of all that was sensed in the context of the research project. Identifying as a trained jeweller, Neo-alchemist, and researcher, membership of the wider European jewellery community was actively pursued. Aside from residing in Idar-Oberstein for the various residencies and visits there was no experience of living there as a local for a longer period of time, and the language spoken, a German dialect, remained largely inaccessible. Thus, all conversations conducted were either in English or supported by the translation by colleagues at the University of Applied Sciences Trier/ Idar-Oberstein. The standpoint as a Belgium/UK-trained goldsmith fostered a common superficial understanding of our trade, however, it is important to acknowledge that the researcher's background influenced critical viewpoints and approaches when interpreting historical texts, anecdotes, activities, and opinions shared and experienced in 'the Valley'. This is therefore an acknowledgement of the author's positionality in relation to the contextual diffractions embedded in this thesis, particularly on events and discussions that occurred outside of the immediate longer-term context.

2.1

Figure 2.1. Sections of Verneuil ruby boules.

Chapter 2. Research Context

2.1. Introduction

This chapter examines the historical and contemporary context of the study. Starting with a review of key historical developments in the growth of lab-grown crystals, the response of the jewellery industry to these developments is documented, including the formation of the branch of gemmology. The chapter then considers man-made gemstones in a fluctuating and complex contemporary jewellery context, discussing the terminology used for their identification and their assigned value. Concepts such as authenticity and artificiality are introduced and interrogated. A new term, 'Neo-gemstone', is proposed and explored. This chapter provides a contextual framework for the subsequent research outcomes, and documents the current state of the field, highlighting the urgency of this research.

The findings presented in the second section of this chapter were supported by a review of the data collected from a survey (Appendix 6), twelve semi-structured in-depth interviews (Appendix 4) (Johnson, 2001), ten guided and nine unguided company visits, and a range of other research visits, including one to a now-discontinued mine (Figure 1.12), as well as gemstone and mineral museums (Appendix 5). These qualitative methods of data collection were used in order to document the, often unwritten, ideas and beliefs held by jewellery professionals in relation to the materials at the heart of the enquiry. All the collected data was used to build a picture of the context around the enquiry, to influence the designs and making practice, and to guide findings. During the PhD project, two papers (Appendix 10) were published reporting on the contextual review: *Man-made Crystals: A Review of their Historic and Contemporary Context and Use* (Boons, 2021b) and *Pierres Precieuses Artificielles: Une Bataille de Mots – Man-made Gemstones: A War of Words* (Boons, 2022b).

Finally, in line with a desire as an artist/maker to bring about social change, this chapter will discuss the artefacts produced as Critical Design, using them as anchors to re-frame the identified challenges, implications and possibilities. Throughout the research project, this contextual review, insights, commentary and discussions informed the creation of Critical Design aimed at visualising findings deemed important to highlight in order to question and perhaps influence the problems identified. This chapter is therefore accompanied by images of a collection of critical jewellery design pieces which are juxtaposed with the text.

2.2

2.3

2.4

Figure 2.2. Gem of glass paste imitating sard, engraved with the head of a warrior in profile, with a crested helmet and a beard in stylised parallel lines; at the back of the neck is a pear-shaped projection. Photography by Samantha Levick and Rebecca Rolfe for the British Museum. License using CC BY-NC-SA 4.0. Available via: https://www.britishmuseum.org/collection/object/G_1867-0507-433

Figure 2.3. Gilded bronze finger-ring, oval bezel with convex paste intaglio (imitating brown sard): bird perched on an uncertain object, perhaps the fore-part of a ship. 323BC-31BC. Photography by Rebecca Rolfe and Samantha Levick for the British Museum. License using CC BY-NC-SA 4.0. Available via: https://www.britishmuseum.org/collection/object/G_1872-0604-457

Figure 2.4. Gold necklace with a large oval pendant containing glass, imitating Sardonyx, in a fretworked setting, with two conical shaped beads, each with a small hook on the base, an elaborate hook and eye, and a cracked glass inset. 3rdC. © The Trustees of the British Museum. License using CC BY-NC-SA 4.0. Available via: https://www.britishmuseum.org/collection/image/1613178370.

2.2. Historical Context

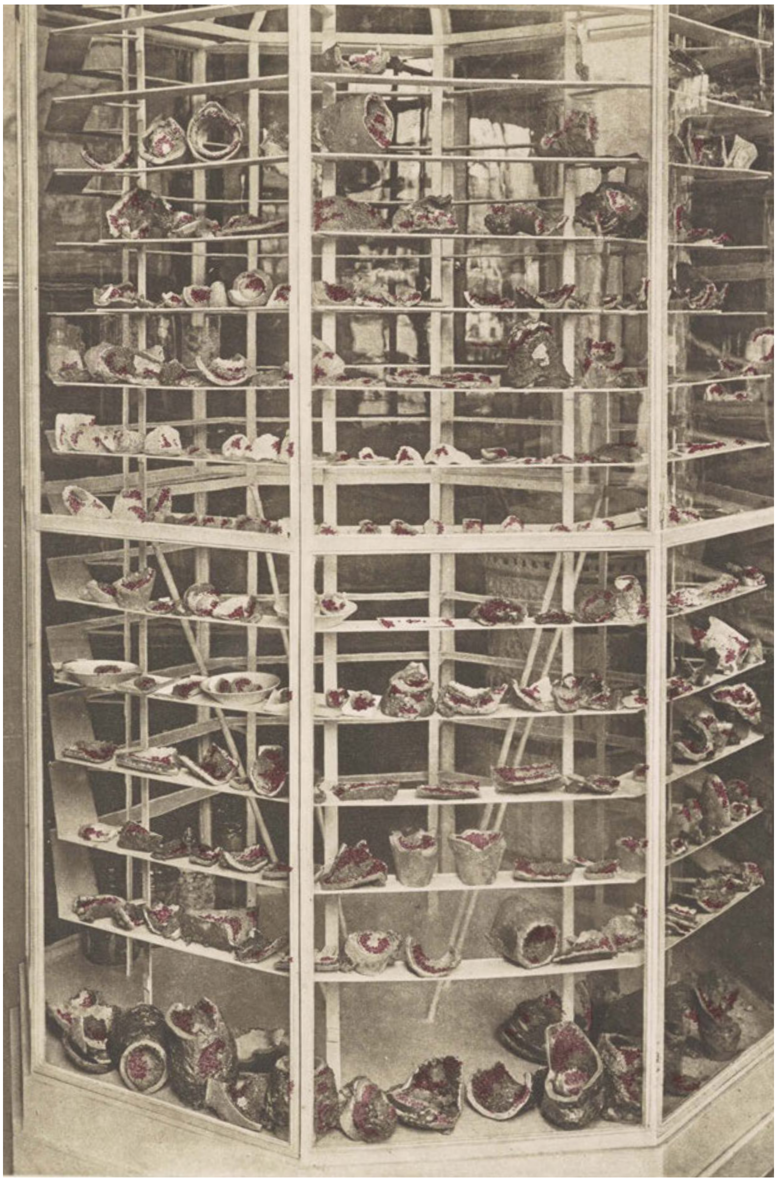
> *"Imitation seems to be one of the universal traits of the human race. The cave man probably amused himself between bear hunts by grunting and growling in the manner of his prey. When he had progressed to the state in which he attached a high value to inanimate things of beauty, he tried to prepare substitutes for them to make them more abundant."*
> *(Pearl, 1951, reproduced in Dieulafait et al. 2011, p.26)*

THE HUMAN DESIRE TO IMITATE

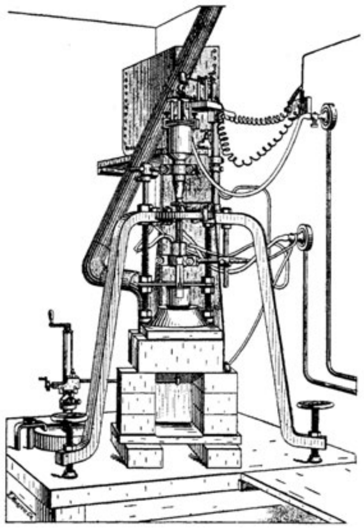
Our fascination with gemstones can be traced back centuries (Ogden, 1992). Many people have adorned themselves with what appeared to be the most precious of crystals, and throughout time they have evoked speculation on their origin and formation (Nassau, 1980). Pliny the Elder in Volume 37 of the now famous *Natural History* (78 A.D.) theorised that quartz was a form of ice. This aligned with the conjecture of earlier writings, such as those by Theophrastus, the author of *On Stones* in 315 B.C. who also believed that stones were the result of solidified fluids (Caley and Richards, 1956). Later, others, such as Sir John Mandeville, who wrote *Travels* in around 1360, considered an alternative theory:

> *"And they [diamonds] grow together, male and female. And they be nourished with the dew of heaven. And they engender commonly and bring forth small children, that multiply and grow all the year."*
> *(Mandeville, 1900, p. 106)*

This uncertainty surrounding their creation and their mesmerising appearance, along with their other unique properties, resulted in a long-standing belief in their magical attributes. With a range of gemstones evoking intrigue and being assigned great value, it is perhaps not surprising that the human desire to imitate gemstones also has a long history. Human ingenuity might be traced back as far as our fascination with gemstones, as the human desire to recreate and imitate that which is considered valuable also extended to gemstones. In his book *Diamonds: An Early History of the King of Gems* Jack Ogden (2018) documents and describes a range of examples, including crown jewels and pieces dating back to ancient India, in which imitation diamonds were incorporated. Egyptian alchemists used furnaces to create glass semi-precious gemstone imitations. Numerous examples can be seen in a range of museums too, including the British Museum, which holds several glass paste imitation coloured gemstones from the Roman empire (Figure 2.2- Figure 2.4).



2.5



2.6

Figure 2.5. Laboratoire de Mr Fremy. Image reproduced from the book *Synthèse du Ruby* by Frémy (1891, p.41).

Figure 2.6. Early Torch of Prof. Verneuil for the Synthetic Production of the Ruby. Image reproduced from the journal article 'Synthesis of Precious Stones' by Levin (1913, p.498). Image in the public domain.

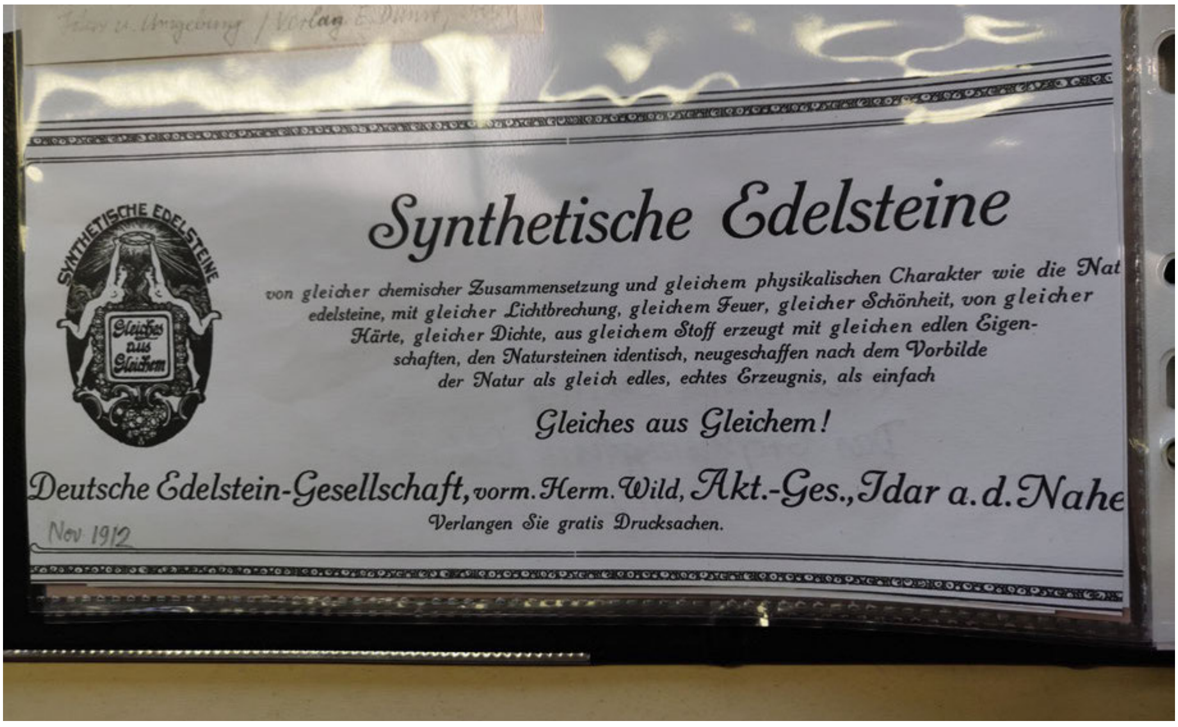
> *"I have often begun a gemmology class by saying that most gemstones are glass, and if you take the total carat weight of all natural, synthetic and imitation stones this is very to be true!"*
> *(O'Donoghue, 2008, p.183)*

Glass was likely the first gem imitation in the form of faience, a glaze ceramic composition that can be traced back to Egypt in 5000 B.C. (Nassau, 1980). Throughout history it has remained one of the most popular materials for the imitation of gemstones (O'Donoghue, 2007). Various colouring agents, metal oxides, are added to achieve a wide array of colours. In ancient times it was often moulded, however, the better more recent imitations are often faceted. With glass being very soft (5.5 – 6 on the Mohs scale) it is easily scratched and is brittle, a direct result of its non-crystalline structure. Despite remaining a popular material for gemstone imitation, glass is not a crystal. It is an amorphous solid, with atoms arranged randomly that do not form a regular, repeating pattern.

THE REALISATION OF THE ALCHEMICAL DREAM: GROWING RUBIES AND SAPPHIRES

It was not until the 19th century that successful experiments resulted in the first man-made crystals. Even though knowledge of the nucleation of crystals can be traced further back, the necessary advancement of technology that accompanied the 19th century resulted in the first man-made crystals being successfully created (Arem, 1973). At that time, mineralogical studies and chemical analyses advanced the understanding of the composition and nature of crystals (Nassau, 1980). Building on the knowledge generated by Gay-Lussac that heating ammonium alum was a good way to achieve pure aluminium oxide in 1817, and the understanding by Rose in 1840 that sapphire and ruby consisted mainly of aluminium oxide, the contest to crack the code of growing corundum started. Regardless of the many people who were experimenting with crystal growth in the 19th and early 20th centuries, it is A. Verneuil, doctor of science and professor of applied chemistry at the Museum of Natural History in Paris, who is considered the father of the technology (Scheel, 2003). Moving away from the work of his mentor Edmond Frémy, who published *Synthèse du Ruby* (1891), summarising his achievements in creating polycrystalline aggregates and small platy ruby crystals of rhombohedral form using ceramic crucibles (Figure 2.5), Verneuil had created his own apparatus (Figure 2.6). The crystal growth technology he developed in 1902, commonly referred to as flame-fusion growth, led to the first commercial production of man-made gemstones. Rubies are single crystal corundum (aluminium oxide) containing trace elements of chromium, which influences its red colour. He treated and prepared the powdered elements, also referred to as feed powder, and melted them through a hydrogen flame, allowing them to neatly fall onto a sintered cone, building up a crystal boule (Figure 2.1). Verneuil had no interest in being an entrepreneur himself and made the details of his technology available to others by publishing two detailed journal articles (Verneuil, 1902, 1904). His technique was so effective that it is still in use today and has led to the development of a plethora of other techniques based on growth from the melt, such as Bridgman, Czochralski, Kyropoulos, Stockbarger, etc. (Scheel, 2003).

2.7



2.8

Figure 2.7. Logo of the Deutsche Edelstein-Gesellschaft, stating *"Synthetische Edelsteine: gleiches aus gleichem"* [translates to: *"Synthetic gemstones: like for like"*]. Photograph of copy located in the archive of D. Jerusalem in Idar-Oberstein, Germany.

Figure 2.8. Photograph of a photocopy of a promotional leaflet by the Deutsche Edelstein-Gesellschaft dated November 1912, stored in the archive of D. Jerusalem in Idar-Oberstein, Germany.

"[...] alchemists who purported to imitate natural processes and even to perfect them, were a threat to the ordered structures of the state."
(Dupre, 2014a, p.13)

That the existing gemstone and jewellery industry was less than excited by the scientific developments of the time became clear both through reviewing the limited available literature dedicated to the subject and during the research visit to the personal archive of D. Jerusalem in Idar-Oberstein (Germany). There letters, articles and posters painted a bleak picture of the turbulence that followed the scientific innovation's introduction in Germany. As documented in the paper by Elisabeth Vaupel (2015) titled *Edelsteinen aus der Fabrik: Producktion und Nutzung synthetisher Rubine und Saphire im Deutschen Reich* (1906-1925) [which translates as: Gemstones from the Factory: Production and Use of Synthetic Rubies and Sapphires in the German Empire (1906–1925)], the technology gained great exposure and, after its open access publication, a number of businesses, first in France and then around Europe, attempted to commercialise the technology. Yet few companies survived much beyond incorporation. One of the few companies that did survive until recently was Hrand Djevahirdjian (Djéva), founded in 1903 which, after moving to Switzerland in 1914, was the most important producer of man-made crystals for use as gemstones in Europe until its closure in 2021.

The story of the struggle of one particular company and the individuals behind it is beautifully documented in the archive and article by Vaupel (2015). Likely inspired by the Paris World Exhibition of 1900, where some of the man-made rubies were shown for the first time, Hermann Wild, owner of a gemstone shop in Idar an der Nahe (now Idar-Oberstein) set about understanding the technology and introducing it in Germany. In collaboration with Adolf Miethe, who had been conducting his own experiments on the growth of ruby, they pitched their commercialisation idea to Elektrochemischen Werke in Bitterfeld, a company majority owned by AEG. AEG was immediately interested in the material's industrial possibilities, and started investigating the production of a range of new items that would enhance current technological advancements in its equipment used to supply electricity. Since the material was, of course, first and foremost of interest to the jewellery industry, Herman Wild's privately owned company was taken over and rebranded as the Deutsche Edelsteingesellschaft (DEG) (Figure 2.7), with the purpose of introducing man-made ruby gemstones into the jewellery market. In order to compete with lower-cost French man-made stones, the company developed additional colours, beyond the transparent (which appears when no chromium is used in the mixture, referred to as sapphire) and red (ruby) that was already available: yellow corundum was achieved by adding nickel and orange corundum by doping the crystal with nickel and chromium. Wild promoted his stones using modern marketing strategies: by giving lectures and advertising broadly (Figure 2.8). This angered traditional jewellers, who feared that the introduction of man-made gemstones would affect the value and price of mined stones and thereby threaten the entire industry.

With the first man-made gemstones causing a significant concern for the merchants of mined gemstones, a science-based method to continue distinguishing between the two types was urgently needed. The influx of these man-made crystals in the European market therefore ultimately inspired the development of the branch of mineralogy and geoscience that we now know as gemmology (Dieulafait et al., 2011), which was set up to distinguish the mined gemstones from imitations. Based on rudimentary principles shared in the 19th century, the first official qualifications in the subject were designed and accredited by the gemmological committee of the 'National Association of Goldsmiths of Great Britain' (NAG) called the 'Gemmological Association of Great Britain' (Gem-A). The incorporation of the use of the refractometer in 1905 and goniometer and spectroscope in 1907 enabled early gemmologists to look inside stones (Bremner, 2018) and make more accurate determinations about their origins. This resulted in the founding of the first laboratory providing a gemstone identification and authentication service in 1925 in London. Later on, in 1929, one of the first graduates of the diploma course, R. M. Shipley, went on to establish the now-renowned Gemmological Institute of America (GIA). Early gemology books like *Gemstones* by G.F. Herbert (1912) clearly depicted man-made crystals as less valuable and fake, even going as far as referencing the knowledge and techniques employed in the endeavour as 'weapons'.

Meanwhile, in Germany, at the annual meeting of the Association of German Jewellers, Goldsmiths and Silversmiths held in 1908, the DEG and its promotional activities were attacked and Wild and Miethe accused of making false claims around the man-made stones' similarity with mined stones and misusing their authority to promote such pseudoscientific propaganda. Following the publication of these allegations in the Deutsche Golschmiede-Zeitung, the DEG sued the board of the Association for damages. Even though that court case was won by the DEG in 1913, the tone was set, and the 'better' jewellers and retailers refrained from selling the 'inauthentic' and 'fake' stones. Since man-made corundum can be produced to be very homogeneous and in larger quantities, the material was far more suitable for industrial applications than mined stones, which often contained inclusions due to the geological conditions they had grown in. Ideal for producing stones for mechanical bearings due to their hardness and polishable surfaces, the electrical engineering industry therefore became the main target market. In 1925 the DEG and the Bitterfelder Edelsteinfabrik merged once again, to form the IG-Betriebe.

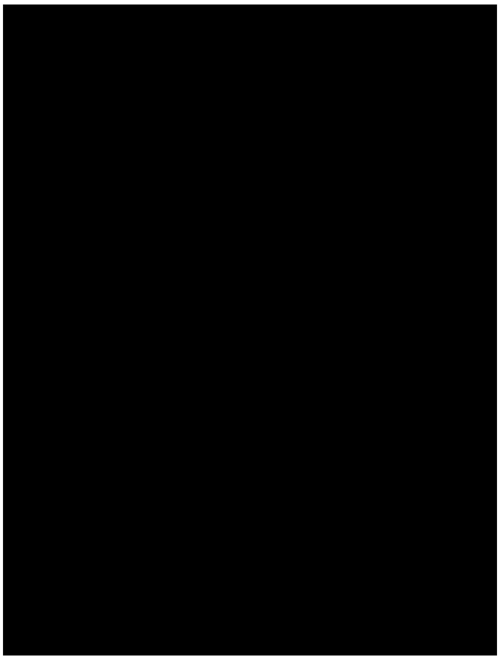
> *"Synthetic rubies and sapphires can be obtained at prices varying from two to three dollars a carat. A natural ruby, on the other hand, may bring as much as three thousand dollars a carat. Fortunately for the ruby miner, many persons of taste and discrimination still prefer natural stones."*
> *(Foshag, 1925, p.25)*

The smaller production of synthetic stones that did prevail as part of the country's operations (partly due to the limited access to mining suppliers outside of Germany during the Second World War, which saw their popularity soar momentarily), due to overproduction and their continued discrediting by the wider jewellery industry for years as an inferior imitation of mined gemstones, resulted in their positioning at incredibly low prices in the costume jewellery arena; industrially produced jewellery for less wealthy customers. Many of the companies in the Valley that today provide services in the machining of hard and brittle materials were once lab-grown gemstone sellers. Having identified that the jewellery market was not sustainable, they pivoted towards an up-and-coming market, looking to provide parts for optical and manufacturing tools that would perform much better if they were made out of hard lab-grown crystal materials available in reliable quality and quantity. The area in Idar-Oberstein is now famous for machining these materials (Stadtverwaltung Idar-Oberstein, 2014).

ACCELERATING THE DEBATE:
THE GROWTH OF DIAMONDS

> *"It constitutes one of the facile paradoxes of economists that while the most essentially useful things like air and water seldom have a price in the market, the utterly useless things like rubies or diamonds command incredibly high prices. But we are not all economists or dealers in paradox."*
> *(al-Azīz, 1942, p.78)*

When thinking about gemstones, diamonds are rarely far from the mind. Diamonds have been the most popular gemstone sold in the industry for decades, even when compared to other, in some cases, rarer gemstones (Gem Rock Auctions, 2019). That the stone is popular is perhaps no surprise given its high lustre appearance and the extensive marketing campaign it has been the subject of, which has propelled the stone into a general perception of a luxury mass produced good (Sybel, 2024). A phrase coined in 1948 by the female copywriter F. Gerety working for the marketing agency N.W. Ayer and Son, which was employed by the diamond company De Beers (who are credited with the longest lasting monopoly on earth), is considered one of the most powerful marketing campaign slogans ever created: 'Diamonds are Forever' (Stone, 2016). De Beers, a company founded by strongmen in the heyday of colonial Africa, has been determined to keep the price of diamonds high by increasing demand and limiting their release onto the market. Even though it no longer maintains the monopoly it once had, it retains a level of control over the industry quite unlike any other (Zoellner, 2007). Segmenting diamonds as a luxury mass product was also helped by the invention of the Tiffany® Setting, created by C. L. Tiffany in 1886, in which a good-sized diamond is held in place by a limited selection of prongs above an understated ring (Figure 2.9 on page 60). Diamonds were pushed as the go-to stone for proposals, a practice heavily promoted in marketing campaigns (Figure 2.11). Working closely with the newly established field of gemmology, De Beers also supported the development of one of the most widely used authentication services resulting in a diamond certificate, which reports on the performance of a diamond against what is popularly referred to as the four Cs: Carat (weight), Colour, Clarity and Cut. The better the diamond scores, the higher its value, and the more confidence the consumer can have in its value retention, when of course left sealed and packaged in a vault. Some were critical of the pseudo-scientific appearance of 'number systems' for estimating colour, clarity and cut, claiming it has a basic failing as it is mostly based on visual estimation (Arem, 1977).



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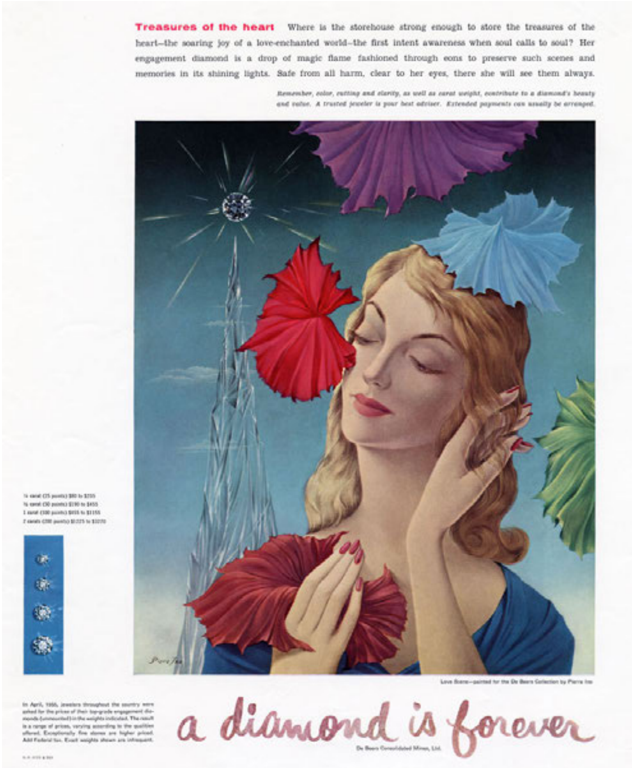

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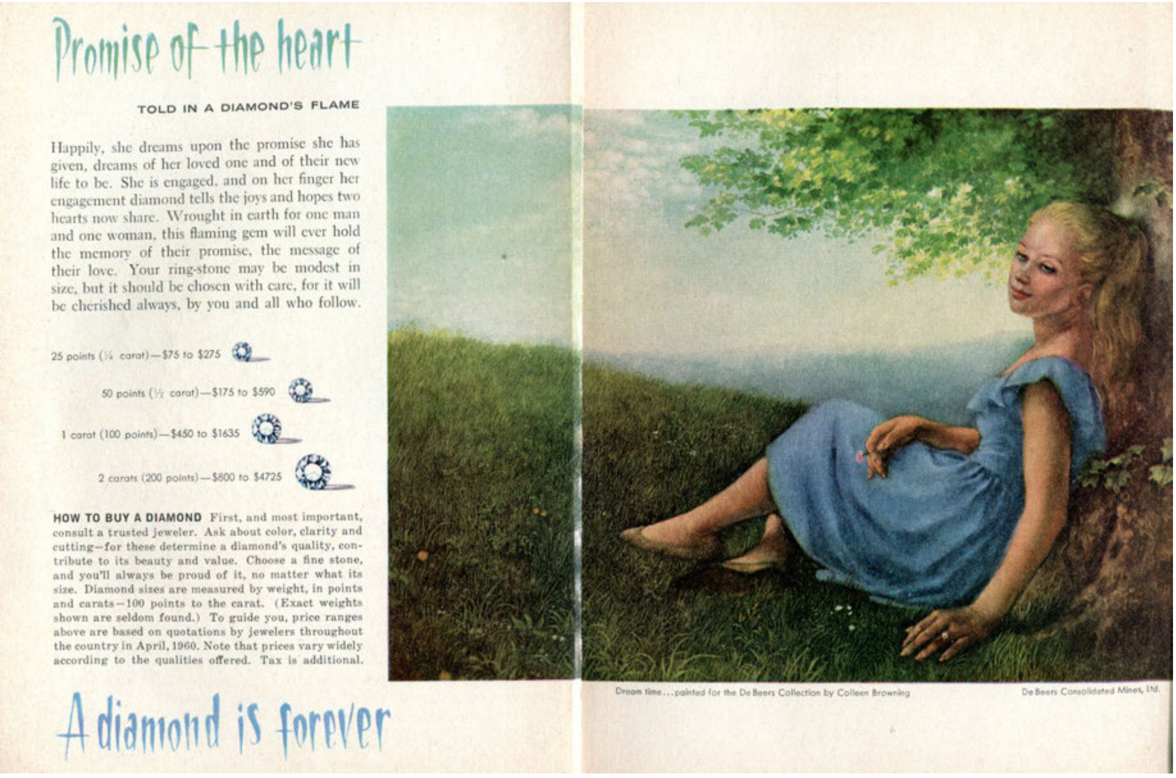


2.11

Figure 2.9. *Tiffany® Setting*, created by C. L. Tiffany in 1886, on a ring in a Tiffany and Co. box.

Figure 2.10. De Beers Diamonds' Advertisement in ***Readers Digest*** August 1960 by SenseiAlan, licensed under CC BY 2.0.

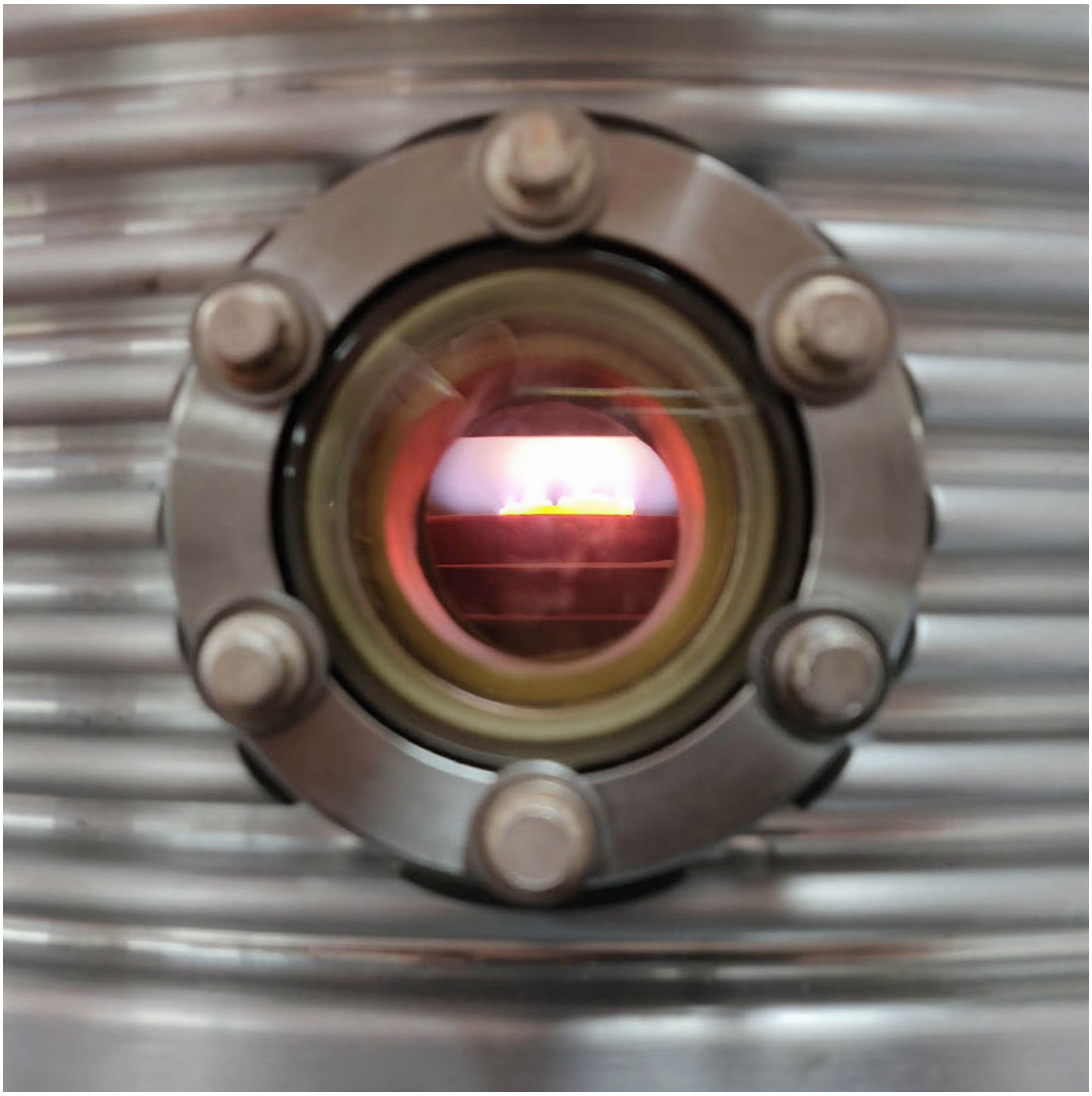
Figure 2.11. *A Diamond is Forever* Love Scene by Pierre Ino for De Beers Consolidated Mines and their Agency, N.W. Ayer and Son. Available via the National Museum of American History licensed under CC BY-NC-SA 2.0, from https://www.flickr.com/photos/nationalmuseumofamericanhistory/6303565444.

But even before diamonds were available and promoted to a larger demographic, their imitation and recreation in the lab preoccupied many scientists. One of the most popular diamond imitation stones, cubic zirconia (CZ), was invented following the discovery of the presence of the cubic form of zirconium oxide by two mineralogists (Stackelberg and Chudoba) who were investigating natural zircon. They discovered that zircon can appear in a cubic form when yttrium or calcium is present. In 1970 a research group in the Soviet Union perfected the skull melting technique, enabling the growth of large single crystals in their own powder, bypassing zirconia's high melting point (2750°C). Stones with a hardness of 8 – 8.5 on the Mohs scale, refractive index of 2.16 (slightly lower than the 2.42 of diamond) and dispersion of 0.060 (slightly higher than diamond's 0.044) were achieved. Without detailed testing even gem experts at the time were hard-pressed to make the distinction (Nassau, 1980), and CZ became an incredibly popular low cost alternative to diamonds.

"It is generally accepted to-day that diamond has never yet been artificially formed, and, moreover, with the means at our disposal its production in the factory or laboratory is unlikely in the extreme. Jewellers may therefore rest assured that there is no risk of catastrophic disruption of their trade by the provision of a supply of cheap synthetic diamonds, and that any one claiming to have produced such stones is suspect."
(Herbert 1912, p. 138)

In contrast to the writing of G. F. Herbert (1912) the alchemical dream of turning charcoal into diamond became a reality in the middle of the 20th century. There are a number of books that reference the stories of the many (sometimes scrupulous and fraudulent) attempts and claims of success that preceded the invention of man-made diamonds by (those mostly accredited for it) General Electric Research Laboratories, including *Gems Made by Man* by Nassau (1980), *The Diamond Formula* by Barnard (2000), *The Heartless Stone* by Zoellner (2007) and *Brilliance and Fire* by Bergstein (2016). Following the formation of a 'Superpressure Group' at General Electric (GE) in 1951, the United States-based group (consisting of Bundy, Hall, Strong and Wentorf) succeeded on 16 December 1954 (Nassau, 1980).

"I attempted many hundreds of indirect. approaches over a period of about a year but to no avail, and I was becoming discouraged. Then, one wintry morning, I broke open the sample cell after removing it from the belt. It cleaved near a tantalum disc used to bring in current for resistance heating. My hands began to tremble; my heart beat rapidly; my knees weakened and no longer gave support. My eyes had caught the flashing light from dozens of tiny triangular faces of octahedral crystals that were stuck to the tantalum and I knew that diamond had finally been made by man."
(Hall quoted in Nassau, 1980, pp.174–175)



2.12

Figure 2.12. Close-up view of the viewing window of a CVD chamber growing diamonds in the Bring Diamonds facility in Newcastle Upon Tyne.

Even though there are claims another company, Allmanna Svenska Elektrika Aktiebolaget (ASEA) [which translates to the Swedish General Electric Company] achieved synthesis before GE (Barnard, 2000), in the months following its discovery the GE group worked out the details of the process that had led to their success, and soon filed patent applications to protect their High Pressure High Temperature (HPHT) technique, rendering them the first to publish and protect the innovation. With this technique, diamonds are produced from carbon in high pressure, high temperature conditions that mimic those present in the Earth when diamonds are formed. A press conference on 15 February 1955 revealed a first glimpse of the catastrophic disruption predicted by Herbert, sending a shock wave through the industry. Following the introduction of lab-grown rubies, sapphires and emeralds, now diamonds identical to those found in nature, could be made in the lab too. De Beers' stock took a nosedive, and industry turmoil followed. De Beers, who had been working on their own synthetic diamond developments, rushed towards patent submission but were beaten to the punch by GE's filing of international patents. What followed was six years of litigation that resulted in De Beers purchasing a licensing agreement for the Belt apparatus, which enabled the achievement of the high pressure needed in the HTHP diamond synthesis process (Barnard, 2000).

Since it was initially only feasible to produce small diamonds, rendering them interesting mainly for industrial purposes, it was not until the 1970s that large gem-grade man-made diamonds were created, through the addition of a seed crystal to start the growth. This development was published by Wentorf, Strong, and Chrenko, as Hall had left the company in 1955. Yet, despite all the predicted doom and gloom, few consumers knew about man-made gemstones, and particularly man-made diamonds, until more recently. With technologies patented and the jewellery industry's vested interest in controlling the spread of the innovation, few scientists and companies managed to reach the market. Ultimately, gemstones are usually sold in business-to-business arrangements, so if the jewellery producers are not interested in the man-made gemstones for incorporation in their pieces, consumers are likely to remain uninformed.

Things started changing following the collapse of communism. Crystal growth had been of interest not only to Western scientists, and in Russia scientists such as N. Polushin had also developed a diamond growth apparatus. Scientists from the former Soviet Union shared classified technologies they had developed during the Cold War with Western businesses. The story of the founding of the lab-grown diamond company called the Gemesis Corporation, is compellingly relayed by Zoellner (2007, pp.258–261) in the book *The Heartless Stone*, describing in detail how, on an unrelated journey to Moscow in December 1995, founder Carter Clarke ended up purchasing three diamond growing machines costing $57,000 each at the time. Once shipped and set up in a warehouse in Sarasota, Florida in America, these machines enabled the start of the company that now, like many others around the world, is using HTHP diamond growing technologies shared via Russia.

Even more lab-grown diamond companies emerged that employed a method of growth called chemical vapor deposition (CVD), which involves filling a vacuum chamber with carbon-containing gas that crystallises on a diamond seed, requiring much lower temperatures and pressures than HTHP (Figure 2.12).

Although this technique built on a thin film application technology that had already been proven to be successful with diamonds in 1952 (Angus et al., 1993), it was only developed into being applicable to a larger surface area in the early 2000s. Apollo Diamond Inc. was one of the first companies that used the technology to be discussed as credible producers of gem-sized diamonds in gemmological circles in 2004 (Wang et al., 2003).

Aside from being of interest to the jewellery industry, diamond as a material had much more potential for industrial purposes once it could be produced in the lab. As the hardest material and the best thermal conductor near room temperature, diamond additionally has the lowest coefficient of thermal expansion, is resistant to heat, acids, radiation, is a good electrical insulator and can be doped to act as a semi-conductor. Its use in thermal management, wear-resistant coatings, optical components, and semi-conductor electronic devices was accelerated due to the possibility of growing it in controlled environments in the lab.

Another industry that greatly benefited from access to lab-grown diamonds is the tooling industry. This was evident in Idar-Oberstein, where there are several companies which focus on producing specialist tools using lab-grown diamonds. During research residencies in Idar-Oberstein two such companies were visited (Appendix 5). In an interview conducted on 12 December 2022 with the general manager of one of these companies, they shared that they had been prepared to launch a collection of faceted lab-grown diamonds for use in the jewellery industry in 2013, which had at that time been met with great protest by the local jewellery industry, resulting in them halting the venture. When discussing the attempts the jewellery industry has undertaken to slow and, where possible, stop the sale of lab-grown diamonds, this interviewee said:

"[...] we were going on the market and we had the same problem, the same problem with the small firms here in Idar-Oberstein. [They] said: "Oh, your [selling] diamonds? You can't do that!" And we don't do it."
Interviewee #11

The pressures companies faced, well documented in the D. Jerusalem archive in Germany, and vocalised by Tom Chatham (Chatham, 2017), who has been outspoken about the challenges his father faced when launching the Chatham company to sell his own created emeralds, were being applied again to companies attempting to enter the diamond market with their lab-grown produce years later. More recently, probably thanks to the interest from large companies, lab-grown diamonds have started entering the market in increasingly large numbers. The interviewee continued:

"[...] three years later [2016], Swarovski comes [along] and nobody said anything. Swarovski is big enough."
Interviewee #11

In recent years, HTHP and CVD growth technologies have become even more accessible to companies, and many have continued to attempt to start businesses producing and supplying lab-grown diamonds for the production of jewellery. Aside from the larger corporations like Swarovski, a few examples of companies that have launched in the United Kingdom are Sky Diamond (2020) and Bring Diamonds (2019). The former company, set up by multimillionaire and environmentalist D. Vince, claims to produce carbon-negative lab-grown diamonds, grown from carbon 'mined' from the sky (Skydiamond, 2021). A visit to the Bring Diamonds company on 13 August 2021 clearly signalled that, even though the technology, equipment and facilities are becoming more widely accessible, the knowledge required to produce diamonds remains highly specialist.

The Gemmological Institute of America (2024b) started providing certificates for Lab-grown diamonds in 2007 and today the valuation service, with stones often performing better against the 4 Cs criteria than natural stones, is widely available. It therefore might have been expected that a change would take place that would favour the natural stone again over the man-made stone, particularly as the inventor of the grading system was none other than De Beers (Zoellner, 2007), arguably the most important name in the history of diamonds. In an article published on-the recently formed *Only Natural Diamonds* webpage (Natural Diamond Council, 2020b), a grading report produced by an independent laboratory which references the other diamond characteristics (Cs) verifies diamonds' origins through lab tests to detect trace amounts of lattice defects and trace elements of other materials (boron and nitrogen). Even though the materials are identical, the advanced laboratory can distinguish a lab-grown diamond by looking for the absence of variations that appear in mined stones. A lab-grown diamond may well perform better against all the 'old' criteria, but it will never have 'authentic intrinsic value'. The fifth 'C' introduced thus signifies Certificate (Natural Diamond Council, 2020b).

2.13

Figure 2.13. Top part of a large silicon crystal boule.

THE CRYSTAL AGE

Outside the jewellery field crystal growing technologies have resulted in countless innovations. With crystals becoming indispensable for technological products, significant investment in crystal growth has resulted in attention being directed at a range of industries outside the jewellery field. Today crystals influence and drive the existence of technologically advanced countries and are present in a plethora of products, ranging from hearing aids, to TV sets, to transportation and communication equipment (Arem, 1977). Ten thousand tons of crystals are produced annually, the bulk of which consists of the semiconductor silicon (Scheel, 2003) (Figure 2.13), for which demand is only increasing, evidenced by the increase in demand for microchips and the world-wide shortage currently threatening our technological fixes (Baraniuk, 2021). It is fair to say that our lives would not look the same without the invention of the techniques needed to create lab-grown crystals.

With a serious interest in crystal growth in a range of industries there is a vast amount of literature dedicated to documenting the techniques, reporting on research, and exploring their applications in relation to crystal growth. There are research centres, conferences and journals on the subject, where subject specialists are working or reporting on crystal growth in a myriad of manners and for a range of applications. This literature, however, due perhaps to its scientific nature, remains largely inaccessible to most jewellery designers and, even though some of the techniques documented could have very interesting applications in a jewellery context, few innovations are successful at making their way into the jewellery field, where most man-made gemstones are still mainly produced to replicate mined gems. To date the limited literature available which is dedicated to man-made crystals in a jewellery context (O'Donoghue, 2007, 2008; Pedersen, 2004; Elwell, 1979; Arem, 1973) has mainly been produced in the field of gemmology, with the clear aim of enabling the continued distinguishing of mined stones from their man-made imitations.

2.14

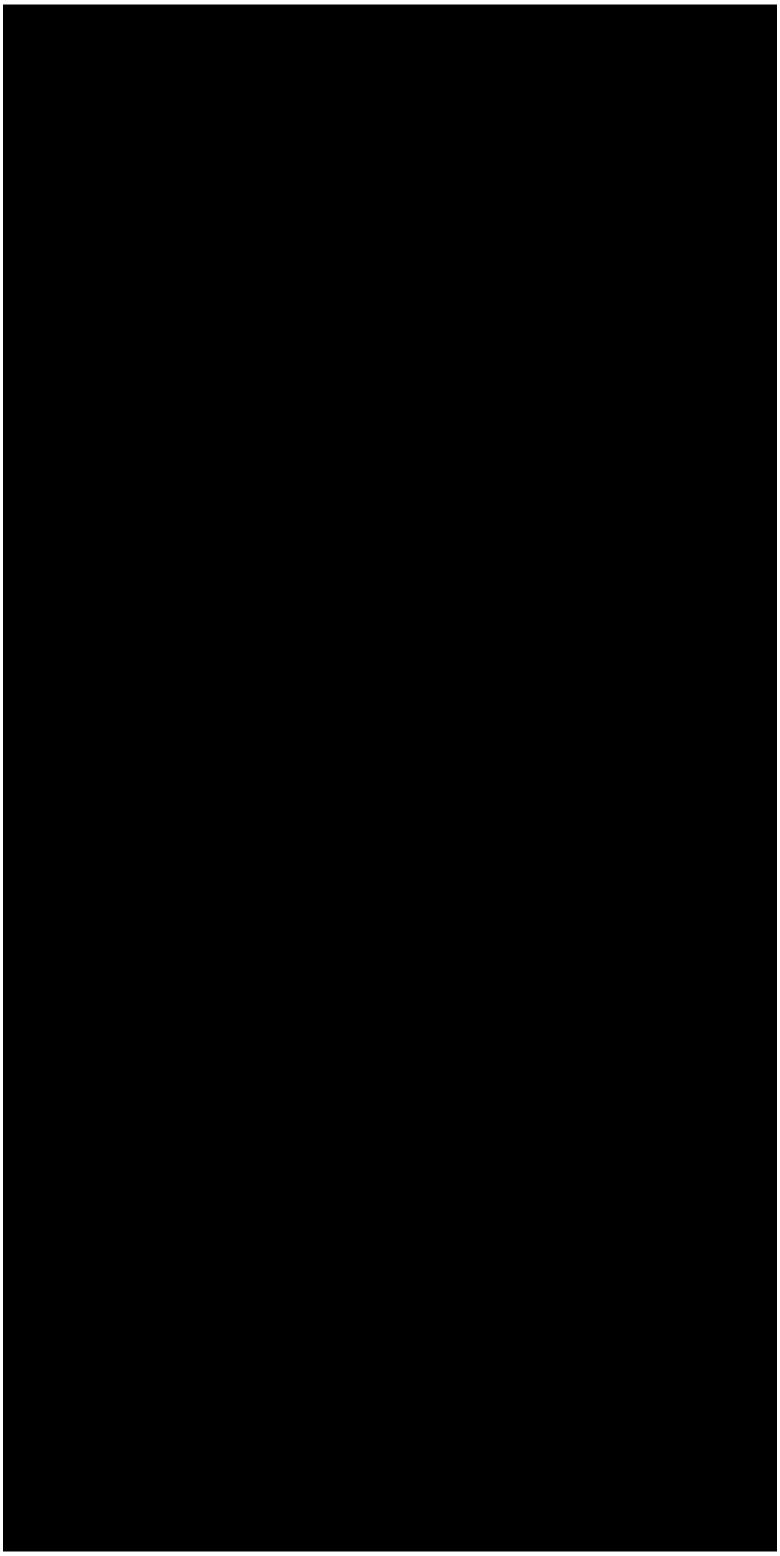
Figure 2.14. *Fake?/Real?*, 18 ct gold and diamond (one laboratory-grown one mined).

2.3. Contemporary Context

> *"A key point to remember in any research environment is that no matter what form issues and problems may take, or how information is created, collected, or collated, it continually changes. The assumption that research involves freeze-framing reality is an artifice that has little relevance to most researchers who are intrigued by the complex realities of everyday life."*
> *(Sullivan, 2010, p.195)*

Having established that literature in the jewellery field dedicated to man-made crystals is limited, it was important for the study to broaden the contextual review, in order to collate 'richer data' on the opinions on the topic from the jewellery community directly (McNiff, Lomax and Whitehead, 2003). This was intended to establish an, albeit momentary, insight into contemporary sentiments in relation to these man-made materials and their usage in a jewellery context or, in other words, to gain an 'insight into the situation' (Yin, 2018). For this reason an extensive investigatory schedule was devised consisting of interviews (Appendix 4), visits to trade fairs, museums, and companies (Appendix 5), and attendance of lectures, which all supplemented continuous monitoring of press coverage, trade reports and social media.

The majority of interviewees spoken to, and organisations visited, were located in Idar-Oberstein (Figure 2.15). This German city, located 80 miles west of Frankfurt, is still deemed the centre of gemstone art in Europe (Gemporia, 2019; Stadtverwaltung Idar-Oberstein, 2014), and was therefore considered the ideal location to conduct this segment of the contextual review within the limited timeframe of this PhD. Located in the Hunsrück mountain range, the area is known for the presence and localised mining of jasper, agate, carnelian and amethyst, which is claimed to date back to Roman times (Gemporia, 2019). Over the years, the mining industry developed, and the region became known for its expertise in gem cutting and carving (Figure 2.16). By the late 15th century, the rivers running through the landscape were powering grinding stones and cutting wheels, which lapidarists used to cut local – and later also large quantities of imported – gemstone materials, resulting in a golden era for the area. It was even rumoured to be the wealthiest town on the planet in the early 1900s (Gemporia, 2019). Skills were passed down from generation to generation, and many of the residents living there today continue the tradition.



2.15

2.16

Figure 2.15. Photograph of Idar-Oberstein, Germany.

Figure 2.16. Photographs of miniature representations of techniques practiced in the valley, as displayed in the Gemstone Museum in Idar-Oberstein, Germany.

Whilst the region has maintained its reputation for cutting quality gemstones, following financial challenges caused by the two world wars, and with competition from competing cutting centres abroad, today, however, it is no longer the hive of activity it once was on the world gem cutting stage (JCK Magazine, 1997). What continues to set it apart, aside from its historic relevance and the fact that it remains the centre for gem cutting in Europe, is undoubtedly its jewellery education provision, focusing on the artistic implementation and exploration of gemstones. The University of Applied Sciences Trier/Idar-Oberstein team, comprised of experts in their respective domains, have established a reputation for educating the next generation of stone carving and cutting artists. In particular, the two-year Master's programme they offer attracts students from all over the world, and its graduates, two of whom were interviewed, are award winning leaders in gemstone art.

The two longer (two months each) and three shorter (between one week and twelve days) research visits to the area (Appendix 3), called 'the Valley' by the locals, enabled an intense exploration programme, which included conducting interviews with experts in the field, and visiting a range of companies and organisations. With 600 gem shops located in the area (Neele, 2022), Idar-Oberstein continues to have the largest concentration of experts in one location than any other place in Europe. The data garnered from twelve interviews (Appendix 4) was supplemented by direct observation notes (Yin, 2018) on nine guided and ten unguided organisation visits, as well as notes from five fair visits (Appendix 5).

In order to conduct a more widespread analysis (McNiff, 2016), a survey (Appendix 6) accessible via personal website and social media profiles allowed broader membership of the industry to participate in the research. In total 51 people responded to the survey, 80% of whom had five or more years' experience in the industry. Half of these participants were located in the UK, and a large proportion in America (35%). Some survey respondents were located on other continents, leaving South America unrepresented.

Applying discursive methods, incorporating the empiricist focus on structure (conceptual practice) and interpretivist emphasis on agency, patterns and inconsistencies in the data were sought out in a process of 'making sense of the data' (Sullivan, 2010). Triangulation of the data (Yin, 2018; McNiff, Lomax and Whitehead, 2003) was attempted to corroborate sentiments, facts or phenomenon. In the following section a narrative is provided that summarises not the total amount of data that was available and where possible collected (as that was impossible), but the highly diverse and ever evolving context of the research that was both influencing and influenced by the collated data. This narrative gives an insight into the affect of interactions on the complex system that underpinned the research, and is structured around the questions found most pertinent to investigate as causes for the lack of innovations with crystal growth within the jewellery sector.

2.17

2.18

2.19

2.20

Figure 2.17. *Asket Hoop Earrings Grace*, CZs, gold-plated silver. Photography by SOMA. Image used with kind permission of Sofie Hallik.

Figure 2.18. *Ring #489*, Karl Fritsch, silver, obsidian, synthetic sapphire, cubic zirconia. Photography by Karl Fritsch. Image used with kind permission of Karl Fritsch.

Figure 2.19. *The (RED) DIAMOND RING*, Diamond Foundry® created diamond. Image available via https://www.sothebys.com/en/auctions/ecatalogue/2018/red-n10000/lot.22.html.

Figure 2.20. *Huge Window*, Olaf Tønnesland Hodne, lab-grown quartz, steel. Photography by Olaf Tønnesland Hodne. Image used with kind permission of Olaf Tønnesland Hodne.

USING AND REFUSING LAB-GROWN GEMSTONE MATERIALS

"There are total opposites in a gemstone. On the one hand, they are very solid, very hard, and on the other they have something with the light you cannot catch anymore."
Interviewee #3

In response to the question 'Do you use/sell or work with man-made crystals?' just over half of the survey respondents answered 'yes' and just under half answered 'no'. The top reasons respondents listed for use were 'financial reasons' and 'sustainability reasons'. This aligns with survey data collated on the European and American market in 2020 by The MVEye (2021). Moreover, out of all those interviewed during the research project, six interviewees could be considered users/sellers of man-made crystals. Three of those interviewees did, however, operate outside the jewellery field, using man-made crystals for industrial applications. The three remaining interviewees' reasons for using/selling lab-grown gemstones mainly pertained to the opportunities lab-grown gemstone materials provide where mined materials fall short, such as consistency of colour and availability of the crystal material in required quantities.

"[...] the playground is much bigger when you have these things around."
Interviewee #7

Despite all controversy and the limited amount of innovation in the creation of man-made crystals for use in jewellery today, lab-grown gemstones are evidently being incorporated into the work of an increasing number of jewellery artists, designers, and makers. An investigation into their use by jewellers indicated that they, for some makers, provided design options that previously would not have been considered financially feasible and/or traditionally acceptable.

"Cutters are paid by weight. So, cutters don't want to waste weight. Because wasting weight is like wasting your own salary."
Interviewee #8

Some artists have taken liberties with lab-grown stones, bypassing conventions; for example, by drilling large holes in them, cutting them into innovative shapes, or even using them in combination with other non-traditional materials. An example of this kind of work is the brand SOMA, whose designer drilled large holes in lower-cost lab-grown cubic zirconia (CZ) to enable them to be hooked onto hoop earrings (Figure 2.17). CZs are significantly cheaper than most mined gemstones, which is likely to be a key driver for these types of interventions. Another example is the all-diamond ring produced by J. Ive and M. Newson (Figure 2.19), who cut the material so that it did not need to be set in a metal ring. Two other jewellery artists, Karl Fritsch (Figure 2.18) and Olaf Hodne (Figure 2.20), have been working with lab-grown materials for a while, and have even produced some pieces that embraced lab-grown gemstone materials in their unaltered, uncut, and unpolished form.

2.21

Figure 2.21. Pamela Anderson featuring in a brand campaign for jewellery retailer Pandora. Available via: https://www.businessoffashion.com/articles/retail/how-jewellery-retailer-pandora-is-evolving-elevating-its-brand-interview-chief-marketing-officer-cmo-mary-carmen-gasco-buisson/.

When reviewing the innovative use of lab-grown gemstones in jewellery, this is most interesting, as here the materials are incorporated into a shape that does not appear in nature. Whether it is cutting holes, cutting stones in half, or cutting them in new ways that would not prove financially viable with mined materials, these interventions become options for artists due to the currently low cost of some man-made crystals and the larger format they can be acquired in. Presumably, if this had been possible with mined materials, lab-grown alternatives may not have been chosen.

The second key reason for use identified by survey respondents is the sustainability of lab-grown materials. Sustainability is currently a key strategy many companies wish to promote. Bring Diamonds, a lab-grown diamond seller in the UK is an example of a company that believes there is a market for its diamonds which, it claims, have been locally produced in a carbon-neutral manner following stringent ethical considerations. During the duration of this PhD study, more and more companies aligned their increased use of lab-grown gemstones to their sustainability agendas. For instance, Pandora announced in May 2021 that from then on, they would only use man-made diamonds grown in the UK as part of their broader sustainability drive (Josephs, 2021).

However, they received a lot of criticism from the jewellery industry for implying that the mined diamond industry is less ethical and sustainable than the lab-grown diamond industry. In a joint statement released by the Natural Diamond Council (NDC), The World Jewellery Federation (CIBJO), the World Diamond Council (WDC), the Responsible Jewellery Council (RJC), and the International Diamond Manufacturers Association (IDMA), the organisations demanded Pandora's retraction of their comment about mined diamonds being less sustainable than lab-grown ones (Roden, 2021).

> *"The misleading narrative created by the Pandora announcement implying the natural diamond industry is both less ethical and the impetus behind Pandora's move to lab-grown diamonds, particularly given the inconsequential amount of diamonds Pandora features in its collections, can have unintended but substantial consequences on communities in developing nations."*
> *(Roden, 2021)*

One lab-grown diamond company in the UK commissioned a meta study by Dr Oluleye from the Centre for Environmental Policy, Imperial College London (Oluleye, 2021). This highlighted the environmental impact of mined diamonds, which was evaluated to have many detrimental impacts on the environment including soil erosion, deforestation, and ecosystem destruction. In his conclusion, Dr Oluleye quoted the Ethica Diamond website (Ethica Diamonds, 2019): *"The diamond industry would like consumers to believe that the benefits of formal (regulated) mining far outway the environmental impact, however, the truth is that mining is catastrophic to eco-systems, the environment and its indigenous people."*

"[…] the mining in the world is slave work. It's a plundering of resources of a countryside that is very poor in infrastructure."
Interviewee #7

All the interviewees consulted with knowledge of the mining industry criticised its practices from both ethical and sustainable perspectives. Whilst it is fair to say that each gemstone, each associated process and all stakeholders involved influence this sustainability and ethics, one interviewee, an experienced reseller of mined gemstones from Pakistan and Afghanistan, commented on the mining of tourmaline by tribes of the region:

"[…] tribes that are very famous for selling drugs, for selling weapons, for building weapons, for selling gems […]."
Interviewee #6

Gemstones continue to be used to finance armed conflicts. Another example of this is the suspected sale of diamonds to fund the war in Ukraine (McClure, 2022) and, whilst there are attempts at regulating gemstone sales, the challenge remains current. Meanwhile, with lab-created diamond production reaching between 6–7 million carats in 2021, of which approximately 50-60% were manufactured in China that year, and with India and the USA identified as growing stakeholders (Linde et al., 2022), it appears challenging to justify listing this entire market, and therefore all lab-grown diamonds, as sustainable. In a report commissioned by Pandora, the corporate governance firm Sphera undertook an independent third-party assessment of the CVD lab-created diamond production process, from raw materials to synthesis, cutting and polishing, and transportation (Boonzaier and Gediga, 2021). This report assigned more than 90% of the process's total CO_2 emissions to the electricity used during synthesis. With varying usages of renewable energy in companies, it is conceivable that the emissions per carat differs dramatically from company to company and from one producing country to another. Sphera's report estimated that a lab-created diamond produced in India resulted in a CO_2 emission of 612kg, which is wildly different from an average of 17kg for one produced using 100 per cent renewable energy in Europe (Roden, 2021). This also applies to the growing of other gemstones. The owner of a large gem-cutting organisation shared the following during an interview:

"The rough that is made in China today – mainly in China but also a little bit in Russia – is very, very, very cheap. OK, very cheap. And this rough is 8 times cheaper than the rough made in Europe. But the rough made in Europe is lead free, it's Chrome 6 free. It's using green energy, and they control the entire manufacturing. Everything is under control, and this has, for me, this has a very high value. […] Ruby from Europe costs five times more. In a 12 by 10 oval, we are talking $1.50 versus $7.50. $1.50, I can buy this in China, with a Chinese rough, $7.50 is my cost when I make it here. So, I have already had on a B2B basis with large users this massive discussion around how we make customers understand that this synthetic

is better than this synthetic, or this lab-grown is better than this lab-grown."
Interviewee #9

Sustainability is a multifaceted term and endeavour; many aspects influence the sustainability of a material. Whilst it was not the intention of this research to establish whether gemstone mining practices were more sustainable than growing gemstones in the lab, sustainability was listed as a key consideration as to why survey respondents choose lab-grown gemstones today. The fact that sustainability is starting to influence the way we value and choose products and materials is a positive development, and one that could undermine the socially constructed need to question the authenticity of materials. Where stones are bought and sold today, with certificates claiming their authenticity, we could ask what benefit the recently-introduced fifth 'C' (Natural Diamond Council, 2020b) brings to the equation, and whether the 'Certification' of origin is still the most important fact to establish? Perhaps the fifth 'C' should in fact be 'Conscious'. Furthermore, as one survey respondent rightly pointed out, arguably the most sustainable way forward is the use and re-use of gemstones, including diamonds, that are already available, which is another area investigated during this research (see Chapter 2).

When speaking to interviewees in Idar-Oberstein, the majority of those who worked with lab-grown gemstones had commercial reasons to do so. This was mainly down to their consistent physical properties, such as colour and clarity, and their reliable supply. All three interviewees working for companies focusing on machining hard and brittle materials for industrial purposes used predominantly lab-grown gemstone materials for these reasons.

"We only machine synthetically grown crystals. [...] Only with synthetic you can make this sort of quality. So, this is one reason, the other reason is of course availability needs. [...] We need to get the same quality reliably. All the time. So, for this we cannot rely on natural stones."
Interviewee #1

What is interesting to note here is that the tools sold containing lab-grown crystal materials are often much more expensive than their natural counterparts (when available). An example of this is diamond grit used for polishing faceted stones. The lab-grown diamond grit (Figure 2.22 on page 78) is more expensive than natural diamond grit, as the control with which the material has been developed allows for greater quality (Figure 2.23 on page 78). Thus, whilst lab-grown diamonds are sold for a lower cost than mined diamonds in a jewellery context, this is quite the opposite in the tooling industry.

Having established in the previous section of this chapter that companies selling lab-grown gemstones have faced great challenges, it is understandable that there is now only one company in the Valley that cuts and sells lab-grown gemstones business-to-business (B2B). They have absorbed the remaining market and, whilst faceted lab-grown gemstone sales are a strong element (one-third) of their business, serving the largest clients in the industry, they also sell mined gemstone materials (two-thirds).

2.22

2.23

Figure 2.22. Synthetic diamond grit.

Figure 2.23. Microscope image of synthetic diamond grit.

When interviewed, the CEO of this company also cited colour consistency and reliability as the main reason for their usage of lab-grown gemstone materials. Here again, should the consistency in colour and the quantity needed be available from mining, mined stones would likely be used instead, as they remained the preferred option for most of the company's customers.

"Colour consistency in combination with precision and price can only be achieved in large volume by using an inexpensive natural gemstone, like black onyx, or a man-made gemstone. So, when you talk about transparent clean materials that you need to produce over generations in the same colour in the same quality, you have to work with man-made gemstones."
Interviewee #9

The owner of a crystal growth company in the USA shared a story around the challenge of achieving colour consistency with mined stones:

"I had an order once for a dozen natural blue sapphires, 7 mm round that had to match. So, I went to the natural gemstone people that I knew, and I said: 'This is what I'm trying to find.' And they said: 'Oh Tom, you got to be kidding. It's gonna take you a year or two to collect from around the world.' 'Are you sure? I mean, are you telling me the truth, that you can't match up a dozen stones?' And in blue sapphires? Not like, you know, super rare, rare. And, they said: 'Yeah, we can't do that.'"
Tom Chatham, in an interview conducted on 8 March 2024

The majority of gemstone dealing companies in Idar-Oberstein do not sell lab-grown gemstones. Whilst interviews on the subject with a selection of the largest companies in the Valley were requested, most declined. Interviews were ultimately conducted with two companies that mainly focused on the carving and cutting of mined gems, both of whom cited reasons similar to those expressed in the survey by those who had answered 'no' to the question if they used lab-grown gemstones.

"They aren't quite the same. A natural crystal has a certain feeling to it, and a natural charm that a synthetic gem can never replicate."
Survey Respondent

"[...] personally, I'm not very much into, into the - let's say - the micro power of these substances."
Interviewee #7

"[...] I cannot think about synthetic, why? We have nature."
Interviewee #2

2.24

Figure 2.24. *The Diamond Journey*, a multimedia campaign for the Natural Diamond Council (formerly the Diamond Producers Association). Designed by BBH London in 2019.

This sentiment was reiterated during an interview with an independent artist and educator too:

"They also feel artificial, so when you work with them, you, you have also this, this strange feeling, and it's very different from a natural grown stone. [...] they do not feel alive."
Interviewee #3

Whilst the other independent artist and the cutter who did not use lab-grown gemstones for their work were open to the idea of using them, the lack of quintessence assigned to lab-grown materials was pertinently present in conversations with those who indicated they preferred to use mined gemstones.

"I'm a bit conservative on that behalf. I can pendulum. [...] I learned very early on how to decide, this is genuine, or this is a man-made thing; glass; synthetics. So, my pendulum says it [...]."
Interviewee #7

"And sometimes, I feel exactly that it was synthetic [...]."
Interviewee #2

There is a long history of believing that gemstones have magical powers. Their use in rituals and in the holy sphere can be traced back thousands of years. These ideas have therefore become part of our cultural memory and society's consciousness, and this preconfigured, often symbolic language is being tapped into by clever advertising agencies in order to increase a gemstone's marketable value (Lindemann, 2016).

"The purest diamond is an emblematic ideation of an elusive and notoriously complex ethnographic object, the commodity. Its capricious and shifting materiality, challenging perceived notions of wants and desires, use and exchange value and rendered to consumers as a veritable icon of value fetishization, is somewhat paradoxical in that diamonds are the only gemstone that is abundant in nature."
(Calvão, 2015, p.193)

Keen to promote the ahistorical and autopoietic process (Maturana and Varela, 1980) through which mined diamonds come into being, for the first time the most recognisable slogan 'Diamonds are Forever' has disappeared from marketing materials in the last few years. Adverts have instead described the mined stones as 'real' (Figure 2.24 on page 80) and, along with the recent re-branding of the 'Diamond Producers Association' to the 'Natural Diamond Council', the aim is clear: to depict mined diamonds as the authentic, natural and valuable choice. For the first time the material's origin is considered more important than its value criteria prescribed by the 4 Cs. The addition of the 5th 'C' for 'Certification' (Natural Diamond Council, 2020b) – or in other words, its origin, makes the organisation's ambition even more transparent.

"If you had to ask me what the biggest mistake was, and I had to probably put my hand up as De Beers, not entirely responsible, but, but certainly part of it: the 4 Cs, the certificate, the Rappaport list and the internet. That is [holds hand like a gun next to his head and pretends to pull the trigger] to our industry. [...] There's a uniqueness to beauty. [...] We've said that colour is not a quality, colour is not a quality of the four Cs, and we said that colour is a preference, and we actually now sell the full range of colours. [...] And it's really interesting, we've done a study, where, even when we talk about the four Cs, everybody's eyes are different, so the idea that what I see when I look at a diamond is the same as what you see is not true. [...] And when you start this selling process, actually, people fall in love with their gemstone. I've heard people say: 'Oh, I've seen like six but this is the one that's sang to me'. What does that mean: 'Sang to me'? Something in there... And that, if we can get into that world, then we're back in the world of luxury. [...] Nature is not about perfection. If you look at 'D flawless' they are a fraction of what nature produced. [...] I don't like 'flaws', it's a horrible word. So, we need a better language first. I used to say 'nature's fingerprints' or 'birthmarks' [...]."

Stephen Lussier, Former Executive Vice President for brands and consumer markets for the De Beers Group (Vicenzaoro, 2020)

Marketing has always been important for maintaining the social construct holding the value of diamonds in place. Even in countries where previously there was no history of diamond engagement rings, like Japan for example, a woman is now commonly presented with one when proposed to (Zoellner, 2007). With the introduction of lab-grown diamonds into the market, marketing has become even more important for diamond mining companies which have, for many years, relied on selling the socially constructed rarity of diamonds controlled by a grading and certification service marking their product against the 4 Cs criteria. Records for 2019 show that more than $200 million was invested in diamond industry marketing, including $70 to $80 million of generic marketing paid for through the Diamond Producers Association (Bain & Company, 2019). This amount was set to increase by a third in 2022 (Linde et al., 2022) by the newly-branded Natural Diamond Council, making mined diamonds the most marketed material on the planet.

The extensive marketing that has supported the product in the market, and the narratives they relay, have likely been a key driver for why the impact of lab-grown diamonds on the market has not been more significant. The price of mined diamonds on average still remains double that of lab-grown diamonds (Queensmith, 2024). With the predicted growth of the lab-grown diamond market, currently representing 17% of the global diamond market (equivalent to £44 billion), set to double by 2031 (Price, 2024), it will be interesting to see what changes arise in this market, as it is inevitably influencing the wider appreciation of all lab-grown gemstones.

AUTHENTICITY, VALUE AND TERMINOLOGY

"So faithful in appearance and perfect in form are all these synthetic stones that only an expert can recognise them with certainty; indeed, their very size and perfection are often the surest clues to their origin, for their rival the famous gems of history, the treasures of emperors and Queens and merchant princes."
(Pearl, 1951, reproduced in Dieulafait et al. 2011, p.27)

"[...] for all intents and purposes, they are chemically the same stone, but a natural stone will always have the sense of individuality and uniqueness that a lab-grown stone will not have. A naturally sourced stone could be one-of-a-kind and although you can grow it, you cannot refer to a lab-grown version as one-of-a-kind. For example, an original Van Gogh artwork will always have an exponentially higher value than a print of that same artwork [...]."
Survey Respondent

"It didn't take 3 billion years for these diamonds to form in the earth. I do not argue the fact that they are billions of years old. As a matter of fact, every rock in my garden is about a billion years old. So, you want to buy one of those?"
Interviewee #12

With the addition of the fifth 'C' for Certificate (Natural Diamond Council, 2020b) to the 4 Cs the jewellery industry has signified that, although both lab-grown and mined diamond materials are identical, their origin influences their socially constructed value. Since there is no grading report service for coloured gemstones (Gemmological Institute of America, 2024a), this development in the diamond market following the introduction of lab-grown diamonds is significant, as it segments this distinction between crystal materials used in the jewellery field. Paired with an extensive marketing campaign that aims to differentiate mined diamonds as 'real' (Figure 2.24 on page 80), the authenticity of lab-grown diamonds is brought into question. Are lab-grown diamonds fake? If one is to follow the terminology guidelines published by the Natural Diamond Council, one certainly would consider this:

"When referring to synthetic diamonds: [...] Do not use the following terms: 'real', 'genuine', 'precious', 'authentic' and 'natural', as those apply exclusively to natural minerals and gemstones."
(Natural Diamond Council, 2020a, p.1)

"Synthetic stone is basically the natural stone, it's just grown in a different place."
Interviewee #4

"It is clear, when it's naturally grown it has this authenticity and that when it is not naturally grown it has another one."
Interviewee #3

"From an industry point of view, there is no issue. Even if there was any white sapphire naturally - I don't think that this exists - I'm sure that the optical quality wouldn't be good enough for our customers. So, for us, authentic is authentically synthetic."
Interviewee #1

When posing this question to interviewees a clear pattern emerged. Some did not make any distinction between the materials, saying that a diamond is diamond, a ruby is a ruby and a sapphire is a sapphire, regardless of where they are formed. Others believed that they each have their own different identity and, therefore, authenticity.

"Synthetic ruby and ruby, if you look at the properties, they will have kind of the same properties, same specific gravity, same Refractive Index and everything. All these gemmological tests, they are pretty much the same, right? But the point is that when I'm cutting them, I will not say that I'm cutting a synthetic or I'm cutting an original untreated ruby. For me, they're kind of, cutting wise, they are the same. Behaviour would be the same."
Interviewee #8

"And let me take, for a moment, the famous sentence from De Beers: 'diamond is forever', well, diamond is absolutely forever. And there's a value, and there's the value of the soul, and there's the value of love, and I'm not making any commercial, simply because it's exactly like this. For sure. When I said to somebody in Moscow that asked me about synthetic diamonds: 'with all due respect', he said, 'what about synthetic diamonds?', I said: 'Well, do you have a girlfriend?' He said: 'Yes'. 'Is she natural or synthetic?' [Laughs and applause]"
Geatano Cavalieri President of CIBJO (Vicenzaoro, 2020)

55% of survey participants (Appendix 6), when asked about the value of lab-grown gemstones, responded that they would never value them higher than mined gemstones. With the value of these materials connected to their appreciation in the market, and this being a highly divided market that is currently undergoing a lot of change, a debate around the authenticity of these materials has been prominent in the press. Mining companies have successfully been lobbying for legislation to distinguish the two identical materials in the marketplace by their origins. This is ultimately aiming to establish rules and regulations to determine the acceptable terminology to be used when describing both man-made and mined gemstones, including diamonds.

"It is unfair or deceptive to use the word 'ruby,' 'sapphire,' 'emerald,' 'topaz,' or the name of any other precious or semi-precious stone, or the word 'stone,' 'birthstone,' 'gem,' 'gemstone,' or similar term to describe a laboratory-grown, laboratory-created, [manufacturer name]-created, synthetic, imitation, or simulated stone, unless such word or name is immediately preceded with equal conspicuousness by the word 'laboratory-grown,' 'laboratory-created,' '[manufacturer name]-created,' or some other word or phrase of like meaning, or by the word 'imitation' or 'simulated,' so as to disclose clearly the nature of the product and the fact it is not a mined gemstone."
(Federal Trade Commission, 2018, p.40674)

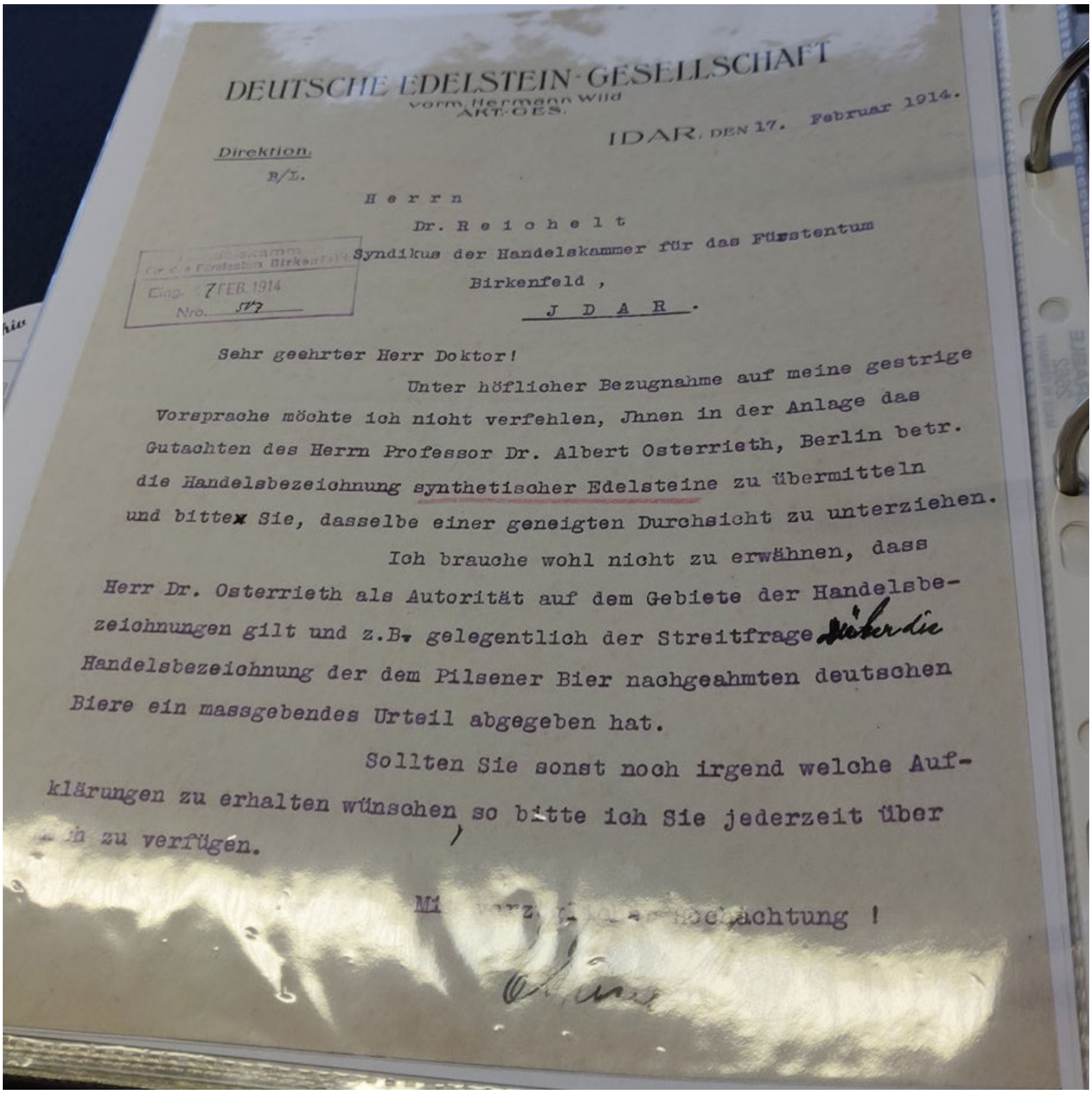
This is the latest development in a battle of words that has been ongoing ever since lab-grown gemstones were introduced to the market. This is evident from materials seen in the D. Jerusalem archive in Idar-Oberstein, where a letter dated 17 February 1914 (Figure 2.25 on page 86) discussed the use of the word 'synthetic' when describing the writer's own gemstones.

It continues today. Following the airing of the Dragon's Den (2024a) TV episode featuring the diamond brand Kimaï, on 26 January 2024, in which the brand secured funding from one of the dragons, another scathing response was published. The open letter directed to the BBC and BBC Studios Productions, signed by the National Association of Jewellers, the London Diamond Bourse and the Natural Diamond Council (previously the Diamond Producers Association), stated:

"Usage of misleading terminology, and outdated misconceptions about natural diamonds, pose a threat to consumer confidence which impacts the ten million people whose livelihood is supported by the industry. For future features, we encourage you to use the established industry terminology, and invite you to use us as a resource to ensure balanced coverage."
(London Diamond Bourse, 2024)

In a field where most terminology and, in particular, the labelling of gemstones has been subject to much discussion and now regulations, the introduction of these legislations could be interpreted as rather elusive in their efforts to inform and protect consumers, particularly when it comes to the labelling of lab-grown gemstones as 'artificial' and 'synthetic', which is what the Natural Diamond Council advocates (Natural Diamond Council, 2020a):

"A synthetic diamond is an artificial product that has essentially the same physical characteristics as a diamond."



DEUTSCHE EDELSTEIN-GESELLSCHAFT
vorm. Hermann Wild
AKT.-GES.

IDAR, DEN 17. Februar 1914.

Direktion.
B/L.

Eing. 17 FEB. 1914

Herrn
Dr. Reichelt
Syndikus der Handelskammer für das Fürstentum
Birkenfeld,
J D A R.

Sehr geehrter Herr Doktor!

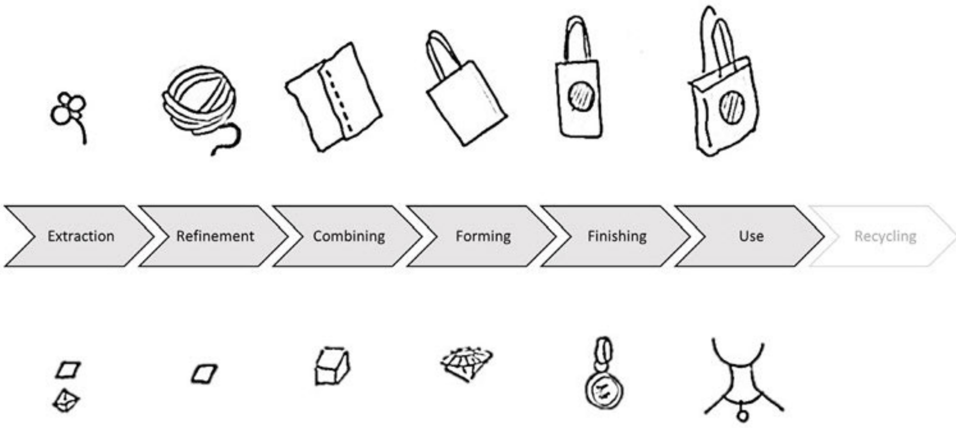
Unter höflicher Bezugnahme auf meine gestrige Vorsprache möchte ich nicht verfehlen, Jhnen in der Anlage das Gutachten des Herrn Professor Dr. Albert Osterrieth, Berlin betr. die Handelsbezeichnung synthetischer Edelsteine zu übermitteln und bitte Sie, dasselbe einer geneigten Durchsicht zu unterziehen.

Ich brauche wohl nicht zu erwähnen, dass Herr Dr. Osterrieth als Autorität auf dem Gebiete der Handelsbezeichnungen gilt und z.B. gelegentlich der Streitfrage über die Handelsbezeichnung der dem Pilsener Bier nachgeahmten deutschen Biere ein massgebendes Urteil abgegeben hat.

Sollten Sie sonst noch irgend welche Aufklärungen zu erhalten wünschen, so bitte ich Sie jederzeit über [illegible]h zu verfügen.

Mi[illegible]achtung !

2.25



2.26

Figure 2.25. Photograph taken of 1914 letter from the Deutsche Edelstein-Gesellschaft to Dr Reichelt at the Chamber of Commerce for the Principality of Birkenfeld stored in the archive of D. Jerusalem in Idar-Oberstein, Germany.

Figure 2.26. Schematic comparison of the production processes of cotton and laboratory-grown diamonds.

The overarching debate around the artificiality of materials is, however, not new – some people have previously tried to investigate the concept in relation to materials. Manzini (1989), for example, proposed artificiality as a scale, on which some materials are more artificial than others. In her book *Synthetic Worlds: Nature, Art and the Chemical Industry* Leslie (2005) suggested that everything that exists is natural, though the processes a material has been exposed to end up rendering it synthetic. The debate is far from over, and one might wonder, if the process a material or product has been exposed to influences its artificiality rating, who decides which processes are acceptable and which are not? When comparing for example the processes applied to the production of cotton fabric, considered a natural material, and those which are parts of growing a man-made diamond (Figure 2.26), it appears that the former is subjected to significantly more processes than the latter. At a minimum, both are grown from a seed, harvested and altered to make their way into products. Yet cotton is commonly considered natural and the man-made diamond is portrayed as synthetic. Some of the methods used to grow gemstones (see the techniques investigated in Chapter 5) are so closely related to the growth that occurs in the earth, the resulting crystals will never be identical to one another. Moreover, the growing process fully abides by the rules of nature, when it comes to the organisation of molecules in the material's crystal structure.

"[...] precious stones are regarded as minerals, cultural objects and artefacts processed in some way by humans."
(Lindemann et al., 2020, p.43)

Artificiality in relation to materials certainly is a concept that evades clear-cut and pragmatic categorisation. In her book ***Genuine Fakes*** Pyne (2019, p.195) concludes that: *"Objects don't have an intrinsic morality to them - context is everything."* When context is everything, it is more important than ever to question the value systems and social constructs holding them in place, not only by those with a vested interest commercially, but also by those appropriating the materials as designers or those buying them as consumers.

Other writers, who see gemstones as a cultural phenomenon, have claimed that the term itself indicates human involvement. In the text *Gemstones – The Crystalline*, Lindemann (2020) reflects on the cultural incorporation of gemstones into the Mediterranean-European area from Antiquity to the 19^{th} century and claims that the faceting of gemstones resulted in the shedding of the historically established symbolic content of stones, which ultimately led to their commodification:

"The light effect replaces the meaning of the material and causes the symbolic emptying of the meaning of the stone as material."
(Lindemann, 2020, p.49)

One could argue that, in Arem's (1977) definition of gemstones, requiring the cutting of the mineral, human involvement is indeed inevitable. With many-faceted diamonds bearing little resemblance to their natural form, and man-made and mined faceted diamonds being hardly distinguishable, one can wonder whether the faceted mined gemstone from this point of view can be considered any more natural than the man-made one.

gemstone

noun [C] (also **gem stone**)

/ˈdʒem.stəʊn/

a jewel (= precious stone), especially when cut into a regular shape

2.27

Figure 2.27. Gemstone, as defined in the Cambridge Dictionary.

GEMSTONE

Let us dive a little deeper into the term 'gemstone' (Figure 2.27). As largely discussed in most gemmology reference texts, the term is hard to narrow down. In his book titled *Encyclopaedia of Gemstones*, Arem (1977) discusses the challenge of definition. He asserts that a gemstone can be any mineral cut and polished for ornamental purposes, with some clear exceptions including pearl, coral and amber. So where does this leave the uncut diamond stones strung on a necklace or incorporated into a contemporary piece of jewellery? Are they not gemstones? Once again, this definition does not seem to extend sufficiently to include all that is considered a gemstone without requiring exceptions or conditions. And what about man-made materials that have no counterpart in nature? In his book *Gems: their sources, descriptions and identification* O'Donoghue (2006, p.472) states:

> *"Present thinking and commercial rules restrict the adjective 'synthetic' to materials which, while being manufactured by man, have a natural counterpart, however unornamental this might be."*

This statement excludes materials that do not have a natural counterpart, such as cubic zirconia (CZ), which is a hard, highly dispersive isotropic version of monoclinic ZrO^2 baddeleyite, and a very popular low-cost stone often used as an alternative to diamonds in jewellery. For this type of material, O'Donoghue suggests using the word 'simulant.' Arem (1977, p.2) goes one step further in his text, aiming to point out the ambiguity and contrast that exists in the labelling of stones as synthetic gemstones:

> *"It should always be remembered, however, that a synthetic gemstone is a contradiction in terms, since a gem is by definition a mineral, which is a naturally occurring material."*

In this statement Arem also links the origin of the material to his definition of gemstones, and therefore excludes both the man-made materials that have a counterpart in nature and those that have not from the term gemstones. When we go back to the origin of the word 'gemstone', however, we find that 'gem' is derived from the Latin word 'gemma', referring to a jewel or bud. Here the quintessence of a material mattered, as only that which could make the divine appear could be considered a gem. So, should we then say that any material present in a piece of jewellery, chosen by an artist who is the best judge of quintessence, is a gemstone, regardless of its origin? There has been much discussion around these definitions and adjectives, as it appears their use in itself might be confusing to the consumer. Perhaps Arem (2011) is correct in stating that:

> *"If gemology is ever to consider itself a true science, it will only do so if it begins to walk in step with other disciplines having a much longer history of empirical and theoretical evolution."*

2.28

2.29

cultured (pearl)

noun

/ˌkʌl.tʃəd ˈpɜːl/

A pearl (= a round, white precious stone) that has been formed artificially

2.30

synthetic

adjective (NOT NATURAL)

/sɪnˈθet.ɪk/

Synthetic products are made from artificial substances, often copying a natural product

2.31

Figure 2.28. Cereal box advertisement poster by Chatham. Image used with kind permission of Tom Chatham.

Figure 2.29. Created Emeralds advertisement poster by Chatham. Image used with kind permission of Tom Chatham.

Figure 2.30. Cultured, as defined in the Cambridge Dictionary.

Figure 2.31. Synthetic, as defined in the Cambridge Dictionary.

SYNTHETIC AND CULTURED

"When they [consumers] think synthetic, they think cheap."
Interviewee #8

Now let us turn our attention to the words 'synthetic' (Figure 2.31) and 'cultured' (Figure 2.30). The use of the word 'synthetic' is known to have a negative connotation for consumers, who are looking for natural products (Pringle, 2017). Rozin (2005, p.652), a researcher of the subject, wrote:

"Instrumental reasons for this preference refer to specific advantages of natural entities: They are often thought to be healthier, more appealing to the senses, or kinder to the environment than entities that are not natural. In addition, our work suggests a very important role for ideational factors; that is, the natural is preferred just because it is inherently better—more moral, more aesthetic, or simply 'right'."

There might therefore be a specific commercial benefit to companies selling mined gemstones to lobby for the requirement of man-made materials or gemstones to be labelled as synthetic. And the reverse could also be stated, that companies growing man-made stones would rather eliminate this description.

"The natural industry pulled some strings and got the Federal Trade Commission on our back and we fought them four years [1959-1963] in Washington DC and we won, but, without that win, all the crystal growers would have had to call their stones synthetic. And we will not use that word. It's confusing. Never mind what the GIA and gemmologists say, a synthetic stone is, you talk synthetic to a consumer and they think fake. [...] It was a fight my father couldn't ignore."
(Tom Chatham as recorded in the podcast for the Lab Grown Diamonds Magazine, 2023)

Chatham has documented his father's battle with the Federal Trade Commision around the terminology used for his lab-grown emeralds in his book *The Chatham Legacy: An American Story* (Chatham, 2023). They ultimately settled on the word 'created' (Figure 2.28 and Figure 2.29.) In an interview with him he recalled that:

"Like 'cultured', even though it wasn't and isn't my favourite word, in my father's opinion that best described what he was doing, in culturing emerald. But it got into a court battle. [...] Richard Liddicoat and Robert Crowningshield and some of the other people from around the world were called in by the government. 'What does Chatham make?' And they all had to say: 'Emerald. Chatham creates emerald.' And, later, in chambers, the judge said: 'Why don't you use Chatham created?' That's where it came

from, the judge, we had never thought of it. We had a list of 25 different words, and created was not among them. Does it thoroughly explain what the product is? Probably not. But we've all come to agreement, except in France, that the word 'synthetic' is confusing."
Tom Chatham, in an interview conducted on 8 March 2024

The World Jewellery Confederation (CIBJO) has published additional guidance (The World Jewellery Confederation, 2021) produced by nine leading diamond organisations, which restricts the use of the word 'cultured'. Cultured and cultivated, they claim: *"refer exclusively to organic/biogenic products"*. Here they reference the use of the adjective cultured when describing pearls that have been produced with human intervention. This relates to an invention from 1893 accredited to Mikimoto, whose pearls are considered 'real' pearls, but whose production involves human assistance where an irritant, often a tiny bead, is inserted into an oyster shell by a pearl farmer. When a pearl is formed without human interaction the irritant is often an organism in the water, or something that finds its way into the shell without being specifically placed there. Some diamond companies have started to use the word 'cultured' to describe their diamonds. As the guidelines from CIBJO state: *"A synthetic diamond is an artificial product"* because unlike cultured pearls which are at present considered 'real', they want consumers to agree that man-made diamonds are 'fake' regardless of their chemically identical composition. It is not surprising the word 'cultured' would be of interest to use in relation to man-made crystal materials, as it is connected to a product, pearls, that itself has survived multiple attempts over several years to be labelled as a counterfeit (Zoellner, 2007).

Instead the word 'synthetic' remains the go-to term for those with a vested interest in mining. In France the term was denominated as the only acceptable qualifier for stones *"whose physical, chemical properties and crystal structure correspond essentially to those of natural stones that they copy"* in a decree dating back to 2002 (République Française, 2002). Following the review of nearly 40 responses to a published questionnaire on the request to adjust the rule to allow the use of the term 'laboratory-grown' in 2022, the majority of respondents were in favour of maintaining the decree, which as a result was therefore not amended (Bates, 2024).

"The common definition of 'artificial' gives: 'something produced by the work of man and not by nature'. But isn't man a product of nature? When man transforms something, isn't that only nature acting through him? This natural versus artificial opposition is nonsense and infers that man is in fact artificial!"
(Kula et al., 2009, p. 346)

Figure 2.32. Neo-Gemstone, as proposed for inclusion in the Cambridge Dictionary.

neo-gemstone

noun

/ˈniːoʊ-ˈdʒɛmstoʊn/

A gemstone grown fully or partially in a studio or laboratory setting. These gemstones show either enhanced properties, or properties not found in nature.

2.32

NEO-GEMSTONE

Having engaged in many discussions around the terminology used throughout this research project, the need for a new neutral term kept on resurfacing as time went on. Where synthetic has connotations that do not align with the materials in question, and the prefix lab-grown is clumsy and indicates the involvement of a lab (which, as demonstrated in Chapter 5, is not always the case), cultured and created were also not deemed sufficiently prescriptive. Whilst searching for a word to replace the prefixes used to describe lab-grown gemstones, in response to the quest for a 'new' term, Dr Hall identified 'Neo-gemstones' as a possible alternative. 'Neo', with its etymology linking back to the Greek néos meaning young, fresh and new, is used in a range of fields to describe *"a different period or form of"*, the *"new and abnormal"*, and even *"a new chemical compound isomeric with or otherwise related to (such) a compound"* (Merriam Webster, 2024). The term proved to be the most applicable to describe gemstones that have been grown in new ways or with varying chemical compositions showing enhanced properties. In anticipation of challenges against the term, a trademark (Appendix 7) has been obtained, not to limit its usage, but to ensure no-one can prevent its usage, at least in the UK.

KNOWLEDGE OF LAB-GROWN GEMSTONE MATERIALS

Despite lab-grown gemstones having been around for over a century, general awareness about humankind's capability of growing them has only recently started to reach the broader population. In response to the question 'How would you rate your knowledge of man-made crystals?' only 16% of respondents to the 2019 survey (Appendix 6) considered themselves very knowledgeable (10%) or extremely knowledgeable (6%). Furthermore, customer knowledge about man-made gemstones was ranked poorly by survey participants. In response to the question 'On average, how would you rate your customers' understanding of man-made crystals, prior to your discussion?' 52% of those who discuss man-made crystals with clients said their customers were not knowledgeable at all, and 37% answered 'slightly knowledgeable'. For a long time even awareness of the existence of lab-grown gemstones was limited. This has, however, improved drastically in the last decade. A 2020 study conducted by marketing firm The MVEye revealed that 77% of surveyed consumers (respondents came from five European countries and indicated that they had received or purchased fine jewellery valued over 250 Euro within the past three years, with at least one being diamond jewellery) were aware of lab-grown diamonds (The MVEye, 2021).

Whilst the marketing of lab-grown diamonds by large brands such as Swarovski (campaign launched in 2018) and Pandora (campaign launched in 2022) is likely increasing the knowledge of lab-grown diamonds, people's knowledge about the growing of other gemstones, and the specifics of the techniques involved are likely to remain less widespread still.

"[...] we can't control the inclusions. So, I mean, we can control them to the extent that we know how to make a better crystal, but we don't, we don't know what causes inclusions. People give us far more credit than we deserve in growing crystals. And it's part of the problem, because they don't understand, it isn't like, maybe people don't even really understand what a hothouse orchid is either, or how it came into being, or some of the hybrids that are created. They just accept it. 'Oh, yes, same as natural'. But when it comes to gemstones, it doesn't work."
Tom Chatham, in an interview conducted on 8 March 2024

When asked, all interview participants who did not work in a company manufacturing tools or were teaching on or researching the topic indicated their knowledge of lab-grown gemstones was limited.

"I don't think I know as much as I should about the topic."
Interviewee #4

The reasons they gave for the lack of knowledge on the topic were partly linked to secrecy:

"If you want to go deeper, it is hard. That's then for secret and for research reasons. [...] Because they [crystal growers and crystal growth companies] do not want to share the knowledge."
Interviewee #3

"This is a secret world. Synthetics, it is a secret world."
Interviewee #8

"Often, they [crystal growers and crystal growth companies] keep it [the information] in the dark zone, like the dark net. That should end. [...] They should not hide it. And, not hiding means openness and transparency. And then, I think, the creators, the designers will use it."
Interviewee #7

Whilst the first successful method to grow ruby commercially was published open source in the early 20th century, this is not common practice in the field of science. Given that the growth of crystals is a scientific endeavour, and it is driving innovations in a range of fields, it is not surprising that the knowledge created in scientific areas is not freely shared, or accessible to jewellery artists. Providing additional knowledge in this area on the topic and demonstrating that there are innovations to be made when scientists collaborate with jewellery artists, is a key endeavour of this PhD study.

2.33

Figure 2.33. *Trigonal*, laboratory-grown (left) and natural quartz (right).

2.4. Practice-Based Contextual Reflections

"As long as we stick to things and words we can believe that we are speaking of what we see, that we see what we are speaking of, and that the two are linked."
(Deleuze, 1988, p.65)

Throughout the research project, the contextual review, insights, commentary and discussions informed the creation of Critical Design (Gaspar, 2013) which aimed to visualise the findings deemed important to highlight in order to question and, where possible, influence the issues identified. This chapter is therefore accompanied by a collection of critical jewellery design pieces, created in line with a desire as an artist/maker to bring about social change, using them as anchors to re-consider the identified challenges, implications and possibilities. The pieces pose a practice-based aesthetical commentary on the research conducted.

REAL OR FAKE?

"[…] scientists, as well as their measuring instruments, are all part of nature. What quantum theory describes, then, is the way in which one part of nature manifests itself to any other single part of nature."
(Rovelli, 2022, p.67)

For the series *Real or Fake?* a pair of earrings (Figure 2.14 and Figure 2.34) and a pair of signet rings (Figure 2.33) were produced to question the labelling and the underpinning beliefs about the authenticity of man-made gemstone crystal materials. Man-made crystals, when grown in mirror of their natural counter parts, are identical, and in some instances are superior, to mined gemstones. Engineered growth techniques enable a crystal to grow following its underpinning crystal structure, molecule by molecule. Two signet rings have been formed out of quartz – one made from man-made quartz and the other from mined quartz. The area where normally an identity marking seal would be positioned on a traditional signet ring on this occasion shows the natural growth patterns these two materials display, in line with their trigonal crystal structure. The rings were carved so that these patterns remained visible on that specific location in each piece, to showcase their quintessence. They both clearly follow nature's predetermined structure, although the mined crystal in a more scattered and less formulated way.

The rings also demonstrate the ability of man-made materials to be grown in such a way that they are flawless, making them in some instances easier to work with and, for this reason, more desirable than the mined crystal.

The labelling of lab-grown and mined materials was further questioned in a pair of earrings which were set, with one containing a faceted brilliant cut man-made diamond and the other a mined diamond. Whilst, at a first glance the traditional-looking gold diamond stud earrings look like nothing special, on them the question 'REAL?' on one, and 'FAKE?' on the other have been engraved. These are the only markers to distinguish the one from the other, as from looking at them one cannot tell the stones apart. Engraving the words on the ear posts of the studs meant that the markers could not be seen when they are worn, so viewers would therefore no longer be able to make the distinction.

2.34

Figure 2.34. *Fake?/Real?*, 18 ct gold and diamond (one laboratory-grown one mined).

Figure 2.35. *Wear the waste*, kimberlite, black ring box.

"What contemporary jewelry has to offer in the expanded field of art and design is not only objects but also a specialized knowledge, a particular way of looking at things and posing questions. The act itself of wearing, and the kind of knowledge embedded there, has become a central question and field of investigation."
(Gaspar, 2013, p.231)

For the series *Wear the Waste* a necklace (Figure 2.36 on page 100) and ring (Figure 2.35) were produced that visualise the average amount of kimberlite waste rock that needs to be mined in order to produce the incorporated or referenced diamond. With on average 4350 kg of kimberlite needing to be removed to mine 1 carat of diamond, the heavy kimberlite necklace (weighing 2.175 kg) aimed to provide its wearer with a tactile appreciation of the effort that is required to displace this amount of rock in order to obtain the featured 0.0005 carat diamond, and served as a commentary on the increasingly promoted sustainability narrative surrounding mined diamonds, its craters now even visible from space. The ring, made from kimberlite waste material, was displayed in an engagement box. It has been engraved with a scale marker, providing an insight into how much kimberlite needs to be displaced on average for a standard 1 carat diamond, a traditional feature in modern engagement rings.

2.35

2.36 a.

Figure 2.36. *Wear the Waste*, kimberlite, carbon fibre rope, diamond.

2.36 b.

2.5. Conclusion

"Everything is what it is only with respect to something else. Every vision is partial. There is no way of seeing reality that is not dependent on a perspective - no point of view that is absolute and universal."
(Rovelli, 2022, p.166)

Chapter 2 explored the historical and contemporary context of lab-grown crystals, particularly focusing on their use and perception within the jewellery industry. The chapter started by detailing the long history of human fascination with gemstones and the equally long history of numerous attempts to imitate them that has accompanied this fascination. Scientists in the 19th century saw the first successful production of synthetic gemstones, which caused a resistant reaction from the jewellery industry, with established jewellers fearing market disruptions. The influx of lab-grown gemstones led to the formation of gemmology to distinguish natural from synthetic stones.

2.37 a.

Figure 2.37. *Trigonal*: (a.) Laboratory-grown and (b.) Natural quartz.

2.37 b.

Section two of the chapter shifted to considering contemporary views and uses of lab-grown gemstones. Survey and interviews highlighted the divided opinion on this issue in the jewellery industry. Some respondents favoured lab-grown gems for their consistency, sustainability, and innovative potential. Others remained tied to traditional views, valuing the 'authenticity' and 'natural charm' of mined stones, and claiming that lab-grown gems lack quintessence. The heated debate around the authenticity and terminology of lab-grown gems has been playing out in courts and the press for decades. Terms such as 'synthetic', 'lab-grown', 'created' and 'cultured' are being debated, enforced or challenged, prompting the proposition of the novel term 'Neo-gemstone' as a suitable alternative.

Marketing, as is demonstrated, plays a significant role in shaping consumer perceptions and industry practices. When context is everything, it is more important than ever to question the value systems and social constructs holding them in place, not only by those with a vested interest commercially but also by those appropriating the materials as designers and those buying them as consumers. This chapter therefore includes critical jewellery designs, created to challenge current perceptions of lab-grown stones. These commentary pieces of jewellery aim to avoid just repeating what it is we are told by those who have a vested economic interest in these materials.

Over the years of writing this PhD, a significant change in attitude towards lab-grown gemstones has been taking place, which could result in a re-appreciation of all lab-grown materials in the market. As will be demonstrated in the following chapters, there are a range of creative opportunities and innovative uses for Neo-gemstones and the growth processes through which they are created. For this endeavour to be successful, however, the context in which these materials are valued should continue to be critically reconsidered.

3.1

Figure 3.1. *Two-Carat Solitaire*, CVD grown diamond seed, oxidised silver.

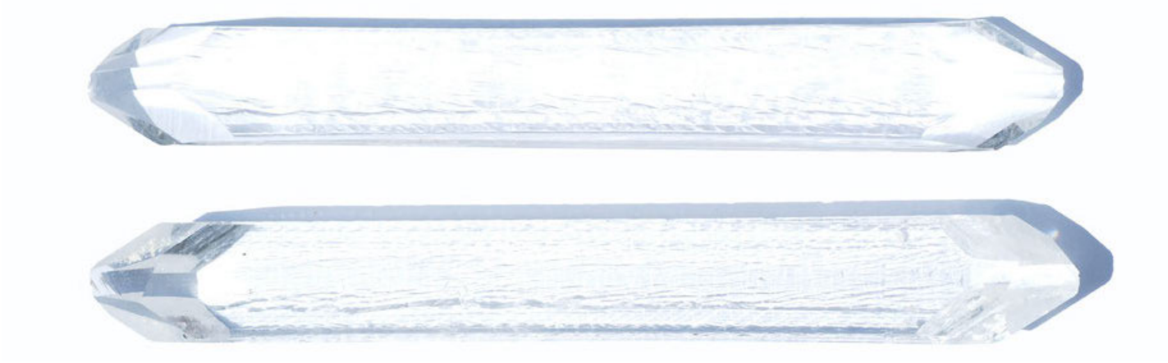
Chapter 3. Case Study 1: Urban Mining Gemstone Materials

3.1. Introduction

This chapter documents Case Study 1, which revolved around the identification and exploration of currently non-utilised man-made gemstone material waste, and its suitability for jewellery and interest to jewellery artists. Following visits to companies during this research project (Appendix 5), the idea of urban mining – which, in the context of the research involved retrieving waste gemstone materials (mining) from a company (urban environment) – became apparent as an opportunity to be explored as part of the project. This chapter therefore shares the findings from two urban mining experiences, the first an individual one at the Bring Diamonds company (United Kingdom), and the second an urban mining experience at Effgen Lapport Schleiftechnik (Germany), which was developed into a workshop for nine participants at the University of Applied Sciences Trier/Idar-Oberstein.

3.2. Case Study Design

During the visit to Bring Diamonds in 2021 the author was shown a large selection of waste CVD diamond offcuts, seeds and growths. As a jewellery artist, this waste was appealing for incorporating into jewellery in its own right and was acquired and subsequently transformed into contemporary pieces of jewellery (Figure 3.1), through which a review of the material properties and the outcomes was conducted. In order to test whether the practice of urban mining could be applied further, and if other jewellery artists would benefit from the experience and usage of retrieved waste materials, a workshop was developed in collaboration with Effgen Lapport Schleiftechnik and the University of Applied Sciences Trier/Idar-Oberstein. The teaching project, funded by a Mary Somerville grant, engaged nine participants in the retrieval and usage of waste following an urban mining experience at Effgen Lapport Schleiftechnik. During the project participants used both materials and associated industrial processes to create new work. This chapter documents the work created using the retrieved waste from the Bring Diamonds factory and the teaching project titled 'Bling It', diffracting the practice of urban mining in the context, as a way to exemplify how waste gemstone materials could be incorporated into jewellery.



3.2

3.3

Figure 3.2. Laboratory-grown quartz, purchased in Idar-Oberstein, Germany.

Figure 3.3. Laboratory-grown crystal materials purchased in Idar-Oberstein, Germany.

3.3. Microcosm

When starting this research project, it was the intention to find opportunities to work with lab-grown gemstones and man-made crystal materials to explore the creative opportunities that incorporating these materials could provide to jewellery artists. As highlighted in the previous chapter, faceted lab-grown gemstones are being incorporated by a growing number of jewellery artists and designers, who cite sustainability and financial reasons as being drivers for their choice. These reasons for use, whilst valid at this moment in time, does not always include advocacy for the use of lab-grown materials due to their differences from mined gemstones. Should a practice of recycling existing stones become more commonplace and financially competitive, those recycled mined stones could potentially become preferable over lab-grown cut gemstones in most instances. What seemed most interesting as an opportunity for innovation in this area was therefore using these materials in ways that mined gemstones could not be used. For this reason, a search for uncut lab-grown gemstone materials started. Whilst it was easy to purchase cut lab-grown gemstones from various websites online, finding uncut materials proved much more challenging. On residency in Idar-Oberstein, there were some shops which sold uncut lab-grown gemstone materials. The Valley is mostly known for its supply of natural materials, so it was not that surprising lab-grown materials, when available, were obscurely stored in an inconspicuous location, largely unsorted. Only one store visited had a large supply, tucked away in a corner. When asked where the materials had come from, it was shared they had come from a company that no longer sold lab-grown gemstones. Whilst there was lab-grown uncut material available in Idar-Oberstein in small quantities in other stores, such as quartz (Figure 3.2), the supply could not be deemed reliable. This is probably different in countries where lab-grown gemstone materials are grown in larger quantities (China and India), in Europe, with supply dwindling, this proved to be challenging. A barrier for their use beyond their faceted appearance could therefore be traced back to the difficulty of purchasing them.

Once some material was purchased (Figure 3.3), a second challenge arose quite quickly: the cut ting of mineral and gemstone materials requires specialist equipment and knowledge – a set of skills usually obtained by gold- and silversmiths during specialised education. To overcome this obstacle, a faceting machine was purchased and online classes in faceting attended (during the Covid-19 pandemic). This, in addition to the ability to use the University of Applied Sciences gemcutting workshops during residencies in Idar-Oberstein (Appendix 2), enabled the addition of the basics of faceting and stone carving to the author's repertoire of traditional goldsmithing skills.

3.4

3.5

3.6

3.7

Figure 3.4. *The Wallace Cut*, Wallace Chan, carved smoky quartz. Photography by Wallace Chan. Image used with kind permission of Wallace Chan.

Figure 3.5. *What Else*, Julia-Maria Kunnap, gold, ametrine. Photography by Julia-Maria Kunnap. Image used with kind permission of Julia-Maria Kunnap.

Figure 3.6. *Sulis, Eye Amulet,* grey and white banded agate, 18 ct gold. Photography by Sian Evans. Image used with kind permission of Sian Evans.

Figure 3.7. *Celestial Moss Agate Signet Ring*, Jacqueline Cullen, moss agate, grey diamonds. Photography by Jenny Llewellyn. Image used with kind permission of Jacqueline Cullen.

The journey into learning faceting in particular was most interesting. Even though many jewellery artists, designers and makers use faceted gemstones, and most faceters cut stones to incorporate them into jewellery, it appeared extremely rare for the skills of each to be shared across both. This can likely be rooted in the time it takes to master both sets of skills, and the fact that an individual usually cannot acquire them in the same location. Two examples of jewellers who did become skilled stone faceters/carvers are Julia Maria Kunnapp (Figure 3.5) and Wallace Chan (Figure 3.4), who have both dedicated a great deal of time to mastering faceting and carving to supplement their jewellery skill-sets. This is becoming more common for stone carving in Europe, thanks to the Masters' course in Idar-Oberstein which combines jewellery and stone carving tuition, and the initiative of a range of jewellers who have found means to expand their skill-sets. Two such jewellers/stone carvers who have expanded their skill-sets are Sian Evans (Figure 3.6) and Jacqueline Cullen (Figure 3.7).

> *"I think university students can use these [lab-grown gemstones] easier, because they are less expensive than real gemstones, but they should not forget to use, once in a while, a real stone, with its special immittance of light."*
> *Interviewee #7*

Returning to the use of lab-grown gemstones, in the world of faceting these materials are often used for training purposes. However, likely due to their low cost in comparison to mined materials, they seem to rarely warrant explorative faceting, as labour costs would out-price the material in the market. Some of the research participants, however, did see the lower cost as an advantage, in order to bypass the need to cut for weight retention:

> *"[...] imagine you have these concave or fantasy cuts on synthetics, that would be amazing. Because you're not worried about wasted material. But then the other issue is: we somehow sometimes think synthetics are cheap."*
> *Interviewee #8*

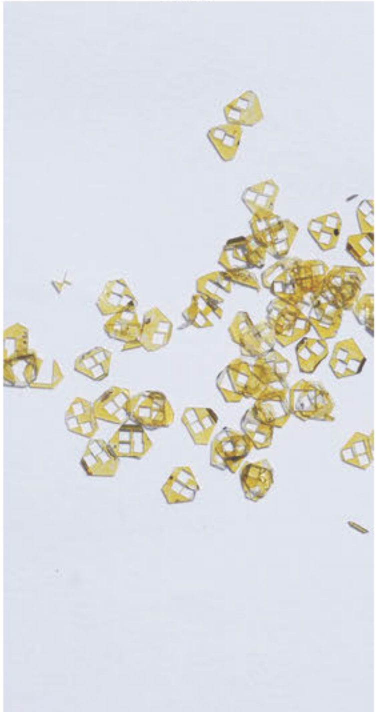
Whilst searching for the various usage of lab-grown materials in the Valley, it became clear that the cutting of lab-grown gemstones was an endeavour pursued by businesses in the past, many of which had transformed their businesses into companies catering to an industrial market with machined hard materials (such as sapphire) and the production of tools using lab-grown gemstone materials (Stadtverwaltung Idar-Oberstein, 2014).


3.8


3.9 a.


3.9 b.


3.10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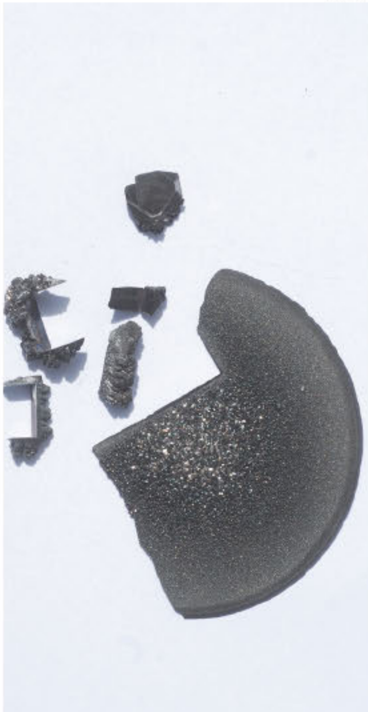

3.12

Figure 3.8. Old faceting machine located at a tooling company in Idar-Oberstein, Germany.

Figure 3.9. Storage of old laboratory-grown cut and faceted gemstones located in a tooling company in Idar-Oberstein, Germany.

Figure 3.10. Waste laboratory-grown gemstone material following coring of laser rods, collected in Idar-Oberstein, Germany.

Figure 3.11. Waste HTHP laboratory-grown diamond material following laser cutting of plates for the production of tools, collected in Idar-Oberstein, Germany.

Figure 3.12. Waste CVD laboratory-grown diamond material following laser cutting for the creation of round brilliant cuts, collected from Bring Diamonds in Newcastle Upon Tyne, United Kingdom.

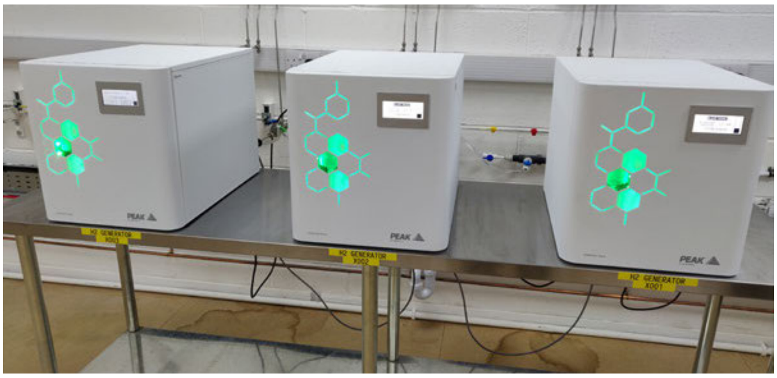
" [We] started with gemstone production almost 80 years ago. And from natural stones, high quality, to synthetic stones, for mass production. I think, during the best times, 40 people were employed here, or even more. [...] this changed in the late 80s, early 90s, because most of this sort of business either went away to the Far East or was concentrated in other companies. So there's really not that many left in Idar-Oberstein. And now we make only technical things, technical items from sapphire, mainly sapphire. The main products are thin micro lenses for medical applications, endoscopes, and also optics, and technical things for research."
Interviewee #1

During a tour of the company where interviewee #1 worked, evidence of the history of selling lab-grown gemstones could still be found. From old faceting machines to a large amount of stored cut lab-grown gemstones (Figure 3.9), these remnants reflected another aspect of the bleak picture of the history of these materials in the Valley.

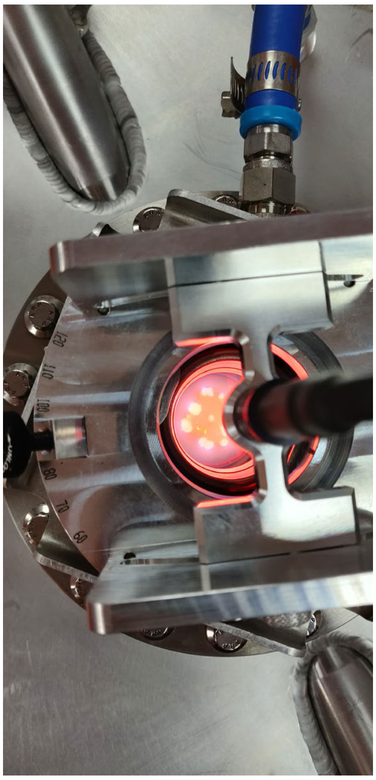
The largest tooling company in the region, Effgen Lapport Schleiftechnik, shared a similar beginning. The company, founded in 1922, first processed precious and semi-precious stones before shifting away from faceting stones to producing tools in the mid-1950s (Effgen Lapport Schleiftechnik, 2019). Just like there were treasures to be found at the previously-mentioned company, in the form of old lab-grown gemstone stock, so here too was another range of materials worthy of attention. The large amount of sparkling reclaimed grit (diamond and other crystal materials) classed as waste in storage at Effgen Lapport Schleiftechnik influenced the direction for the first case study.

Interesting waste materials could be found in nearly all the industrial manufacturing and crystal growing companies visited (Figure 3.10, Figure 3.11 and Figure 3.12). These materials appeared to be an exciting alternative in the search for uncut lab-grown gemstone materials. Here was a supply of materials, accumulating in storage, which had the potential to be reused for interesting applications in jewellery. Being financially attractive as they were theoretically waste, and sustainably attractive as they had already served a purpose and would essentially be a re-use material, these materials could provide opportunities for innovation. Looking for this type of high value waste and incorporating it into jewellery as an exemplar became the focus of Case Study 2. Whilst many materials could have been chosen, due to the heated and ever-evolving debate around lab-grown diamonds being traced throughout the PhD study, the diamond waste retrieved during a visit to the Bring Diamonds Factory in the United Kingdom and the diamond waste kindly donated by Effgen and Medidia in Germany was selected as Materia Prima for Case Study 2.

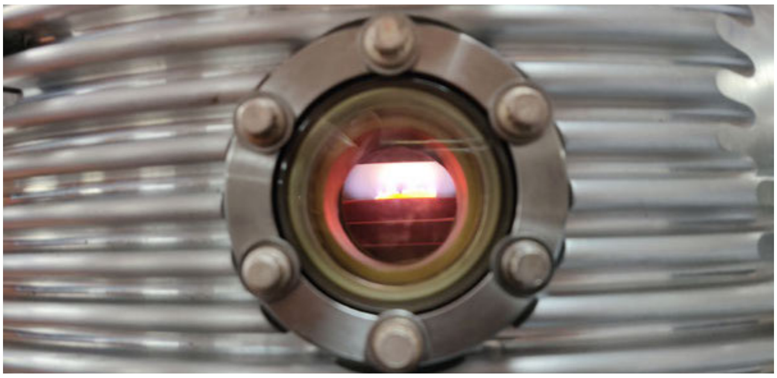

3.13


3.14


3.15 a.


3.15 b.


3.16


3.15 c.


3.17

Figure 3.13. CVD laboratory-grown Bring Diamonds diamond pre-laser cutting (left) and after laser cutting (right).

Figure 3.14. Hydrogen set-up at Bring Diamonds, Newcastle Upon Tyne, United Kingdom.

Figure 3.15. CVD chamber containing diamond seeds in Bring Diamonds, Newcastle Upon Tyne, United Kingdom: (a.) pipes supplying required gases, (b.) top view, (c.) front view.

Figure 3.16. CVD diamond growth set up, including computer monitoring growth in the CVD chamber.

Figure 3.17. CVD grown brilliant cut diamond by Bring Diamonds post faceting.

3.4. Materia Prima: Carbon Shimmers

During the visit to the Bring Diamonds factory in Newcastle Upon Tyne on 14 August 2021, an introduction into the growing of diamond using the Chemical Vapour Deposition (CVD) technique provided an insight into the ease with which diamonds can be grown today, and the challenges the technique continues to pose to achieve the company's desired outcomes. According to the company's co-owner, a diamond seed, also referred to as a substrate, was positioned inside one of the three operational chambers located on the premises. A gas mixture of hydrogen, produced on site (Figure 3.14), and methane was activated by microwave radiation, creating a plasma inside the chamber (Figure 3.15 and Figure 3.16). Following activation, the methane decomposed into carbon radicals and atomic hydrogen, with the hydrogen stabilising the diamond surface, allowing the carbon to deposit on the seed to form a diamond layer. Layer by layer a diamond seed was then grown into a larger diamond (Figure 3.13).

"Our reactors replicate the physics that created the universe, stars, planets, and the foundations of life itself. It does this by simulating the vacuum of space and the hot plasma of a star in miniature."
(Bring Diamonds, 2024)

Following growth, the seed was removed from the chamber and, using a laser cutter, its offshoot carbon/diamond growths were removed, leaving a black coloured cube of diamond (Figure 3.13). The grown diamond was then given to a diamond faceter, who cut the diamond into a traditional brilliant cut (Figure 3.17). The company, run by two engineers/inventors who had little or no experience of the jewellery field, hoped to perfect their product, expecting that the industry would be keen to receive a 'sustainable' diamond (Bring Diamonds, 2024) grown in the United Kingdom. As they continued to grow diamonds, they realised that achieving a clear diamond was much more challenging than anticipated, and the growth process, which follows the rules of nature, has a mind of its own, sometimes producing inclusions, and nearly always a different hue. As a result of their attempt to provide the industry with yet another strand of box standard brilliant cut diamonds, a significant amount of waste was accumulated along the way. Seeds that displayed inclusions early on in the process were decommissioned; offcuts of successful seeds were packaged in small plastic bags; not unlike anything they had seen before during their research, these were considered undesirable side effects. Out of the several boxes of waste, a selection was picked to interrogate in a jewellery making process.

3.18

Figure 3.18. *Two-Carat Solitaire Rings*, CVD diamond seeds, oxidised silver.

> *"In the early 18th century, the mineral, now transformed into a gemstone, found its ideal form with the prototypical shape of the round, faceted diamond, which has essentially been preserved and perfected to the present day with the theological striving for perfect brilliance. It was the effort in achieving as perfect a reflection or collection of the light inside the stone as possible through faceting and radiating it in the direction of the observer. The goal was the transformation of the stone into light, its dematerialization in elevation to a symbol, into which the buyer or owner could project anything he or she desired. In this form, the traditional gemstone has reached its ultimate goal. It is a place of solidification, where the mineral as a material becomes a dead stone. It even developed especially in the association with greed and commerce – after its transformation into exchangeable goods – into a mythical and literary symbol of misfortune and death. A gemstone curse existed that derived not from the stone itself but from greed, a form of crystalline thinking. Some believe that the diamond acquired thereby its 5th 'C': the Crime. A characteristic of this crystalline thinking could be the liaison of rationalistic-led trade and lack of ethical constraints."*
> *(Lindemann et al., 2020, pp.73–74)*

Two-Carat Solitaire

The technology of growing diamonds is an incredible scientific feat. The chosen CVD offcuts had been used to create *Two-carat Solitaire* rings (Figure 3.18) that have nothing in common with their blindingly brightly faceted counterparts apart from the name the organisation of their carbon molecules carries: 'diamond'. On display, their shimmering black graphite edges, countless nucleations and intriguing inclusions, were considered undesirable in the pursuit of the clear brilliant cut, but clearly visualised the extreme transformation they had been through. Centring this waste in a traditional solitaire ring format alludes to their materiality and communicates their preciousness whilst aiming to position them in the spotlight they deserve, as remarkable feats of engineering and science. The solitaire ring is however blackened, commenting on the piece's underdog status in a context of capitalism, where that which is polished and shines brightest attracts the most attention.

3.19 a.

3.20

3.21

3.19 b.

Figure 3.19. *Undervalued CVD*, CVD diamond growth offcut, oxidised silver, CZ: (a.) left earring, (b.) right Earring.

Figure 3.20. CVD diamond growth offcut.

Figure 3.21. *Brilliance*, CVD diamond growth offcut, oxidised silver.

Brilliance

> *"[...] for all the rationalistic interpretation of the brilliant cut, the brilliant trompe l'oeil effect shows a deep uncertainty: it is based upon a deception of the senses, which simulates a living, coruscating stone while in reality it is simply an effect produced by external motion. In the meaningless ornament - emptied of its purpose - the 'vanitas' motif and death appears." (Lindemann et al., 2020, p.69)*

Whilst initially uncertain how to approach the black cloudlike structures (Figure 3.20) that had been removed by laser from the purer diamond cores that later shed their dark colour by faceting, it seemed important to visualise what was now missing from these leftovers. Highlighting the pursuit of the traditional brilliant cut, the structure was positioned around an empty round setting. Framing this separation, this ring (Figure 3.21) speaks of absence and presence. Positioned proudly atop a traditional solitaire ring, the strong graphite structure attracts all the attention, thereby reclaiming its identity and status – as its unusual appearance would have done all along if separation had not been pursued. No longer punished for its appearance and dominant presence, its glints and shimmers provide a playful hint of its structural reality with brutalist honesty. Reminiscent of approaching volcanic rock following eruption, or dark carbon clouds emanating from the chimney of a large industrial factory, the strong shapes paint a picture of the economic context carbon is positioned in today, as humanity's greatest luxuries and innovations, but simultaneously its greatest shame and threat.

Undervalued

Fixated by the resolution with which these laser-cuts have separated that deemed precious from that deemed undesirable, the lines these cuts have traced have been expanded and used to separate left from right and right from left. By cutting a diamond simulant (CZ) in half, that which should not be done is done to it, as was done to the diamond underneath it before. Juxtaposed next to each other, simulant not quite diamond in structure and offcuts not quite diamond in organisation and shape, each speak of their role in society as 'unvaluable' or 'non-precious', forever separated from acceptance and celebration. Yet, as they sit along this black line (Figure 3.19), this underscored reality, perhaps they do not care. Unapologetically jewellery, boasting ear posts and butterfly backs, their wearer may neither.

3.22 a.

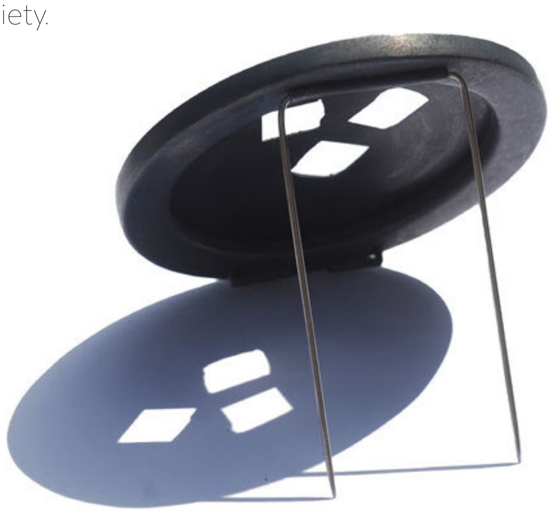
Figure 3.22. *Universe*, carbon and diamond formation grown around CVD diamond seeds, oxidised silver, steel: (a.) side view, (b.) back view.

Universe

> *"The rationalistic development of production technology corresponded to a relationship to nature that changed from the end of the Middle Ages onwards. Natural resources were no longer an expression of the gift of divine care and love; especially in the 15th and 16th centuries of the Reformation, they became the divine mission of controlling nature: subdue the earth. The facet cut also stood for this spiritual change."*
> *(Lindemann et al., 2020, p.71)*

They speak of replicating the physics that created the universe, the stars and the planets. When looking at the plate used to hold diamond seeds in the CVD process, its circularity can be interpreted as a scaled-down representation of our planet Earth. A compelling visual analogy, presented through the scaling-down of this process into a diamond producing machine, especially considering that some still believe the earth to be flat. The idea 'let's create diamonds' has captivated and cursed many. As this idea became a reality, it expanded, gaining space and time, its matter emerged. Just as the universe cooled following the Big Bang, forming atoms, stars and galaxies, so is our reality of lab-grown diamond settling in, its gravity and electromagnetism influencing all aspects of modern humans – from their dependence on luxury to technology.

Following the creation of a few diamonds, a trace of carbon is left on the machine's round plate. The black layer surrounding the removed diamonds shows evidence of random nucleations, with unplanned patterns emerging, not unlike those visible in the sky. Yet, once the diamonds grown from substrates are removed, this plate is classed as waste. To those blinded by the brilliance of a cut diamond, the statement that the process resembles the creation of the universe might seem like a marketing ploy, and the part that actually bears witness to this process is discarded. In the piece titled *Universe* (Figure 3.22 and Figure 3.23 on page 120), such a plate is set in a brooch. It invites anyone to explore the tiniest of details, and bear witness to its wonder. The hollow spaces where once a diamond was remain hollow, like the black holes in the universe we still don't grasp, so they resemble the black hole that is the brilliant cut diamond in society.



3.22 b.

3.23.

Figure 3.23. *Universe*, carbon and diamond formation grown around CVD diamond seeds, oxidised silver, steel.

SOLVE ET COAGULA

Following the visit to the Bring Diamonds factory, the waste samples became sparring partners in a diffraction process (Barad, 2007) involving thinking and making. The technology used to create these lab-grown diamonds had a momentous impact on both thinking and making. Whilst the dingy location, and its unassuming equipment alongside a sales pitch for the unimpressive laboratory-grown diamonds that were being launched into the jewellery market could have distracted from the impressive technique and its possibilities, the samples were a tangible reminder and pull into a material discursive exploration of the phenomenon.

It is appropriate to here speak of diffraction, as documented by Barad (2007), as neither the subject nor objects documented above pre-existed, instead they had emerged through intra-actions. The only way to 'know' the technique was to study and interact with the samples, incorporating them into the practice, engaging in a differential becoming. As the waste samples were material realisations of the technique through which they had been created, differences and relationalities were untangled while thoughts and emotions entangled with them. The admiration for the technique and the pieces collected resolutely directed the making practice towards one of Critical Design once more.

Aligned with a diffraction methodology, a desire to make a difference in the world, underpinned the creation of objects that, aside from wanting to celebrate their importance and aesthetic qualities, also wanted to reposition these materials classed waste into pieces that would provide a critique on their context – ethics, ontology, epistemology. As a conceptual artist, the practice of urban mining, as applied here through the recovery of these waste samples from the Bring Diamonds factory, fostered a different kind of engagement with matter. No longer searching for materials to evoke an idea, these materials were brought into the artistic practice and engaged with through intra-actions. If one believes in the quintessence of materials, then this investigation aimed to be sensitive to the material's quintessence, which practically meant embarking on a respectful engagement, attending to details both in material and in evoked thinking.

[redacted]

3.24

[redacted]

3.25

[redacted]

3.26

[redacted]

3.27

Figure 3.24. Electroplated bond: the grain is bound to the part by an electroplated coating.

Figure 3.25. Vitrified bond: a ceramic bond, which is profiled on a machine.

Figure 3.26. Resin bond.

Figure 3.27. Sintered metal bond.

3.5. Materia Prima: Diamond Bling

Having moved on from initially producing gemstones (1922-1950), Effgen Lapport Schleiftechnik now fully focuses on the production of grinding tools by attaching or embedding small particles of crystal materials (grit) to base components through an electroplated bond (Figure 3.24), vitrified bond (Figure 3.25), resin bond (Figure 3.26) or metal bond (Figure 3.27).

For a large percentage of their processes, they use lab-grown crystal materials (including diamond). When shown around the facility, the room where the grit used for these tools was measured and stored was most interesting, as there was a large selection of containers stockpiled that were described as waste (Figure 3.28 on page 124). Taken off the shelf one by one, each plastic lid's removal opened up a colourful world of bling. Countless tiny shimmering pieces of crystal had been reclaimed from old tools and were stored in these containers organised by size and colour. The company offers the re-application of grit as a service, which enables its customers to send their old, electroplated tools back, instead of discarding them to purchase new ones. This is particularly valuable for customers in regard to large tools, since a large proportion of the cost of making these, often bespoke tools, lies in the production of a shape that holds the grit, which can be reused through this service. With electroplating being a reversible process, the now-flattened grit is removed from old tools and collected, before a new fresh layer of grit is applied. The reclaimed grit, precious by nature, but no longer useable in the context, as it would be too expensive to be reshaped, is stored.

Medidia is a company that specialises in diamond components used mainly for tools, such as diamond scalpels used in eye surgeries. The parent company in Switzerland grows diamonds using High Temperature High Pressure (HTHP) and Chemical Vapour Deposition (CVD) techniques. The two- or three-carat diamonds are then sent to Idar-Oberstein for cutting, lasering or processing. Tool components are often cut from manufactured plates ranging in size from 8 mm to 1 mm thickness. All diamonds grown in the lab will grow following the cubic lattice structure, which gives the material its hardness. CVD grown diamonds, as discussed above will, however, not appear the same as diamonds grown using the HTHP process – the latter will look much more like mined diamonds as the process will enable the diamond to grow in its octahedral shape. When sections are cut, this results in plates that are not rectangular.

3.28

3.29

Figure 3.28. Waste grit available at Effgen, Idar-Oberstein, Germany.

Figure 3.29. Ute Eitzenhöfer, Ohrschmuck, Diamant grit, wood, oxidised 925 silver. Photography by Michael Müller. Image used with kind permission of Ute Eitzenhöfer.

Figure 3.30. Waste material collected from Medidia, Idar-Oberstein, Germany.

Furthermore, due to inclusions, which can appear in diamonds grown with either of the techniques, there can be sections of the manufactured plates that are not useful to the company. This results in a range of diamond sections classed as 'unbrauchbar' (unusable) in the company (Figure 3.30 and Figure 3.40 on page 142).

After a discussion with both companies, involving Julia Wild from the University of Applied Sciences Trier/Idar-Oberstein, a workshop was devised for nine Bachelor Jewellery students at the university, during which the students could engage in an urban mining experience at Effgen Lapport Schleiftechnik and incorporate the waste materials discussed above into pieces of their work. The company offered its electroplating facilities and expertise for use, if participants wished to apply the grit to found objects or designed structures. This technique had previously been used by jewellers, such as Ute Eitzenhofer (Figure 3.29), yet had never had been used by anyone with these waste materials.

3.30

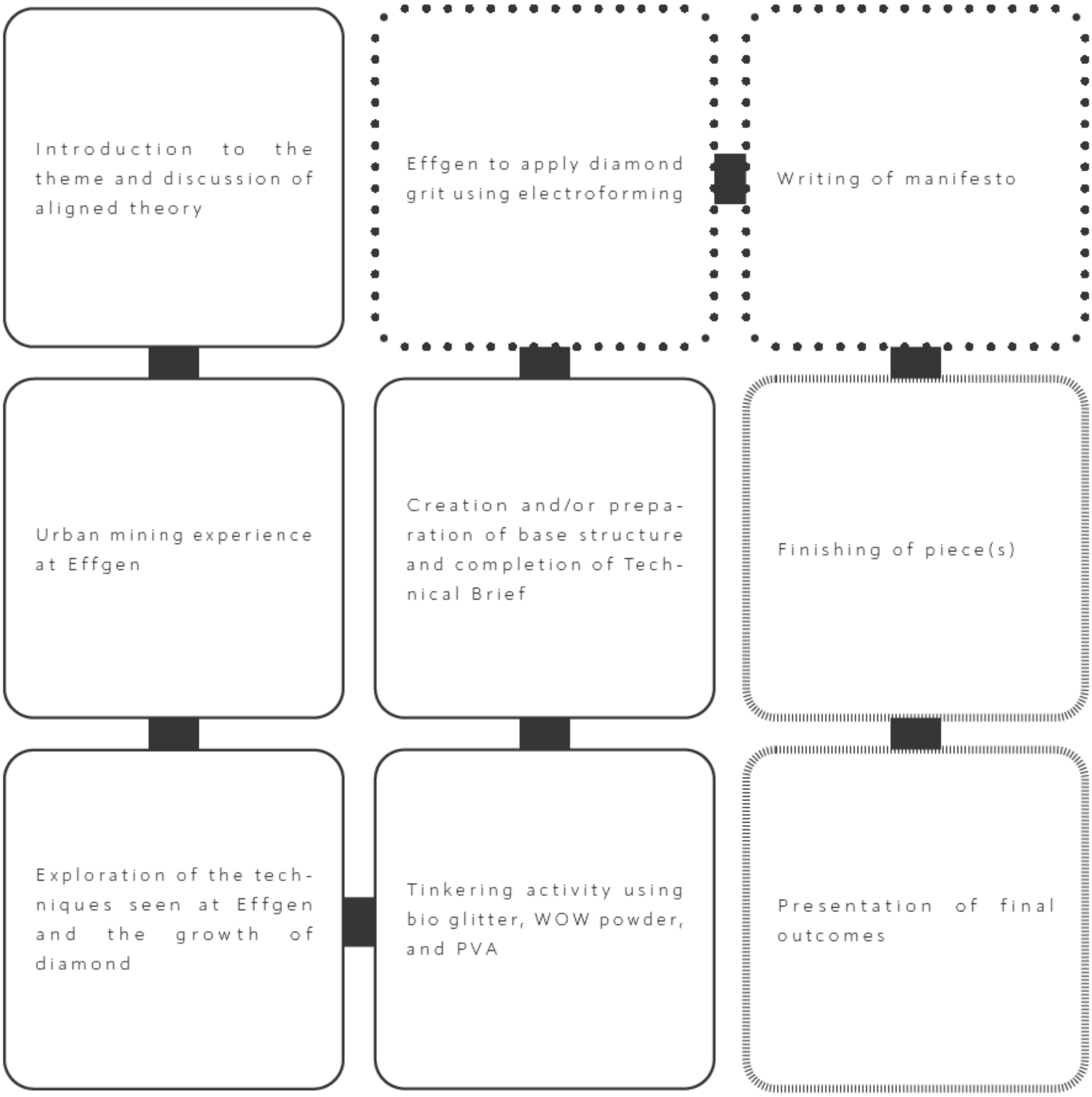


Table 3.1

Table 3.1. Vertical Bending Process overview of the activities planned for the 'Bling It' project. Activities listed in a solid line box were conducted in week 1. Activities listed in a dotted line box were conducted between week 1 and 2. Activities listed in a dashed line box were conducted in week 2 of the workshop.

TRANSMUTATION

"A workshop cannot be taken for granted or defined as a given format or medium, and therefore cannot guarantee any outcome. […] A workshop situation may produce disruptions and reciprocal challenging of assumptions ingrained in disciplinary habits of how we are practising. Specific moments of transformation are evoked by making things together, in the here and now."
(Groten, 2022, pp.154–155)

Following the identification of the Materia Prima in the companies, a workshop brief and scheme of work was created (Appendix 9) to engage the nine identified participants in the exploration of the topic. Whilst acknowledging that a workshop cannot guarantee outcomes, the following objectives for the workshop were identified as desirable for participants to achieve:

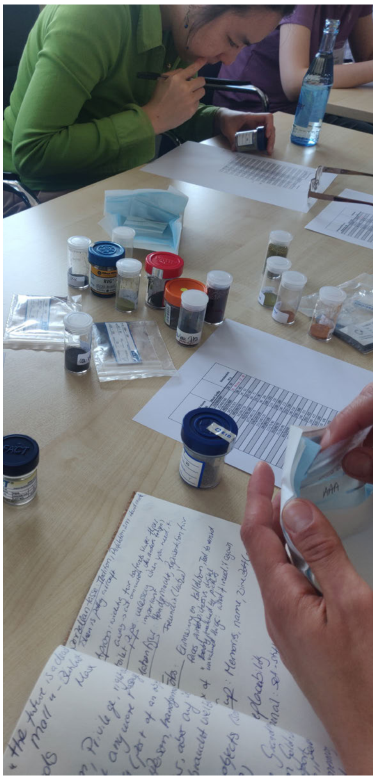
1. To introduce the concept of 'value', 'authenticity' and investigate our fascination with 'bling'.
2. To introduce an 'urban mining' practice.
3. To develop basic knowledge of man-made diamond production, use and application.
4. To consider sustainability in relation to the production of jewellery.
5. To develop skills in the writing of artist manifestos.
6. To develop skills in the communication and pitching of ideas to industry.

In order to attempt to achieve the listed objectives during the two one-week workshops the activities listed in Table 3.1 were scheduled:

SOLVE ET COAGULA

"In my agential realist account, matter is a dynamic expression/ articulation of the world in its intra-active becoming. All bodies, including but notlimited to human bodies, come to matter through the world's iterative intra-activity—its performativity. Boundaries, properties, and meanings are differentially enacted through the intra-activity of mattering. Differentiating is not about radical exteriority but rather agential separability. That is, differentiating is not about othering or separating but on the contrary about making connections and commitments."
(Barad, 2007, p.392)

On 12 June 2022, participants gathered for the first workshop week of the 'Bling it' project in a teaching room at the University of Applied Sciences Trier/Idar-Oberstein. The tone for the workshop was immediately set, as every participant described two objects they had brought with them, explaining which they considered the most valuable and the least valuable.



3.31

3.32

3.33

Figure 3.31. 'Bling It' workshop participants being introduced to the waste diamond grit by a company employee at Effgen, Idar-Oberstein, Germany.

Figure 3.32. 'Bling It' workshop participants searching a waste container for additional materials at Effgen, Idar-Oberstein, Germany.

Figure 3.33. Set-up of materials available for use by 'Bling It' workshop participants, at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Image used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein.

This introductory activity allowed all to catch a glimpse of the others' lives and consider the material world through the lens of our social constructions of value. Skating across spacetimematterings, students diffracted and collectively re-diffracted (Barad, 2014) the importance and discardable nature of these brought objects. As they were passed from one student to another, invisible threads were formulated between them, as connections were made between functions, sentiments, material-realities and emotions. The emerging collective of participants contemplated the power of objects and, through iterative intra-actions with these non-human objects, ethical relations were extended. Responsibility for the role that we play in the world's becoming was transformed into a consideration of response-ability, the ability to respond as part of the project.

Following an introduction to the overarching research and a discussion about some texts, the participants read in preparation for the session, to introduce some theoretical thinking around value, humanity's fascination with shiny and kitsch objects and the consideration of the small (such as dust). Then a visit to the Effgen Lapport Schleiftechnik factory was embarked on. Under the premise of urban mining, the participant collective was introduced to the Materia Prima. Supported by an employee, the grit was shared out in small containers to enable intra-action, and a discussion of the various techniques available to be used at the factory were clearly relayed. Immediate questions were answered around the feasibility of certain ideas for using the grit waste, and a message of support from the company's owner underpinned the value they saw in the project and its participants. As the employee gained insight into the curiosity of the visiting jewellery collective, a tour of the facilities was started. The main site of the Effgen Lapport Schleiftechnik company, located outside the city of Idar-Oberstein, in a neighbouring town called Herrstein, consists of a range of buildings, each of which centres on a certain production process. Whilst initially the project was focused on urban mining and incorporating the reclaimed diamond grit, as the group were shown around the numerous other facilities, and the company employee gained a greater understanding of the participants' interest in a broader range of waste materials available, more and more materials were mined.

"We gathered material and horded it like tiny dragons."
Workshop participant

Thanks to the intra-actions of the employee and participants with examples of waste in the company (Figure 3.31 and Figure 3.32), the concept of urban mining became clearer and the desire to enable the project's success grew stronger. As we walked around the company, no cupboard was left unopened, no binbag or waste collection overlooked and, bit by bit, the participants became urban miners and the experience an exemplar of urban mining. After several hours exploring the company's many facilities on the large grounds the collective left the site with a vast quantity of diverse materials (Figure 3.33).

3.34

Figure 3.34. Workshop participants working during the 'Bling It' workshop at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Images used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein

"Besides methods, techniques, tools, and protocols, workshops also bring about certain social dynamics that evolve from the particular composition of participants, as well as the context and conditions they find themselves in. Such 'moods' shift and slide and cause particular forms of production and knowledge to emerge, intervene or evaporate. Workshop participants and workshop hosts together shape and reshape the dynamic present."
(Groten, 2022, pp.151–152)

Following the urban mining experience, which exceeded expectations, the project was expanded in scope. An extra task was given to participants in order to take advantage of the opportunity to explore the methodological impact of working with a wider selection of waste materials. As a result, the participants were asked to both create a piece of jewellery using (at least one of) the waste materials mined 'sensitively' (Task 1), reflecting on the theme of value, as well as develop (at least one) piece of jewellery incorporating the diamond grit (Task 2), reflecting on the theme of Bling. Through tinkering (Cermak-Sassenrath and Møllenbach, 2014; Sundström and Höök, 2010; Brown and Sarkar, 2008; Buxton, 2007; Zimmerman, Forlizzi and Evenson, 2007), the participants were encouraged to explore the materials in a safe space, with room for failure, as the nature of these materials posed a range of challenges (both technical and aesthetical). A selection of materials that would support tinkering (such as a type of re-castable resin and bio-glitter as a substitute for the diamond grit) were provided. The participants embarked on a schedule of collective and independent intra-actions with materials and each other (Figure 1.8 on page 38, Figure 3.34). A range of discussions supported both aesthetical and technical progress. A final group presentation of the intermediate outcomes concluded a week of intense thinking through making.

Shortly following project week one, participants submitted found/created object(s)/material(s) to be coated with diamond grit by the company using their electroplating process, with the intention for them to be finished by project week two. For this purpose, a technical brief was created, to underpin communication between participants and the company's employees supporting the project (Appendix 9). As is common in industry/collaborative projects a setback – the unexpected absence of the member of staff looking after the project at Effgen – meant that only three participating students received one or more 'blinged' objects/materials back at the start of project week two. In response to this change in circumstances, participants were able to dedicate more time to the completion of Task 1, in addition to dedicating time to writing an artist manifesto – which was intended to give participants an opportunity to write down their thoughts in relation to the value of materials, the practice of urban mining and our overarching responsibility and response-ability in a wider context.

3.35 a.

3.35 b.

Figure 3.35. Group discussion of outcomes with participants of the 'Bling It' workshop at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Image used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein.

The project concluded with a collective presentation which involved both discussion and engagement with all the outcomes created as part of the project. Whilst many of the students had engaged with the themes of value (Task 1) and bling (Task 2) in a range of ways, it would not be feasible to include a discussion of all their outcomes in this thesis. A selection of images has, however, been included alongside the text to provide a rhythm of space-time disruptions (Figure 3.37 on page 136, Figure 3.38 on page 138 and Figure 3.39 on page 140). Similarly, the texts created as part of the manifesto activity, whilst influential to the interpretation of the students' work, and certainly in some sense underpinning the diffraction activity described later, have not been included in this thesis as they were deemed too personal and their detailed reproduction unnecessary to reiterate the conclusions that emerged through the workshop.

3.35 c.

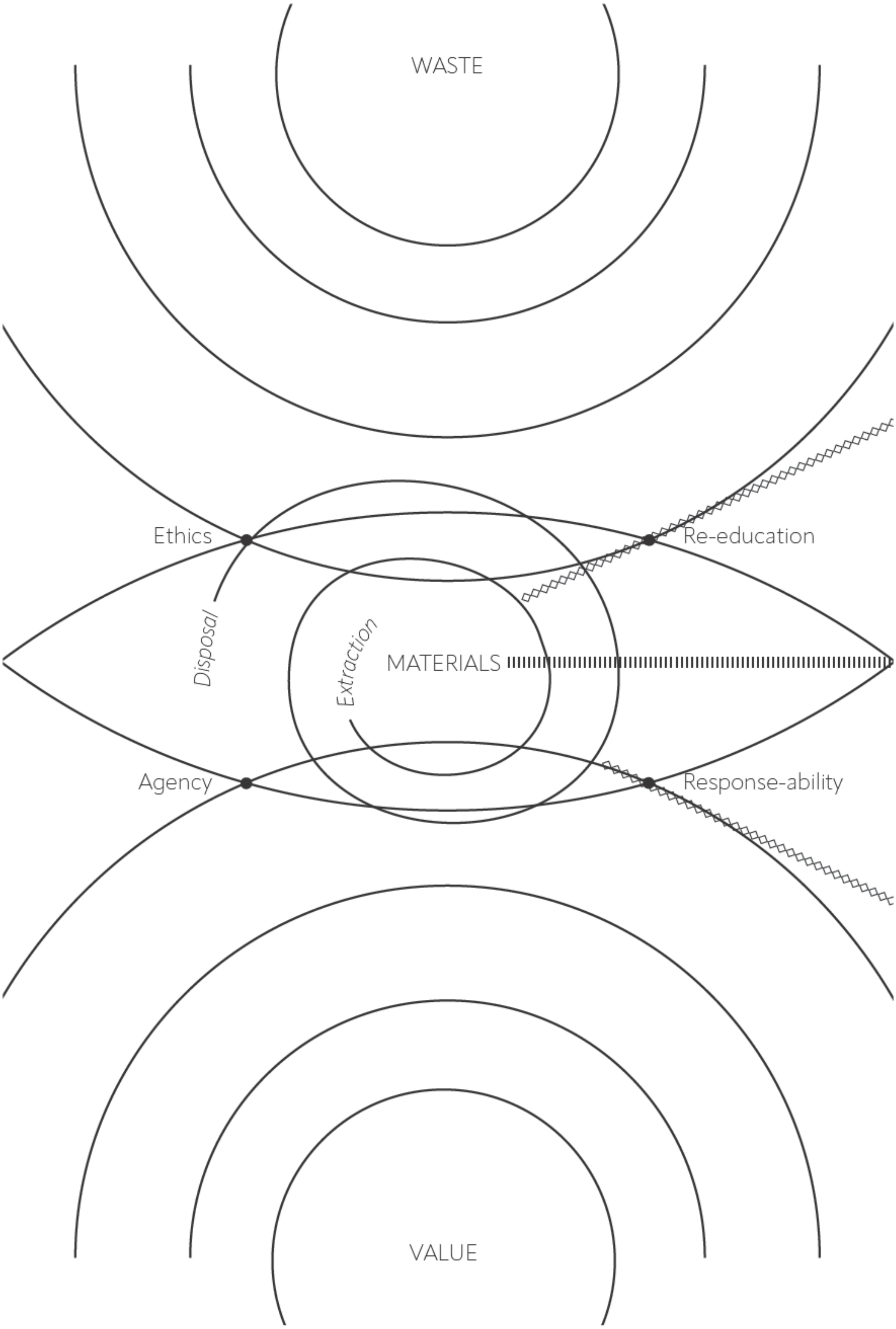
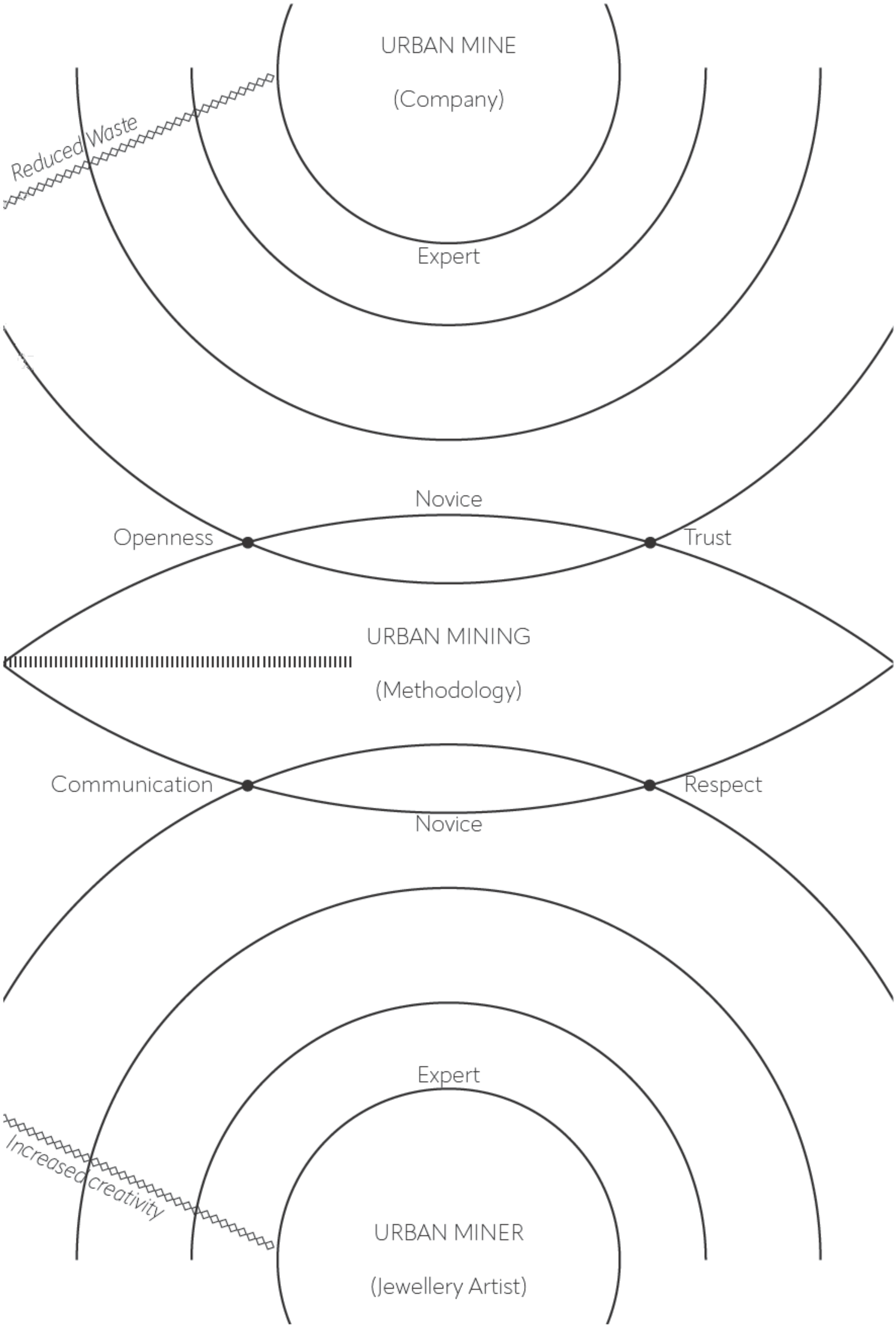


Figure 3.36. Diffraction map of urban mining.


URBAN MINE
(Company)
Reduced Waste
Expert
Novice
Openness
Trust
URBAN MINING
(Methodology)
Communication
Respect
Novice
Expert
Increased creativity
URBAN MINER
(Jewellery Artist)

3.37

Figure 3.37. Participant outcomes created during the 'Bling It' workshop at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Images used with kind permission of the University of Applied Sciences Trier/ Idar-Oberstein

3.6. Ouroboros

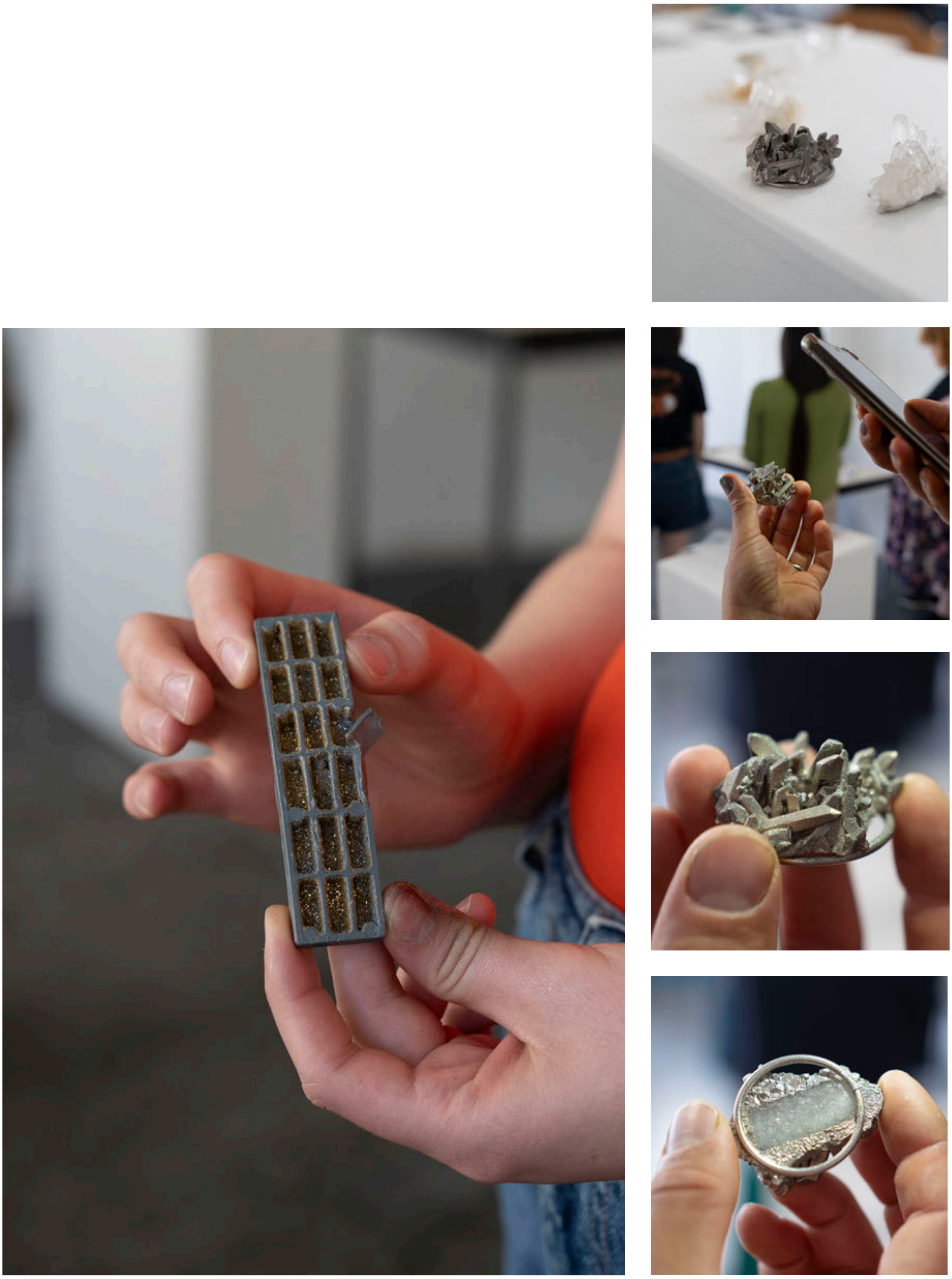
"Urban mining can help reduce waste and promote resource recycling, aligning with environmental sustainability principles. [...] These materials can be given new meaning, functions, and value. Additionally, projects like this offer opportunities to express our ideas and advocacy through artistic creativity. Urban mining projects can also promote community interaction and collaboration, enhancing social impact."
Workshop participant

Following the diffraction activity, in which participants examined their outcomes through a range of lenses, a set of synergies, tensions, commonalities and contradictions were established. These patterns of interference dynamically emerged through the intra-actions of the participants, the objects and the various ideas and perspectives being debated. Whilst this activity was conducted verbally, the diffraction pattern identified, amalgamating findings from both the urban mining experience at the Bring Diamonds factory and the collectives' experience at Effgen Lapport Schleiftechnik has been re-created in Figure 3.36 on page 134.

In the continuum of the urban mining methodology, three entities were intra-acting, in this case: the company (the urban mine), the jewellery artist (the urban miner) and the materials. Where their intra-actions were successful, they were engaging with the practice of urban mining, which required openness, communication, trust and respect – all of which need to develop and strengthen over time.

"I think trust is one of the main reasons why such a relationship can work. You have to show people that you respect their work and that you are interested in their work and that you are not interested in stealing any ideas or replacing them, in fact it is the opposite."
Workshop participant

"Clear communication helps all parties understand goals and vision, ensuring consistency and synergy."
Workshop participant



3.38

Figure 3.38. Participant outcomes created during the 'Bling It' workshop at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Images used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein

"[Urban mining partnerships require] respect and time."
Workshop participant

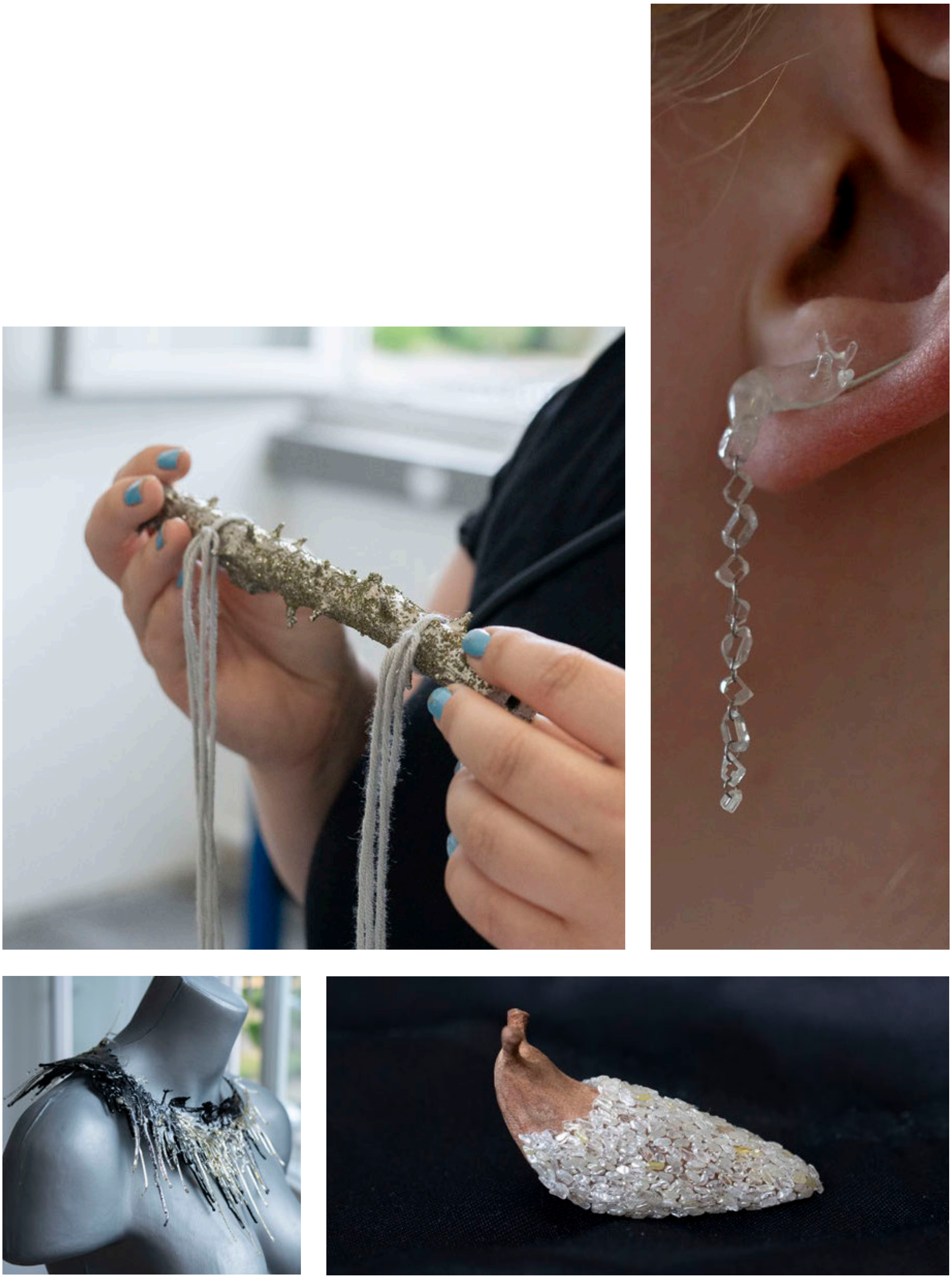
It was not until the company employee gained a greater understanding of what jewellery artists would find interesting in materials, and when the jewellery artists were able to share their approaches and practice, that opportunities for urban mining were identified. In each instance, expert jewellery artists had to appreciate that they were novices when it came to understanding the company materials and techniques, and vice versa for the employee at the company, who had little understanding of what an artist would find interesting in materials prior to the urban mining experience.

"It is also about showing them how you think and that they can also learn something from you and show them that it is beneficial for both parts of this partnership."
Workshop participant

"It was very interesting to see their production work and how they handle their materials. The way they treat their materials is so different because they have them on a larger scale and for us they are so precious because we only have them on a small scale, also they see them as a technical working material and for me the look is more important."
Workshop participant

At the centre of this methodology of course lay the Materia Prima – in this case materials that would be valuable to jewellery artists yet had lost their value to the company (classing them as waste). No material had not just appeared in the company, it was all part of its own story, from its formation somewhere on or in the planet (an often invisible path to us humans, far exceeding our lifetime), to its extraction, after which it could cycle through the social constructs of value and waste, until being disposed of (after which another invisible path is begun). The continuum from waste – value is, however, a challenging one from a societal angle, where agency and ethics are not considered sufficiently. This is something all parties should engage with if the practice of urban mining were to be expanded. Through the process of urban mining there was, however, an immediate re-education cycle – as waste was suddenly seen as value – which provided all with an ability to respond to the current context where too often waste is discarded, and values not sufficiently explored.

"This project was an overall emphasis on the saying "one man's trash is another man's treasure", which can go both ways. Also, an artist can have things or material they cannot or do not wish to work with, so instead of throwing it away immediately it can pay off to first offer it to others which is more sustainable and additionally can help create or keep positive relationships to other artists and people."
Workshop participant



3.39

Figure 3.39. Participant outcomes created during the 'Bling It' workshop at the University of Applied Sciences Trier/Idar-Oberstein, Idar-Oberstein, Germany. Photography by Gina Müller. Images used with kind permission of the University of Applied Sciences Trier/Idar-Oberstein

"The workshop showed that the mind of an artist doesn't see waste, because it always can be something else. For people in the technical industry for example it's hard to see. An object doesn't fulfil its purpose it's not worth anything anymore. It was interesting to see how the companies revalued their waste and tried to find new purpose and beauty in trash after they saw the excitement of group of students emptying their rubbish cans."
Workshop participant

Using materials that are cycling along this continuum can be an interesting narrative for artists explore. An example can be found in the jewellery field, where Otto Kunzli re-used wedding rings from a divorced couple in a necklace. The necklace gained its narrative from the material and created an object that is spiralling through the value – waste continuum.

"I believe it is important to have an open mind towards new materials and possibilities, but also not go into it with very specific expectations."
Workshop participant

"You have to adapt your way of working and thinking to the materials. [...] You must accept failures and rethink your ideas and be open to change. You have to learn how each new material behaves, which is a lot of experimenting and time consuming."
Workshop participant

The shift in working for both company and artist was evident. The latter, now responding to material, rather than sourcing materials to create work, resulted in an increased opportunity for creativity, as materials encountered became conduits for new ideas and work. This, however, also provided a challenge to the jewellery artists who, due to their lack of knowledge of the materials, had to, in some instances, resort to problem solving when applying them.

"You never know what you actually get. You have to accommodate the materials and find new solutions. It's quite impossible to work the idea out first and then search for the material. With urban mined materials and the approach we took in the workshop there was no other option than to get inspired by the material to get into the working flow."
Workshop participant

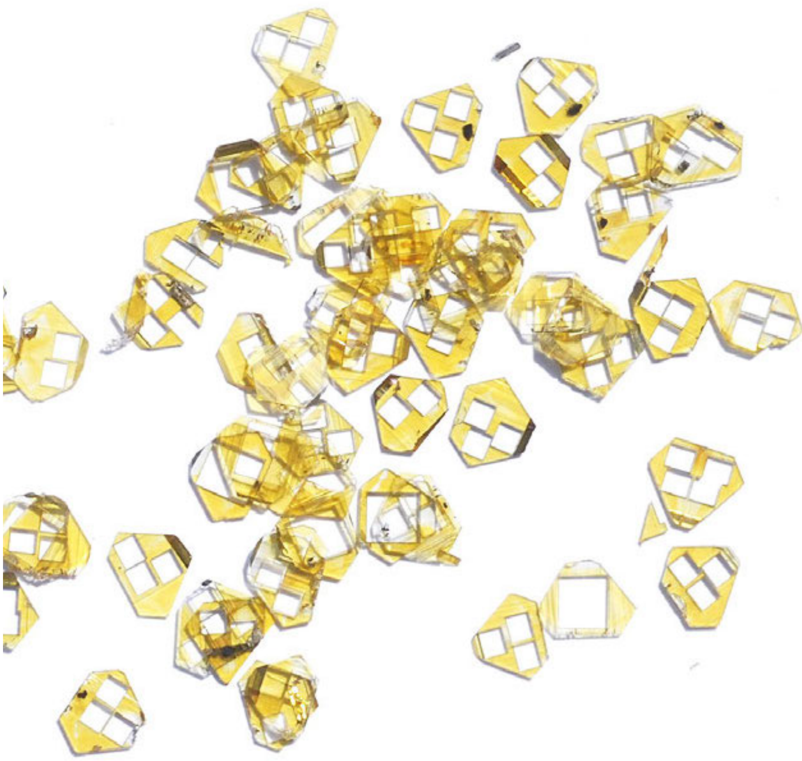
"On the one hand, all the challenges of the urban mined material can be difficult, but on the other hand, they can take you a lot further in your artistic work. For me personally, the new forms and material surfaces were very interesting and inspiring. [...] For me, they were the starting point for more artwork."
Workshop participant

It is important to understand and appreciate the agency of materials produced for industrial purposes, something a novice would need to dedicate time to. As the intra-action continues, an exchange of knowledge can push the novice along the expert continuum, which is expected to benefit both parties.

"Providing technical support and training would also be beneficial, helping participants learn how to effectively use and process urban mined materials."
Workshop participant

As these materials move along the waste – value continuum, their changed appreciation is hopefully a powerful signifier of the fickle nature of the continuum and the need for our societal relationship with materials to be questioned and challenged.

"The project made me rethink the value of materials and our relationship with them, emphasizing resource recycling and sustainability."
Workshop participant



3.40

Figure 3.40. CVD diamond offcuts donated to the 'Bling It' project by Medidia.

3.7. Macrocosm

This Case Study, whilst expanded on in the workshop with nine participants in Germany to include other materials, mainly revolved around the use of waste diamond materials to create jewellery pieces. Diamonds, interesting for their societal status and assigned value, are useful for a range of manufacturing companies, who use this hardest material on the planet to produce a variety of tools serving a range of sectors, including the automotive and medical industries. In these contexts any material that does not, or no longer, meets the quality standards is classed as waste. This waste offers a unique opportunity for urban mining. Where diamonds are grown in the lab to be faceted and incorporated into jewellery, here too interesting waste materials can be mined, which might be an additional venture for suppliers claiming to produce sustainable materials that aligns with their sustainability drive. However, with many diamonds already in circulation, it is questionable why the growth of more diamonds to imitate those already mined is a necessity. Urban mining diamonds from both the tooling industry and, for example, old jewellery pieces would provide a significantly more sustainable alternative. Whilst urban mining as a methodology is not new, and arguably has been practiced with precious materials (particularly in gold recycling) for many years, its application to crystal materials is still limited, yet could provide both sustainability and creativity benefits. As a Neo-alchemist, engagement with, in particular these crystal materials, in the context of the research felt like a response-ability to the global context which requires all of us to take responsibility.

4.1

Figure 4.1. *Neo-gemstone*, composite stone (BRG + Garnet). Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

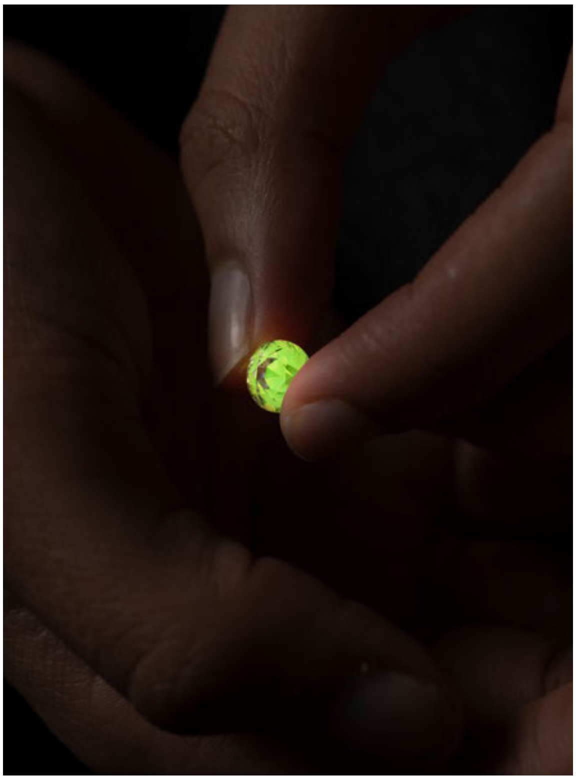
Chapter 4. Case Study 2: Developing Neo-gemstones in Collaboration with Crystal Growth Experts

4.1. Introduction

"The actor of this process is not a subject distinct from phenomenal reality, outside it, nor any transcendent point of view; It is a portion of that reality itself. Selection has taught it to make use of useful correlations: meaningful information. Our discourse on reality is itself part of that reality. Relations make up our 'I', as our society, our cultural, spiritual and political life. It is for this reason, I think, that everything we have been able to accomplish over the centuries has been achieved in a network of exchanges, collaborating. This is why the politics of collaboration is so much more sensible and effective than the politics of competition."
(Rovelli, 2022, p.166)

Chapter 4 documents two collaborations with crystal growers, one from industry (BREVALOR – Switzerland) and the other with an academic crystal growth department based in Bristol University. The overarching case study was set up to explore whether the collaboration between art/design (jewellery) and science (crystal growth) practitioners could result in innovative man-made crystal materials that would be interesting for the production of jewellery. In collaboration with BREVALOR, BRG and BRB crystals (both phosphorescent gemstone materials previously not used in jewellery) were grown and manufactured for their application in jewellery. Dr Hall, Dr Potticary and PhD candidate Michaela Whitehurst set out to test novel formulations of aluminium oxide in combination with various dopants, using a low temperature crystal growth method in order to map and identify new colours. In this chapter the collaborations, outcomes and diffraction of achievements and ongoing work are documented. The focus of this chapter and the underpinning case study is to re-consider the opportunities and challenges such art-science collaborations (jewellery and crystal growth) pose and how they could result in innovative outcomes.

4.2



4.3

Figure 4.2. Faceted composite stone (YAG + BRB + YAG) phosphorescing after excitement with UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.3. Faceted doublet (YAG + BRG) phosphorescing after excitement with UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

4.2. Case Study Design

Following on from the first case study, where interesting existing crystal materials were located in relevant contexts (i.e. companies working with crystal materials) for investigation and incorporation, the second case study aimed to expand the search for the innovative potential possible by collaborating with those who have expert knowledge of, and expertise with, crystal growth. For the second case study, a selection of crystal growth experts were contacted to explore the possibility of setting up a collaborative project. Crystal growth experts are generally located in either academic or industrial contexts, and both areas were considered interesting to engage with, as there may be differences in approach and possible outcomes in each.

Once a suitable collaborative partner was identified, and a collaboration agreed, a range of data was collected to triangulate conclusions in relation to the analysis of the innovative potential of outcomes. The data supplementing the physical outcomes, documentary photographs and diffractions listed below included email records, meeting agendas and minutes, sketches, models, proposal documents, textual records, formulas and lab notes.

Each collaboration (industrial and academic) is described below, documenting its incorporation, development and most notable activities and outcomes. Following the prescribed format underpinning good case study research documented by Gilham (2000), care is given to documenting the activities, how the case study remained aligned with the aim of the research, and how it influenced the research questions in response.

Finally, an intermediate evaluation of the collaborations in relation to the macrocosm is provided, to serve the theorising section as part of the case study. This evaluation is considered intermediate, as both collaborations remain ongoing, and the impact of the work started is expected to exceed beyond the PhD project.

4.4

Figure 4.4. D. Rytz illuminating BRG boule, explaining the internal structure by using a model.

4.3. Microcosm: Industrial Crystal Growth Collaboration

At the end of July 2020, less than a year into the PhD journey, contact was made with a company visited in 2016 that initially sparked the interest in the subject of crystal growth. Electro-Optics Technology GmbH (a subsidiary of Coherent Corporation since April 2021) has been conducting research and development in the field of technical crystals and laser components since 1990, specialising in the production and growth of technical crystals as well as the processing of technical crystals and all related activities (Northdata, n.d.). The company, which had previously been accommodating to a visit by jewellery students in 2016 as part of an Erasmus+ project bringing together three European institutions (British Academy of Jewellery, 2017), was additionally judged as of great interest to the project due to its location in the city of Idar-Oberstein in Germany which, for the reasons discussed above, has been, and remains, a significant location for gemstone trading in Europe.

The company's research and development manager, Daniel Rytz, a physicist and crystal grower active in the fields of crystals for optical, piezoelectric and other applications since 1977, responded positively to a request to discuss a collaboration proposal. What followed is an ongoing collaboration with Rytz (Figure 4.4), who participated in meetings, both in person and virtually over 60 times (Appendix 8) over the course of the PhD project. As an experienced scientific PhD supervisor, he supported the research by providing crystal material for experimentation (for the production of artefacts) and crystal growth lessons (enabling the acquiring of facts), mentoring meetings and providing crystal technology-related input for press releases and presentations.

Even though the original collaboration request had been directed to Electro-Optics Technology GmbH, Rytz, who in 2012, together with his partner Corinne Siegrist had founded BREVALOR to develop crystals with novel properties for ornamental applications in watch making and jewellery, felt the work he was conducting for BREVALOR aligned more closely with the ambitions of the PhD. Following an initial online meeting, in which Rytz explained the company's approach to the materials he had been developing, a range of design ideas were shared, and an agreement was made to attempt to investigate the materials created by BREVALOR for incorporation into jewellery.

4.5

4.6

4.7

Crystal	Specific Gravity	Hardness	Refractive Index	Lustre	Colour
Diamond (Carbon)	3.4-3.5	10	2.42	Adamantine	All colours
Sapphire (Aluminium Oxide)	4-4.1	9	1.76-1.77	Adamantine to vitreous	Most colours
BRG/BRB (Aluminates)	2.9-3.6	6.5-7.5	1.72-1.94	Vitreous to subadamantine	Yellow-green and blue
Garnet (Silicates, Aluminates)	3.1-6.5	6.5-8	1.72-1.94	Vitreous to subadamantine	Most colours
Quartz (Silicon Dioxide)	2.65	7	1.54-1.55	Vitreous	All colours

Table 4.1

Figure 4.5. BRG (Eu^{2}+,Dy^{3}+:$SrAl_2O_4$) boule. Height = 50 mm. Left, without excitation in natural light. Four boules on the right document the light emission continuously decreasing from excitation to ten hours later. Photography by D. Rytz. Image used with kind permission of D. Rytz.

Figure 4.6. Decay of intensity of phosphorescent light with time for BRB (Eu^{2}+,Nd^{3}+:$CaAl_2O_4$) and BRG (Eu^{2}+,Dy^{3}+:$SrAl_2O_4$) crystals. For such measurements, the samples are excited by a UV source emitted at 365 nm for 5 minutes. The emitted intensity is recorded over time, with a start initiated 20 seconds after stopping the excitation. The data was recorded and analysed by V. Castaing (Castaing, 2019).

Figure 4.7. BRB (Eu^{2}+,Dy^{3}+:$SrAl_2O_4$) boule, light emission following excitation with UV source. Photography by D. Rytz. Image used with kind permission of D. Rytz.

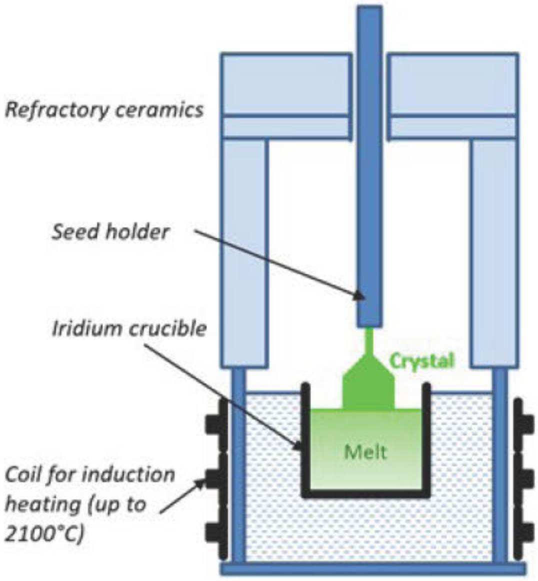
Table 4.1. Comparison of gemstone properties and BRG/BRB.

In 2013, BREVALOR produced a new type of strontium aluminate in the form of transparent crystals with similar luminescence effects as that known from pigments but with additional striking features. Such crystals and several new compositions emitting persistent luminescence light with various colours have properties very close to classical gemstones: their hardness allows them to be shaped and faceted, and their physical properties give them the optical appearance of gems. Following exposure to a few minutes' illumination by sunlight, unlike traditional gemstone materials, their entire volume emits light for many hours (Figure 4.5 and Figure 4.7).

Long-lasting (or persistent) luminescence, sometimes also called phosphorescence, is a natural phenomenon known as far back as ancient Chinese or Japanese inks used in paintings that remained visible at night (Xu and Tanabe, 2019). Minerals with persistent luminescence were first observed by the shoemaker and alchemist V. Cascariolo from Bologna in 1603 after transforming the mineral barium sulphate into barium sulphide (Lastusaari et al., 2012). In 1866, the French chemist T. Sidot (1866, cited by Xu and Tanabe, 2019) synthesised zinc sulphide containing cobalt. Sulphides were the dominant persistent luminescence materials until 1993, when specific modifications of strontium aluminate were discovered in Japan and implemented in pigments with very intense and long-lasting luminescence effects leading to the emission of green-yellow light. Phosphorescent materials we encounter in daily life are usually based on pigments embedded in plastics, lacquers, paints or other support materials. The phosphorescence occurs at the surface of these non-transparent substances. With single crystals, new design effects based on three-dimensional transparent volumes can be used. This paves the way to introducing a new functionality in gemstones and gem-like ornamental objects, by enabling the use of an internal light source that needs only a brief activation by daylight. After activation, the energy absorbed will lift the atoms of the material into an excited and unstable state (Gundermann, 2023). In an attempt to return to an unexcited state, the material undergoes a transition and will re-emit light for a period of time. This period of time, also referred to as the luminescence efficiency, depends on the degree of transformation of excitation energy into light (Gundermann, 2023), which can be adjusted by fabrication parameters, something the crystal grower continues to perfect. Visibility in the dark can currently last for 24 hours or more, with an intensity that decreases over time (Figure 4.6).

The blue glowing effects of BRB (Figure 4.2 on page 146) and green glowing effects of BRG (Figure 4.3 on page 146) are due to the Eu^2+ ions introduced into the crystal matrix and to so-called traps related to Dy^3+ and Nd^3+, which allow them to store the light for a period of time. The exact nature of the traps is still the subject of ongoing investigations and optimisation efforts. Further technical details of these materials is covered in a number of scientific publications co-authored by Rytz, including the paper ***Persistent luminescence in strontium aluminate: a roadmap to a brighter future*** by Van der Heggen et al. (2022) and ***Highly Transparent Ce^3+,Cr^3+ Co-doped GYAGG Single Crystals with Enhanced Persistent Luminescence*** by Delgado et al. (2023).

Even though the detailed compositions of the crystals are in ongoing development, the resulting boules (Figure 4.5 and Figure 4.7) and crystals are already suitable for cutting, faceting and polishing, and their overall properties (Table 4.1) are in alignment with most common gemstone materials.



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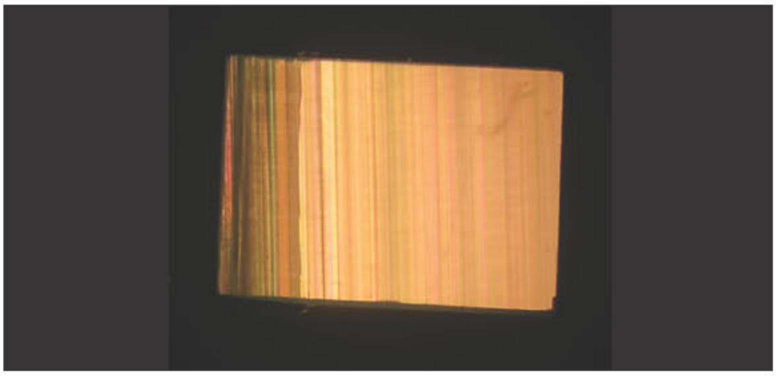


4.9

4.10

Figure 4.8. Czochralski Puller, D. Rytz. Image used with kind permission of D. Rytz.

Figure 4.9. Polished BRG Type 1 sample (8 x 5 x thickness = 0.5 mm) with characteristic lamellar structure. Photography by D. Rytz. Image used with kind permission of D. Rytz.

Figure 4.10. BRG Type 2 crystal, diameter 40 mm, total length (from seed to tip) 117 mm. The crack-free cylinder is 45 mm long. Photography by D. Rytz. Image used with kind permission of D. Rytz.

Using the most important method of crystal growth today, mainly due to its large-scale application to the growth of the semiconductor crystal silicon, the crystals are pulled from a melt contained in a crucible, a method also referred to as the Czochralski technique (Scheel, 2003). BREVALOR uses various Czochralski pullers (Figure 4.8): a typical machine has a height of 3.20 m and a footprint of 12 m^2. When this technique is used for oxide crystals it involves induction heating with Iridium crucibles, which allows growth temperatures of up to 2100°C, with an adequately controlled atmosphere. The growth process is controlled by a balance recording the weight of the growing crystal. Carefully monitoring the weight and comparing it with the targeted value allows crystal growers to control the shape of the crystal, resulting in boules of 20 – 50 mm in diameter grown in approximately 20 days (Figure 4.10).

Since 2013 BREVALOR has grown approximately 25 BRG and BRB boules, each time adjusting the composition of the chemicals and/or adjusting the growth cycle and routine, in order to perfect the crystal growth. As shown in Figure 4.9 BRG crystals show characteristic lamellar structures, inducing light scattering and making parts of the resulting boules cloudy. Lamellas can be viewed as playing a favourable role as outcouplers of the light generated by phosphorescence in polished samples. They are the subject of several studies aimed at understanding and controlling the appearance of lamellar structures in crystals with different thicknesses and orientations. Lamellas appear when the as-grown (near 1900°C) crystal is cooled down to room temperature. They are typical for crystals growing with a hexagonal symmetry and undergoing a phase transition at approximately 665°C to a monoclinic structure. The lamellas are the result of twinning induced by the transition. The first pieces using BRG Type 1 (an earlier iteration of the formula) displayed these lamellae in some areas, which had no impact on cutting, but influenced the physical appearance of the produced samples.

The development of a novel type of crystal takes on average about 20 years from the discovery of the material to its use in small series of commercially available products. Eleven years since the first growth of BRG Type 1 and BRB, the present thesis presents simultaneously a conceptual analysis of the potential of this gemstone-like material emitting light without an external energy source and a prototyping step, demonstrating real-world effects in the first gemstones manufactured with the material. Moreover, in parallel to the work described in the thesis and influenced by this work, BREVALOR has developed several additional phosphorescent single crystals emitting at other wavelengths (such as lighter blue and red), phosphorescent crystals with increased hardness (Ce^3+ doped garnets derived from $Y_3Al_5O_{12}$, labelled BRG type 2).

BRG & BRB Gemstones	
Materia Prima - Applied (using the material in its original form)	Applied - Transmutation (material combinations to maximise impact)
(1) Enabling use with other gemstones	
→ Lapis Solaris	Doublet/triplet ←
(2) Experimenting with effects	
→ Pooling light	Reflecting light ←
(3) Artefact creation	
→ Octagon	Cameo ←

Table 4.2

Table 4.2. Taxonomy of the artefacts created with Materia Prima and Transmutation of BRG and BRB.

SOLVE ET COAGULA

Whilst the start of the research did not immediately provide clarity of direction in the usage of the BRG/BRB Materia Prima, two pathways of investigation did appear in applying the materials in a jewellery context (Table 4.2). In light of the cost and complexity associated with producing large crystals, particularly at the start of the collaboration, a second strand of work in addition to applying the Materia Prima, revolved around a further transmutation of the material in combining it (either through crystal bonding or gluing), with other lab-grown or relevant materials. These two pathways of investigation enabled an extensive array of possibilities in relation to each of the areas of investigation conducted. The underlying question, 'When does the material display the quintessence of a gemstone, moving beyond that which can be achieved with pigments and resin?' was a constant undercurrent in the process of making which, despite being portrayed here with clarity and logic, was a cyclical process of trial and error, in which the dissolution and solidification of the concept and quintessence of a gemstone was continuously lost and found. The listed selections are those that came the closest to capturing the intended outcome.

Having never been applied to the production of jewellery before, the first area of investigation, in response to Rytz's input, revolved around an initial investigation of the material's role and identity as a gemstone. The question 'How can this material be shaped so it can be incorporated into a broad variety of jewellery pieces?' was first to be asked and answered. Whilst a torus-shaped cut (*Lapis Solaris*) was developed to enable the material to be incorporated underneath traditional brilliant cut stones, an investigation was also conducted to explore the ideal dimensions and composition of a doublet (BRG) and triplet (BRB), so that an effective faceted glow in the dark stone could be incorporated into designs too.

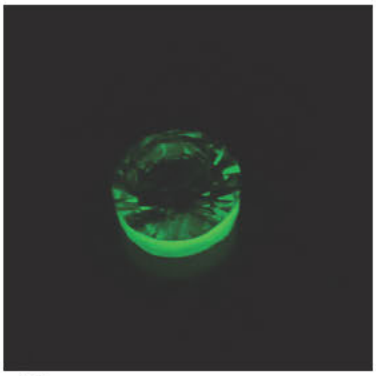
Following hands-on experimentation with the material, and an alertness to light effects that can be observed in a daily context that could be applied to the material, the next area of investigation aimed to push the envelope by identifying an effect of the material and using it as the main feature of the outcome. This resulted in a stone that was not faceted as a brilliant cut, but instead engraved, allowing the *pooling of light* on engraved edges to feature the lines of the traditional cut.

As a further transmutation of the effect of light, a stone was also cut with a single column of phosphorescent material in the centre which, through the cut of the stone, resulted in the *reflecting of light* around the stone, maximising the impact of the light in the dark.

Whilst these first two areas of investigation were intended to inspire commercial interest in the material, a further investigation into the material for artefact creation was undertaken. Here the unique ability of the material to light up its surroundings was utilised in constructing the design, extending the emission of light to the sculpting of light (*Octagon*).

As a further transformation the material's ability to enable light to travel through other materials was exploited in an artefact that consisted of a heightmap of a traditional brilliant cut in a translucent material. Where the material was thicker less light was transmitted, and where the material was thinner more light was transmitted, resulting in an optical illusion of the patterns formed by a traditional brilliant cut (*Cameo*).


4.11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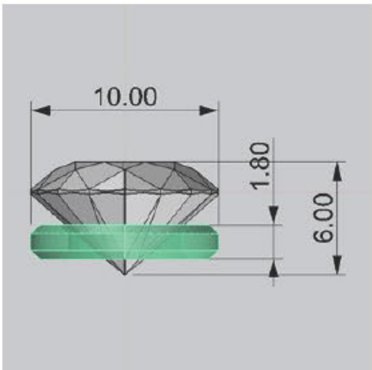
4.13


4.14



4.15


4.16

Figure 4.11. Blue and green glow in the dark powder, used for model making.

Figure 4.12. First model produced with glow in the dark powder and re-castable resin.

Figure 4.13. Brass cast of 3D printed wax model.

Figure 4.14. 3D printed model with adapted setting to accommodate the torus shaped test model and a brilliant cut stone.

Figure 4.15. Rhino model of BRG stone with the ideal dimensions.

Figure 4.16. *Lapis Solaris Ring*, BRG Type 1, CZ, brass. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.17. Adapted faceting tools to enable faceting edges of pre-cored BRG material.

Lapis Solaris

Following the first meeting with Rytz, where an explanation was provided of the BRG and BRB materials in development, an ideation phase followed. Since the materials had not yet arrived, and were expected to be limited in quantity due to the size and cost of the boules available, at first, tests with re-castable resin and glow in the dark pigment (Figure 4.11) were conducted. This makeshift material enabled tinkering and provided freedom of experimentation. Furthermore, as training in faceting had only just started, the casting of shapes (Figure 4.12 and Figure 4.14), as well as the softness of the material to carve using non-gemstone working tools, enabled fast diffraction cycles of experimentation and thinking. With incorporating the material into the existing jewellery gemstone material pallet, the first idea that progressed for prototyping was the creation of a BRG torus-shaped stone, which could be positioned underneath any round faceted gemstone of similar width and would illuminate this gemstone from below (Figure 4.12). To test sizes, in order to achieve optimal reflection of the light in a hovering stone, a range of models were created using an Anycubic 3D printer, which were consequently used to create a silicon mould for casting the makeshift glow in the dark resin material. Following prototype iterations, the ideal size was established (Figure 4.15) which, as a model, could be scaled up and down to be used in combination with other sizes of brilliant cut stones. Once the ideal sizes were determined, a prototype was created in the material, which was supplied by BREVALOR in the form of a pre-cored slightly oversized disc (Figure 4.17). A bespoke tool (Figure 4.17) eenabled faceting of the outside edges. Applying faceting to the inside edge and subsequent polishing were completed at the University of Applied Sciences Trier/Idar-Oberstein using a traditional spindle. The 10 mm BRG torus was then set in a bespoke mount (Figure 4.15), which had provisions for setting it directly below a 10 mm brilliant cut CZ. The resulting piece (Figure 4.16 and Figure 4.18 on page 158) serves as proof of concept.

4.17

4.18

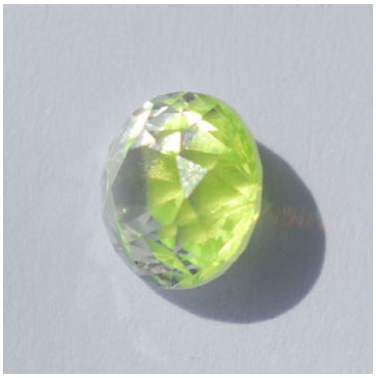
Figure 4.18. *Lapis Solaris Ring*, BRG Type 1, CZ, brass. *Pooling Light Earring*, BRG Type 2, silver. Photograph taken after excitement with UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.19. BRG faceted stone phosphorescent after excitement with UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

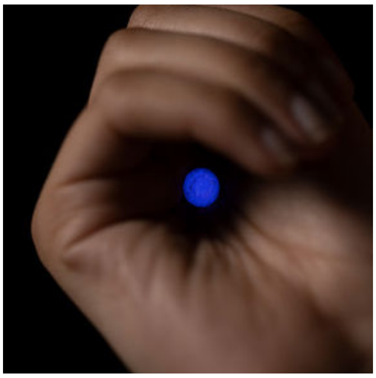
4.19

4.20

4.21 a.



4.21 b.



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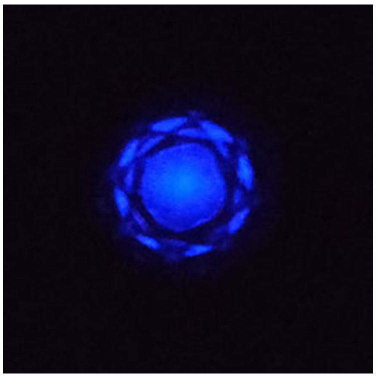
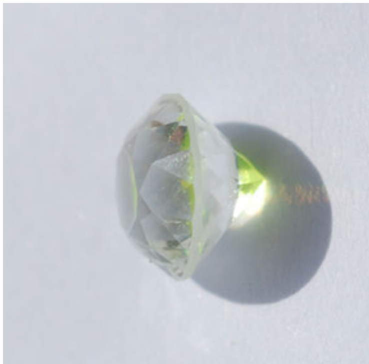


4.23

4.21 c.

4.24 a.

4.25 a.



4.21 d.

4.24 b.

4.25 b.

4.21 e.

Figure 4.20. BRG Type 1 doublet, excited by UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.21. Various views of BRG Type 2 doublet in natural light. Doublet diameter = 8.3 mm. Top section of doublet (YAG) = 4.5 mm bottom section (BRG Type 1) = 2 mm.

Figure 4.22. BRB triplet, excited by UV light source. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.23. BRB doublet excited by UV light source. Doublet diameter = 8.3 mm. Top section (YAG) = 3.5 mm bottom section (BRB) = 3 mm.

Figure 4.24. Top and side view of BRB triplet in natural light, excited by sunlight. Triplet diameter = 8.5mm. Top section (YAG) = 5.5 mm, middle section (BRB) = 1.5 mm and bottom section (YAG) = 1 mm.

Figure 4.25. Top and side view of BRB triplet, excited by sunlight.

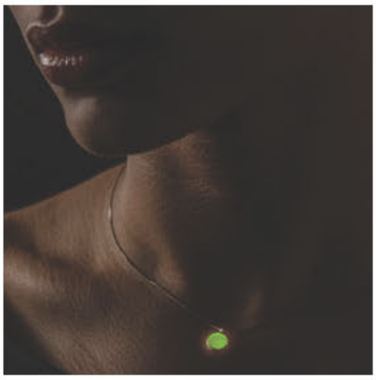
Doublets and triplets

Having established that interesting effects could be achieved when the BRG material was reflected in a translucent faceted gemstone, the next logical step appeared to be the creation of a doublet stone. This would once more provide opportunities for the material to be incorporated into a component that would enable jewellery designers using gemstones to incorporate the material in their designs. Quick tests of this concept were executed by cutting the culet of an existing brilliant cut CZ stone larger and gluing a small section of BRG (Figure 4.20 and Figure 4.19 on page 158) and BRB (Figure 4.23) at the bottom. The bottom half of the stone was then re-faceted.

Depending on the size of the BRB/BRG segment, various visual effects were achieved. In order to achieve optimal colour and light distribution in the stone, the measurements of Figure 4.21 are recommended to be applied. This composition was also recreated in a final stone, for which the CZ material was replaced with YAG (a material closely related to BRG/BRB). It is, however, at the discretion of a stone-cutter, commissioning artists, what would be preferred, as smaller segments result in a less dominant colouring of the stone in daylight and a lesser glow in the dark effect in the absence of light, whereas a larger segment will have a greater effect on colour, being distributed in zones in the stone.

For later tests the process of gluing was replaced with bonding, which enables materials with a similar lattice structure (BRG/BRB and YAG for example) to be connected in a crystal growth environment. Bonding results in a material that, albeit formed of multiple parts, can no longer can be considered as such. A bonded material is monolithic (in the sense that it can no longer be separated by delamination) and will therefore facet as such. Whereas glued materials remain fragile at the glued intersection and this area during faceting can result in a very small indent (glue is softer than the materials it is gluing), no such issues are experienced with a bonded material. The concept of phosphorescent composite gemstones was developed by Rytz in a document of 2018 and filed as a patent application in parallel to the fabrication of the prototypes made for the present thesis. Technical details about the so-called diffusion bonding process that is known for standard laser crystals can be found in the patent US 5'441'803 granted to the company ONYX Optics in 1995. What is unique in the composites described here is the fact that the high temperatures needed for bonding can be made compatible with the physical reasons for the occurrence of phosphorescence in the composite.

Investigations into doublets also sparked an interest in the effects and possibilities of creating triplets. Whilst the visual appearance of the BRG Type 2 doublet was desirable, from a side angle the difference in materials was still noticeable. Whilst this can be considered a feature to appreciate, in the gemstone field the homogeneousness of stones is usually a desirable property. For this reason, two versions of a triplet were also executed with the BRB material (Figure 4.22, Figure 4.24 and Figure 4.25). As expected, both displayed a greater homogeneity than the doublets. While further tests will be required to establish the ideal size of the various components, the start of this work indicates that this too is a viable option.



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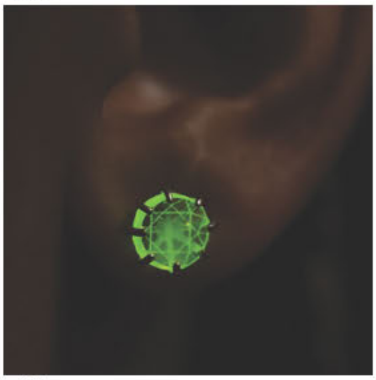
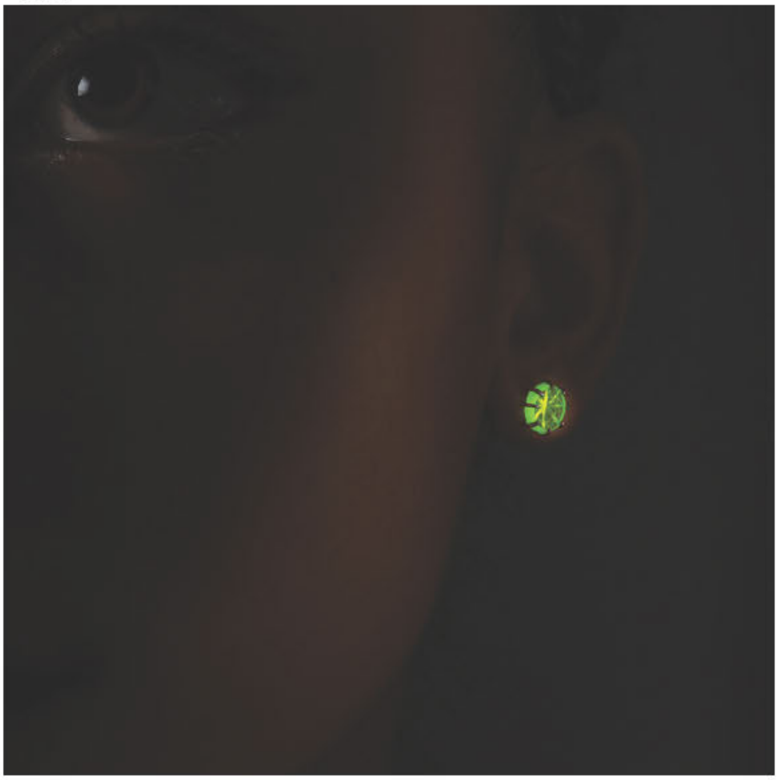


4.27 a.

4.28



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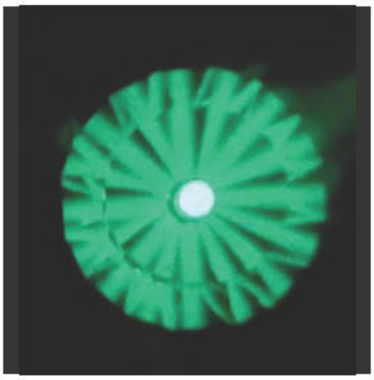
4.29 a.



4.29 b.

Figure 4.26. *Pooling Light* necklace excited by UV light source, BRG Type 2, silver. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.27. *Pooling Light* earring excited by UV light source, BRG Type 2, silver. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Figure 4.28. *Pooling Light* necklace in natural light.

Figure 4.29. *Reflection* doublet: (a.) in natural light, (b.) excited by UV light source. BRG Type 1 + YAG. Diameter = 9.3 mm. Photography by D. Rytz. Image used with kind permission of D. Rytz.

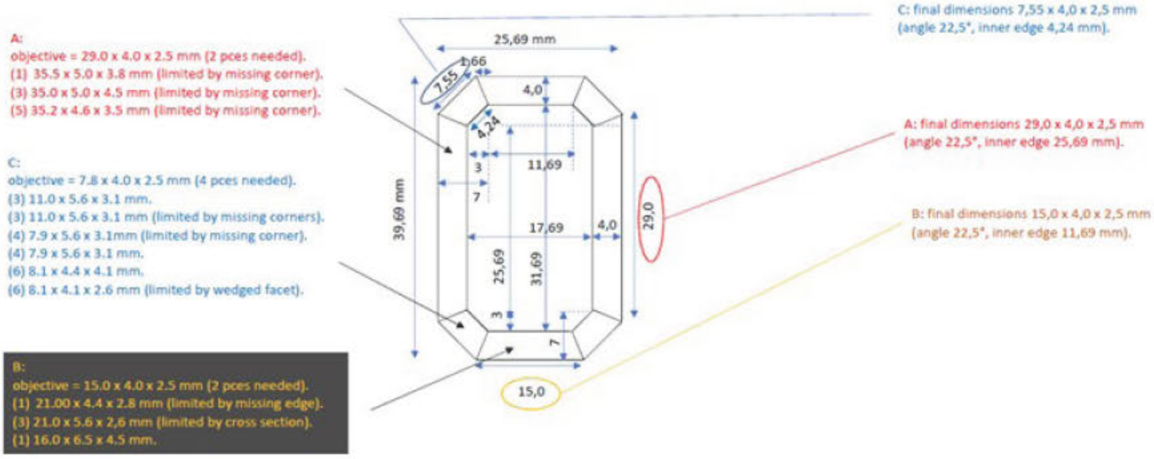
These experiments established that varying the cut of the stone and the colour of the material to be combined with BRG/BRB would also affect the mentioned effects. This was considered an investigation to be completed beyond the timeframe of the PhD, as it would not provide a further response to the research questions underpinning the project and therefore falls outside of its scope.

Pooling Light

Once the above work had been underway for some time, and the collaboration had reached a stimulating level with numerous new concepts for fabrication paths and prototype designs, further ideas for execution were discussed. Progressing beyond the perhaps expected formation of the materials in a traditional faceted gemstone, it was a desire to investigate the properties of the material that could be explored in different formats. One such property of the material is its ability to pool light towards scored or engraved lines, due to its ability to act as a guide for light. The engraved areas disrupt the uniform travel of light in the material, causing it to scatter and concentrate at these disruptions, making the engravings visible. It is a phenomenon often used for signage; one such example was seen on an entrance sign at a local store in Idar-Oberstein. Here Perspex or an alternative translucent material is fitted with a light source at one end, light travels through the material until it meets the engraving, which lights up due to the scattering and concentration of light, creating a bright and clear display. Considering the status of the material as gemstone, a piece was created which, instead of featuring the facets of a brilliant cut, now solely featured its graphic representation, the line drawing of the brilliant cut. These stones – small, polished discs of around 2 mm high – were engraved using a Protec laser cutter, and then set in a necklace (Figure 4.26 and Figure 4.28) and earrings (Figure 4.27 and Figure 4.18 on page 158).

Reflecting Light

Whilst the pooling of light can be achieved through scoring, it can also be achieved by directing light through reflection. This was explored in a stone cut that featured 16 divisions of facets that reflected the light of a BRG rod positioned at the centre of a transparent YAG stone (Figure 4.29). Even though further explorations of stone cuts were not undertaken as part of the PhD project, this fantasy cut does signify the opportunities the reflection of light could hold when attempting to adapt the stone cut in order to enhance or control light reflection in response to a light inclusion. Whilst it was not feasible to expand on this idea within the context of the PhD, this is an area of investigation that holds great promise and lies at the base for a range of further design ideas reconsidering the material as desirable light inclusions to achieve optical effects by including light sources into the volume of a stone or a carved piece of jewellery.



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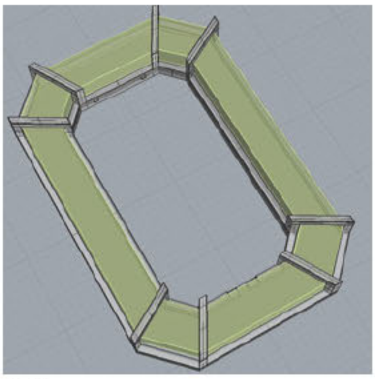

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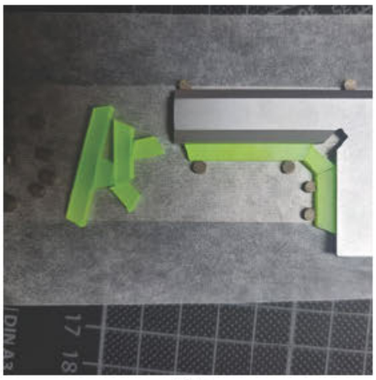

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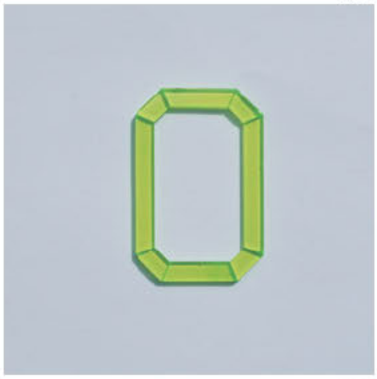

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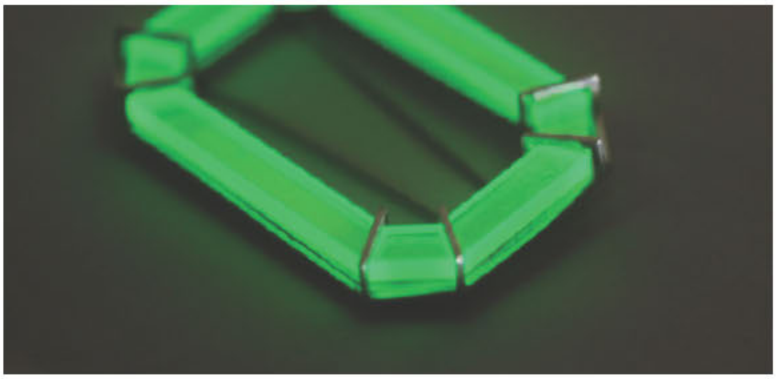


4.34

4.35

Figure 4.30. Calculations of parts for cutting of Octagon pieces in BRG Type 2. Image used with kind permission of D. Rytz.

Figure 4.31. 3D model in Rhino of octagon and metal compartment holding the stone.

Figure 4.32. BRG Type 2 segments being prepared for gluing by Klein & Becker. Photography by C. Morsbach. Image used with kind permission of C. Morsbach.

Figure 4.33. Glued BRG Type 2 segments in natural light.

Figure 4.34. Octagon in silver model. Photograph taken after excitement under UV light source.

Figure 4.35. Octagon in 3D printed model.

Octagon

> *"We still know too little, but at the same time alchemy was understood as a discipline or an enterprise that could illuminate - illuminate nature and illuminate the human mind seeking nature. This fundamental issue of alchemy as a philosophy was present from the early, formative period of western civilization - from the very first text translated."*
> *(Haaning, 2006, pp.32–33)*

Whilst the experiments and tests described above all provided viable means for the material to be used as a component for the creation of jewellery designs (an agreed and desirable outcome of the collaboration), as a jewellery artist questioning these materials as gemstone materials they also inspired the creation of artistic responses. One piece was ultimately created following the kind donation of a large selection of material mined from leftover sections of a boule grown by Rytz for testing purposes. When working with BRG and BRB, one does not just work with the handleable matter that is at hand, the facetable material which looks and feels similar to garnet. The Materia Prima's borders, particularly when observed in the dark, are less defined than that. With light being stored, pooling on its edges and bouncing off neighbouring objects, illuminating surroundings, one is sculpting as much with light as with matter. An analogy became apparent between the material's ability to visually demonstrate its release of energy (in the visual form of light) with the quintessence of a gemstone, often referenced by those interviewed as part of the PhD project (albeit in those contexts often in relation to mined gemstones). The material BRG, with its yellow-green light emission, is a gemstone material, with the soul of a gemstone. To visualise the soul of the gemstone, which extends beyond its physical boundary, a piece was constructed out of eight BRG components, which were cut, positioned and combined to form the outline of a rectangular emerald cut (Figure 4.33). Whilst the middle facets of the emerald cut were represented by the pieces, the light these pieces cast sideways formed the additional facets that made up the cut, constructing the full structure with both matter and light (Figure 4.36 on page 166). The piece (Figure 4.51 on page 184), which was carefully planned in collaboration with Rytz (Figure 4.30), and cut by Mr. Morsbach from the company Klein & Becker in Germany (Figure 4.32), was positioned in a silver setting (Figure 4.34) that amplified its light effect through its structure (Figure 4.35).

4.36

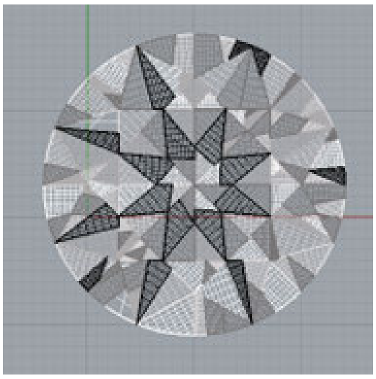
Figure 4.36. *Octagon*, BRG Type 2, silver, steel. Photograph taken after excitement under UV light source.

Figure 4.37. *Cameo*, BRG Type 1, bio-resin, silver, steel. Photograph taken after excitement under UV light source.

4.37

4.38

4.39



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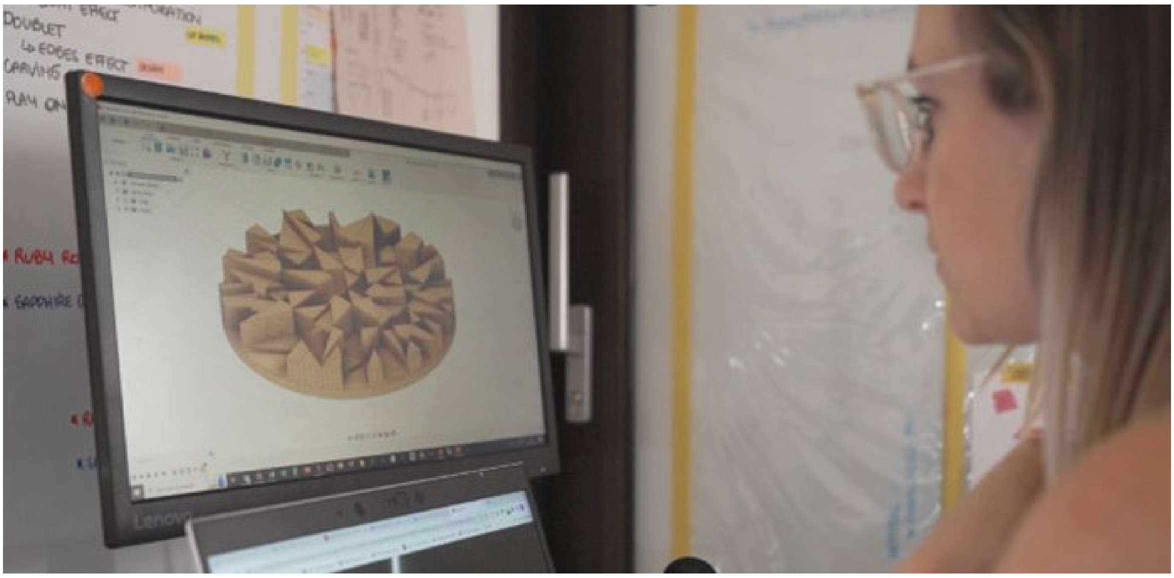


4.41

Figure 4.38. *Cameo*, BRG Type 1, bio-resin, silver, steel. Photograph taken in natural light.

Figure 4.39. Top view of a brilliant cut diamond.

Figure 4.40. Translation of brilliant cut diamond brilliance into sections with various heights in Rhino.

Figure 4.41. Author working on 3D model in Fusion 360. Photograph taken by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

Cameo

As it is being perfected in the laboratory by Rytz over the course of time, the Materia Prima BRG has an increasingly long remanence time (the time the stone remains visible in the dark), which is expected to increase even more with further growth experiments in the near future. Whilst its role as a gemstone has been under investigation throughout the project, its ability to perform as a light source in the dark is unquestionably a major feature of the BRG material. Whereas a play of light in faceted gemstones is evident, there are other gemstones that demonstrate optical effects.

Cameos are layered stones in which the lighter layer (usually at the top) is carved to create an image that stands out from the darker background layer. When the top layer of a cameo is translucent, the darker colour of the background layer will shine through more where the layer is thinner and less where the layer is thicker, thus resulting in a tonal image. The thickness of the translucent layer ultimately affects how light is refracted, reflected and partially absorbed by the darker background layer, an effect that can also be found in basse-taille enamelled pieces.

The idea of replacing the background darker layer of a cameo with the BRG material came from a discussion with Rytz on porcelain tealights, in which a tonal image is portrayed due to light transferring through thinner and thicker parts at varying intensities (thinner is lighter and thicker is darker). A similar effect could be achieved with a layered BRG gemstone. In order to extend the investigation of the material as a gemstone, the pattern chosen to apply to the lighter translucent white layer on top was based on the facets of a traditional brilliant cut, which when seen from above will display a tonal image of lighter and darker triangles as a result of light refracting in the gemstone (Figure 4.39). This image was brought into the CAD software and a height was established for each tone displayed. The resulting heightmap (Figure 4.40 and Figure 4.41) was then 3D printed in bio-resin and overlayed over a segment of BRG Type 1 material of 30 mm diameter and set in a setting (Figure 4.37 on page 166 and Figure 4.38).

Here once again, the artistic interpretation of the material revolved around the Materia Prima's ability to emit light, a property unlike any other gemstone materials available, and the faceted brilliant cut, which symbolises the general cultural appreciation of what qualifies as a gemstone.

It is the intention for the piece to be re-created with a doublet (white translucent YAG + BRG), the cutting of such a stone in the intended shape is being tested in collaboration with the company Klein & Becker.

4.42 a.

4.42 b.

Figure 4.42. *Neo-gemstone*, BRG Type 2 + garnet doublet: (a.) photograph taken following excitement with UV light source. (b.) photograph taken in natural light.

OUROBOROS

"The sciences open themselves in their everyday way of life to the artists, at least to a certain extent, and many artists discover – or rediscover, as one should say looking back into history – the instrumental media and the materials of the sciences as so many possibilities of creative appropriation."
(Rheinberger, 2018, p.242)

Whilst these prototypes and artefacts created as part of the collaboration with BREVALOR illustrate but a small selection of the wider range of designs proposed and concepts in development, they can already be used to draw some intermediate conclusions in relation to this study's overarching research question.

Firstly, when considering the innovation opportunities lab-grown gemstones provide, the Materia Prima BRG and BRB are clear demonstrators of the ability we have to create new crystal materials with properties that exceed the properties of crystals mined from the earth. Examples of ongoing innovations and improvements initiated by BREVALOR since their first crystals grown in 2013 include increasing light intensity and the remanence time, correlating these properties for the first time with the actual concentrations of specific dopants in the crystals (by measuring their optical spectroscopic properties), understanding the lamellar structure and working towards suppressing it and, last but not least, growing single crystal boules with larger dimensions and ever improving homogeneity.

The opportunity to work with a new material can be inspirational for artists, and has been a driving force for other sci-art collaborations (Miller, 2014). It was no different in this instance. The materials supplied by BREVALOR, whilst useable as a gemstone material, with their light emitting properties posed a range of challenges and questions that required (and still require) investigation and creative exploration, a most appealing challenge to an artist.

The development of the brilliant cut in history is the documented quest of faceters trying to perfect a geometric cut, applying the laws of optics, that would optimise light emission by reflection in gemstone materials (Lindemann, 2016). A light-emitting gemstone material, now capable of storing energy and generating its own light, provides an interesting avenue for exploration, where all that was considered resolved, can be questioned again. This is something that was certainly started during the PhD study, in which some Critical Design pieces were also created as commentary on the context in which these materials are appraised. Is it a gemstone or is it not a gemstone material? When the *Neo-gemstone* piece (Figure 4.1 on page 144 and Figure 4.42) is seen in the light it appears to be a normal gemstone, but in the dark a big line shows through it. When considering the labelling of this material, the term 'Neo-gemstone' seems most appropriate, as it is more than the gemstones that exist today. This gemstone material demands a reconsideration of its appearance and application in jewellery, a new quest that will span well beyond the duration of this PhD. A new material by definition will lead to a range of innovative outcomes and, collaborating with scientists who dedicate their time, resources and apply their knowledge to this challenge is most rewarding.

Another conclusion that can be drawn from the collaboration and the resulting outcomes achieved at this intermediate stage is that, in order to experiment with materials, one does need access to said materials. Whilst a certain amount of exploring and playing can be performed with substitute materials (that lend themselves better to tinkering, in this case glow in the dark pigments embedded in a re-castable resin), in-depth knowledge of a material is only really acquired through hands-on trial and error. The requirement of a supply of material in order to investigate the Materia Prima was met, thanks to BREVALOR's generous investment in the collaboration. This would ultimately be a necessity for future similar collaboration, and could certainly pose challenges to artists, since not all collaborators are willing to invest in these types of artistic explorations.

Furthermore, the limitations in size of the donated materials, in some cases due to the limit in size the boules are currently being grown in, did provide some challenge and certainly influenced the final outcomes of the project. Here, in stark contrast to the general appreciation of man-made gemstone materials being abundantly available, there were limitations on availability. Whilst in the future, the limitations encountered with respect to availability and size of phosphorescent crystals is expected to progress towards the general appreciation of man-made gemstone material being abundantly available, size will remain connected to production cost, the equipment and technology being used and applied, and its accessibility to artists.

4.43

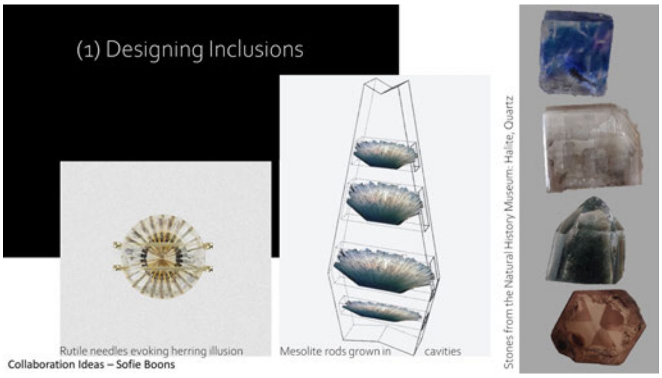
Figure 4.43. Faceting dop with doublet (BRG Type 2 + YAG).

"The artist in the laboratory stands before the choice of two options. Either she or he engages with the products of laboratory work. [...] In this domain, scientists tend to love to be confronted with the aesthetic aspects of their research products, and it is not the least function of such reworking to decorate the covers of their prestigious journals and textbooks. Or else the artists engage with the technologies of data generation and visualization themselves, that is, with the means and the media through which and with which the results of the sciences acquire contours. As a rule, this is the thornier path to take, for it requires a more indirect, reflexive take on scientific data production [...]."
(Rheinberger, 2018, pp.242–243)

The limited material available during this project could therefore be attributed to the timing of the collaboration, which took place whilst Rytz was still in a material development stage (rather than at a commercial production stage). The timing of the collaboration, however, was deemed an interesting aspect to interrogate in relation to the benefits of the collaborative work. In response to the challenges faced when faceting the glued doublet stones, Rytz developed an alternative technique to enable the bonding of BRG and YAG, bypassing the need for gluing, and resolving the technical challenge whilst faceting (Figure 4.43). Whilst increased proximity would potentially benefit this interplay and enhance the level of discussions of similar problems and resolutions, the problem and resolution identification by maker and scientist at a stage prior to commercialisation is considered to be important and impactful to the further material development.

Over the course of the project, crystal growth knowledge was shared between scientist and artist/maker, and making and artistic discussions were also held. Aside from the fact that this enriched the thinking of both partners, it also led to a significantly more collaborative approach to the practices conducted by each. Overall, this collaboration with industrial partner BREVALOR enabled the start of an exciting exploration of a new material. The collaboration, which remains ongoing, provided the author with hands-on experience of experimenting with a material currently unknown in the jewellery field, and provided the scientific partner with an opportunity to test the material for its technical and creative potential.

4.44



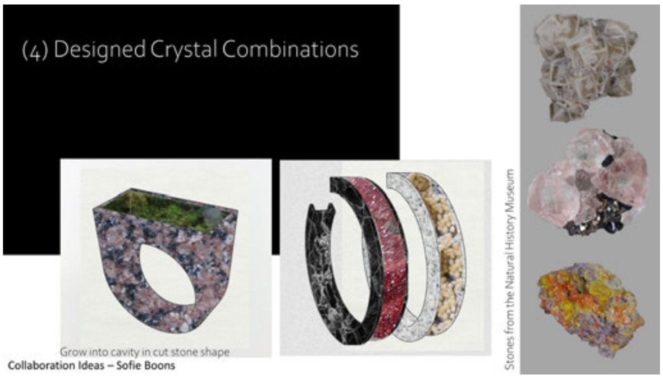


Figure 4.44. Slides of a presentation shared with the Bristol University team documenting collaboration ideas.

4.4. Microcosm: Academic Crystal Growth Collaboration

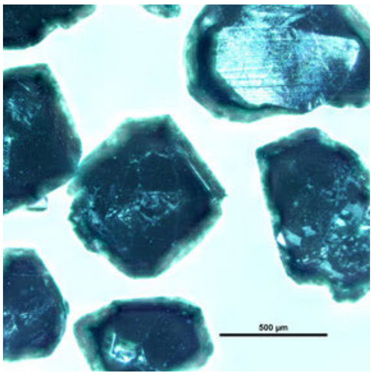
In September 2020 contact was made with Bristol University's Dr Hall, now Head of Inorganic and Materials Chemistry at the University of Bristol and his, at the time, Post Doctoral assistant Dr Potticary. This department investigates complex functional materials, with an interest in improving their functionality by controlling, for example, crystallisation. Material behaviours such as superconductivity, piezoelectricity, magnetoresistance and ferroelectricity are investigated and enhanced by controlling crystal morphology in multi-component inorganic systems (Hall, 2024). Upon meeting Dr Hall and Dr Potticary, an immediate synergy was established. Having gained hands-on experience from growing sugar, salt and alum crystals and, after having extensively reviewed the literature on low temperature inorganic crystal growth (see Chapter 5), a range of ideas had been identified as interesting to explore in collaboration with experts, which were discussed with the team (Figure 4.44).

Whilst there was no funding to support a collaborative project, they committed time to several explorative meetings (Appendix 8) and reviewing the literature that had been signposted. As their department had not previously grown gemstone crystals, the idea of experimenting with colour by adapting formulas of low-temperature aluminium oxide (Al_2O_3) growth was most interesting to them.

4.45

Crystal	Specific Gravity	Hardness	Refractive Index	Lustre	Colour
Ruby (Aluminium Oxide)	4-4.1	9	1.76-1.77	Adamantine to vitreous	Red
Sapphire (Aluminium Oxide)	4-4.1	9	1.76-1.77	Adamantine to vitreous	Blue, pink, orange, yellow, green and purple

Table 4.3



4.46

4.47

Figure 4.45. Ruby and sapphire Verneuil boules.

Table 4.3. Comparison of ruby and sapphire properties.

Figure 4.46. Microscope image of sapphires grown by Bristol University team.

Figure 4.47. Vial of sapphires grown by Bristol University team.

MATERIA PRIMA

"As natural corundum contains many elemental impurities, it is unlikely that only a select few are responsible for their colouration, yet there is limited research into alternative mechanisms.!
(Whitehurst, 2022)

Corundum is the collective term for the thermodynamically stable α phase of aluminium oxide (Al_2O_3). In the jewellery field, corundum is used to describe rubies (red aluminium oxide crystals) and sapphires (all other colours available). Corundum single crystals have a trigonal lattice structure and have a range of mechanically desirable properties (Table 4.3) which have resulted in their popularity for incorporation into jewellery, often as faceted gemstones.

Pure corundum is colourless. When corundum is red (ruby), 1-13% of its aluminium ions have been replaced by chromium, a phenomenon explained by crystal field theory (Whitehurst, 2022). However, not all chromium-doped aluminium oxide appears red. Chromium impurities can also result in different colours, depending on their concentration and the crystal field effects. When the percentage of chromium exceeds 64%, the crystal will appear green. Anything between 13-64% will result in grey-ish red, grey or grey-ish green crystals (Singh, 1958). The colour of blue sapphires can be attributed to the intervalence charge transfer (IVCT) between iron and titanium, present as impurities in the crystal. This electron transfer results in light absorption in the yellow-orange region, leading to the sapphire's blue appearance (Ferguson and Fielding, 1971). Orange Corundum, also referred to as a padparadscha sapphire, has a distinctive pink-orange colour which is believed to result from the combination of chromium impurities and iron-related colour centres. These colour centres can involve trapped electrons or holes within the crystal structure, with the exact hue being influenced by the specific impurities and their interactions. It is fair to state that any colour presented in corundum is dependent on the concentration of impurities and the mechanisms in which these impurities interact, of which there are an infinite amount of combinations possible (Whitehurst, 2022). For this reason, it is considered an attractive crystal to experiment with, to create new pigment or gemstone colours.

TRANSMUTATION

Following their review of the identified literature of the low-temperature growth of aluminium oxide (Al_2O_3), the Bristol University team embarked upon experimenting with found formulas and were successful at creating corundum powders and even growing a few small rubies at low temperatures (Figure 4.47 and Figure 4.46) These experiments were made possible through the purchase of a platinum crucible by the University of the West of England, which was lent to the Bristol University department to conduct the experiments.

4.48 a.

4.48 b.

Figure 4.48. Enamelling samples using pigments grown by Whitehurst: (a.) back of samples documenting percentages of pigment and flux, (b.) front of sample, showing left top flux only, right top white on flux, left bottom flux+pigment and right bottom flux+pigment on white base.

After months of running some tests in between research work in the department, which resulted in slow progress, Dr Hall proposed appointing an undergraduate to focus on the topic. Michaela Whitehurst, at the time a third year Bachelor's student, was invited to work towards the project and submitted a thesis in partial fulfilment of the requirements for a BSc Honours Degree at the University of Bristol titled *The Effect of a Dopant on the Colour of Synthetic Corundum* (Whitehurst, 2022). Her thesis provided a detailed account of the scientific literature surrounding the production of lab-grown corundum and confirmed that there was a considerable gap in research related to the growth of corundum with different colours than those most popular in the jewellery trade (red – ruby and blue – sapphire). Her project investigated the ten colour results of produced corundum powders, each achieved by individually adding one of the following dopants to the aluminium oxide formula: germanium (IV) oxide, vanadium (IV) oxide, chromium nitrate nonahydrate, potassium hexachloropalladate (IV), gallium (III) oxide, niobium (V) oxide, niobium (V) chloride, iron (III) chloride, and cobalt (II, III) oxide. The method employed during the project proved inefficient for optimal crystal growth, which meant that the powders could only be considered for use as enamels or glazes. Furthermore, the colour of the powders was deemed not representative of the colour in single crystals, so opportunities for innovative colours could not be established at this stage.

> *In this project, only a small proportion of the hypothesised dopants were trialled, and hence, there are many more opportunities to investigate individually doped corundum.*
> *(Whitehurst, 2022)*

Following the completion of her BSc, with support from Dr Hall, Whitehurst submitted a request for funding to carry on the research started as part of a PhD. She was granted a funded research place in September 2022, and is currently continuing the investigation into possible colours in corundum.

SOLVE ET COAGULA

To support Whitehurst with identifying relevant applications for the produced pigments, initial tests were carried out at the Centre for Print Research, adding the pigments to traditional flux used in enamelling, and firing these onto test plates to investigate the colour. Whitehurst has now also been trained in enamelling, and uses the facilities at the Centre for Print Research to continue testing the colours she achieves as enamels (Figure 4.48).

Following the investigations Whitehurst and the team at Bristol University have been conducting on the formulas identified in the literature for the low-temperature growth of crystals, they have also made additional discoveries of the system. In their paper titled *New and Unforeseen Crystal Processes for a Metal Oxide* (Whitehurst and Hall, 2023) they shared their observations of a new crystal growth process which they named the molten intermediate decomposition (MIND) mechanism. Their continued investigations of the formulation and crystal growth process will enable greater scientific understanding of the process, which will ultimately benefit all those who wish to apply it.

"The second form of the artistic engagement with scientific laboratory worlds I call to be of esoteric nature. Here what is at stake is, in parallel with the exploratory handling of materials under the perspective of knowledge generation, as being characteristic for the research process, to find forms appropriate for the arts of handling materials under an aesthetic-epistemic perspective in the realm of artistic work."
(Rheinberger, 2018, p.244)

When starting to work with the Bristol University team, it was the intention to set up a science-art collaboration that would result in contributive works (Halpern and Rogers, 2021): *"Rather than representing or presenting existing knowledge, these pieces contribute new ideas, techniques, or processes to scientific discourses and public understanding."* There were, however, a number of challenges to achieving such a collaboration.

"[...] it already allows us to raise the question of the "field of resources" that contemporary art and cutting-edge science, be it as a matter of institutional marketing or artistic research, are said to share or compete for. This question hints at a tricky ménage-à-trois (between, say, art, science, and institutional politics), rather than a "binary economy" of historical values per se."
(Sormani, Carbone and Gisler, 2018, p.5)

Firstly, as each University (Bristol University and the University of the West of England respectively) has their own sites, equipment and personnel, by choosing to enrol with one, you gain access to the resources of that university. Whilst doctoral research projects are now more commonly spread across institutions, this research was not officially registered with Bristol University. For reasons related to, for example, insurance and costs, it is not always an option to use the facilities of another university without being enrolled there. This appeared to be the case with Bristol University, as the team managed any proposed research experiments in-house, without inviting involvement. Whilst the results of experiments were discussed during our meetings, this format resulted in 'interactional expertise' rather than 'contributory expertise' (Collins and Evans, 2002), which is required in order to achieve contributive works. Furthermore, since initially any experiments discussed were conducted in between other work, the speed at which the experiments were executed was slow at the start. This changed, however, when Whitehurst was appointed.

Surmounting the barriers of specialization and engaging the epistemic with the aesthetic can create surprising effects, and it can certainly have a critical social function. But it happens far less frequently that the scientists engaged get something out of the artistic procedures for their own scientific work.
(Rheinberger, 2018, p.244)

Secondly, as Heinich (2018, p.47) points out, art *"is not a search for truth, but a search for perceptual experience, whether it is on the side of the producer of the artwork or on the side of the perceiver; and something which occurs regardless of how we define the object of this experience."* Moreover, the ideas proposed to the team (1-4, see Figure 4.44 on page 174) were challenging to achieve technically, and also perhaps not fully aligned with their scientific research interests.

> *"[...] artistic research in this case is not so much interested in actual technical or scientific objects or research projects, but rather in flirting with various scientific instruments, devices, and machines, as well as being curious about new media and complex technology, if only to subvert their ordinary use and imagine artistic alternatives."*
> *(Sormani, Carbone and Gisler, 2018, p.6)*

It was for these reasons that independent experiments were set up at the University of the West of England, where the freedom to conduct 'playful experiments' (Sormani, Carbone and Gisler, 2018) could be achieved (Chapter 5). Following this development, in an attempt to practice what is preached, enamelling skills have been shared with Whitehurst, who has now been granted access to the Centre for Print Research (University of the West of England) facilities to utilise the technique for the creation of colour samples. Whilst the work conducted initially by Dr Hall and Dr Potticary, now continued by Whitehurst, has not led to finalised jewellery outcomes, their research shows great promise for the future. For jewellers or companies using enamels or glazes, the innovations in colour could drastically improve the range of colours available, and their safety (Helwig, 1991). With production potentially possible at low temperatures, it is possible that enamellers of the future could grow their own enamels. Furthermore, the researchers involved intend to apply for funding to support future contributive work on the subject.

> *"What appears to be necessary is to carve out and to delimit discursive spaces, in which it becomes possible that scientists and artists can get mutual insight into their work, less into what they say, but more into what they do when they practice their trade. It appears thus first and foremost in the material circumstances of shoptalk among artists and scientists, rather than in a lofty and detached discourse on their supposed practices that the potential and prospects for a "hybrid heuristics" challenging both sides may finally lie."*
> *(Rheinberger, 2018, p.248)*

4.49

Figure 4.49. Author in studio. Photography by Simon Regan for the Centre for Print Research. Image used with kind permission of the Centre for Print Research.

4.5. Macrocosm

"A discussion of the relation between the sciences and the arts hinges on finding a common ground for the comparison of their innovative practices. It has to be a ground from which this relation can be formulated in a manner such that the involvement with the unprecedented stands in the foreground, without – and it is important to stress this – denying the right to being different in approach and performance."
(Rheinberger, 2018)

"Collaboration is bloody difficult" says the Wellcome Collections' head of public programmes from 2007-2016 Ken Arnold (2014, as cited by Miller, 2014, p.313), in relation to art-science collaborations. Even though the last four years of collaborative work have not felt difficult, and the path of collaboration with both the industrial partner BREVALOR and academic partners at Bristol University is still developing, what can already be said about their evolving directions is that they were unexpected.

In contrast with Arnold's belief that collaborations work best if both parties are clear from the beginning as to their contributions, aims, and what the finished product should be (as cited by Miller, 2014, p.314), when one starts a similar long-term collaboration, an unexpected trajectory and unexpected outcomes have to be accepted. This is perhaps unsurprising, as one only knows what they themselves know prior to starting a collaboration with an expert in a different field. With naivety one embarks on a collaboration, with some areas of investigation and interest identified prior to starting. These have to evolve as the collaboration progresses in order to remain equally interesting to all collaborating partners, and so it provides room for differences in approach and intent. Concessions may have to be made.

Whilst a personal interest in the commercial application of the BRG and BRB material was not initially of interest, through exploring this avenue the partnership developed and, as the collaboration expanded, more creative outcomes were explored. Similarly, where initially the collaboration with Bristol University was intended to enable the development of contributive works, it became clear that the opportunity to do so has to evolve within the context.

"Research processes – whether they be of a scientific or of an artistic nature – have to be arranged in such a way that new things can make their appearance in them. But the new, insofar as it deserves that name, cannot be anticipated. It is unprecedented. It happens in the working process as a result of the procedures and constellations to which the working materials are exposed. Whereas in scientific research, the new has a predominantly epistemic connotation, what is relevant in artistic research is that the knowledge of the materials is connected to and intertwined with aesthetic effects of sorts that irritate perception."
(Rheinberger, 2018, p.246)

The focus of this chapter and the underpinning case study was to review the opportunities and challenges art-science collaborations (jewellery and crystal growth) pose and how similar collaborations could result in innovative outcomes. As the outcomes of this chapter indicate, art-science collaborations can be fertile grounds for innovations. In the collaboration with BREVALOR the new materials BRG (Figure 4.50) and BRB (Figure 4.7 on page 150) were used to create test models that provided the scientists with insights to direct adaptations and alterations to the material and the techniques used with them. Following hands-on experimentation, artefacts were produced that utilised the material's unique properties, firmly establishing it as one with an interesting future as a gemstone. In the collaboration with Bristol University an entirely new direction of research was established in the department by the appointment of Whitehurst, first in her undergraduate role and then whilst pursuing a PhD on the subject. The department's investigations are already leading to new discoveries, and whilst the research has not resulted to date in jewellery outcomes, the opportunity for novel colours to be explored in a jewellery context is most promising.

4.50

Figure 4.50. BRG Type 2 cored material as supplied by BREVALOR.

Figure 4.51. *Octagon*, BRG Type 2, silver, steel. Photograph taken in natural light.

Overall, the art-science collaborations engaged with for this PhD also provided an insight into the differences between academia and industry. Where industrial partners were set on protecting ideas and developing them with commercial outcomes in mind, academic partners seemed keener to look for innovations that could further their careers and portfolios as researchers. What appears most challenging in art-science collaborations in the context of crystal growth, both in industry and academia, is the speed at which developments are made. As Rytz suggested, it takes around 20 years to develop a material before it is ready for commercial application. This is a pace artists and makers may not be accustomed to. The rigour in place in a scientific context is partially responsible for this pace and, whilst rigour is important in a scientific context, this can be stifling to an artist who cares less about the repeatability of experiments and more about the production of outputs. Perhaps this was why contributive work with crystal growth in the lab was not established. It was for this reason that some of the ideas pitched to collaborative partners were ultimately attempted individually (Chapter 5), as it was believed engagement with the process of crystal growth would yield further innovative opportunities. It is, however, important to note that the knowledge and experience gained from collaborative work was instrumental in the furthering of individual experiments and, whilst the collaborative partners may not have been directly involved in the case study described in the subsequent chapter, the collaborative experiences did inform it.

4.51

5.1

Figure 5.1. Sugar crystal grown on silver ring.

Chapter 5. Case Study 3: DIY Neo-gemstone Crystal Growth

"The best way to learn is to interact with the world while seeking to understand it, readjusting our mental schemes to what we encounter and find."
(Rovelli, 2022, p.117)

5.1. Introduction

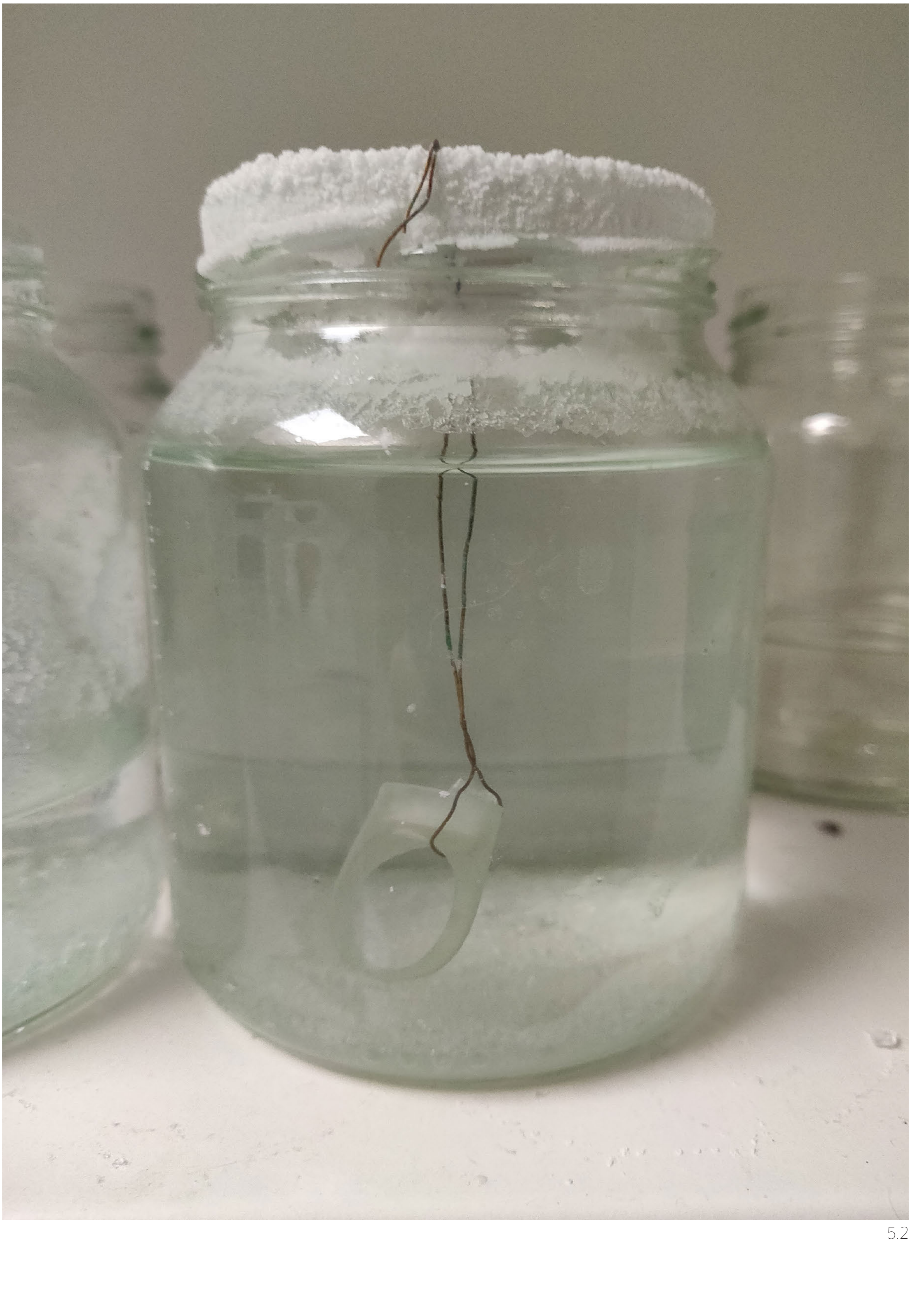
Chapter 5 discusses the final case study, in which the Do It Yourself (DIY) growth of crystals was explored. The solution growth method, first documented using the growth of salt, sugar and alum, and later applied to the growth of ruby, was incorporated into the jewellery design process, and reviewed as a methodology in the context of the author's jewellery practice. Linking to bio-design/art methodologies, hypotheses derived from the characteristics and advantages of Growing Design were tested to explore the design opportunities the method provides.

The chapter illustrates that the DIY growth of organic crystals can be a powerful learning process for jewellers wishing to gain a deeper understanding of crystal growth, and that it is expected to be a valuable tinkering process to investigate ideas involving the process of gemstone quality crystal growth in the development of jewellery.

Furthermore, the hands-on engagement with the process in a hybrid studio/lab will be captured to present the learning that took place. Unplanned outcomes enabled further avenues of exploration, which are expected to expand beyond the PhD project.

This chapter is accompanied by samples and pieces which have been produced using the described processes and techniques, where possible photographs aim to contribute to a diffractive appreciation of the experiences illustrated.

The focus of this case study was to explore the technique of crystal growth through a jeweller's lens, and how these technologies could be applied within the jewellery making process.



5.2

Figure 5.2. Organic crystal growth set-up during lockdown. Salt jar in the front.

5.2. Microcosm

"What appears to be necessary is to carve out and to delimit discursive spaces, in which it becomes possible that scientists and artists can get mutual insight into their work, less into what they say, but more into what they do when they practice their trade. It appears thus first and foremost in the material circumstances of shoptalk among artists and scientists, rather than in a lofty and detached discourse on their supposed practices that the potential and prospects for a "hybrid heuristics" challenging both sides may finally lie."
(Rheinberger, 2018, p.248)

In March 2020 the world had to grapple with a very serious challenge. As the Covid-19 pandemic unfolded, most people had to re-think their ways of working, reducing their contact with others and, when and where possible, stay at home. With working from home a reality for nearly one and a half years, it quite quickly became paramount that acquiring knowledge and achieving progress had to be pursued differently in this new reality. As a practice-based researcher, artist and maker, having just embarked on a part-time PhD investigating lab-grown crystals, the limit in opportunities to engage with the subject beyond reading about it and discussing crystal growth processes of interest with collaborators through online meetings provided a catalyst to embark on a Do It Yourself (DIY) journey to understand crystal growth. Since crystal growth is a key scientific endeavour, a large amount of literature from scientific authors was available, documenting various highly complex procedures and findings related to crystal growth. It was, however, more challenging to locate literature that communicates the process in laymen's terms. The book *Crystals and Crystal Growing* by Alan Holden and Phyllis Morrison (1982) proved to be the most accessible, yet detailed introduction to crystal growth, with the specific purpose of explaining how to grow DIY crystals.

5.3

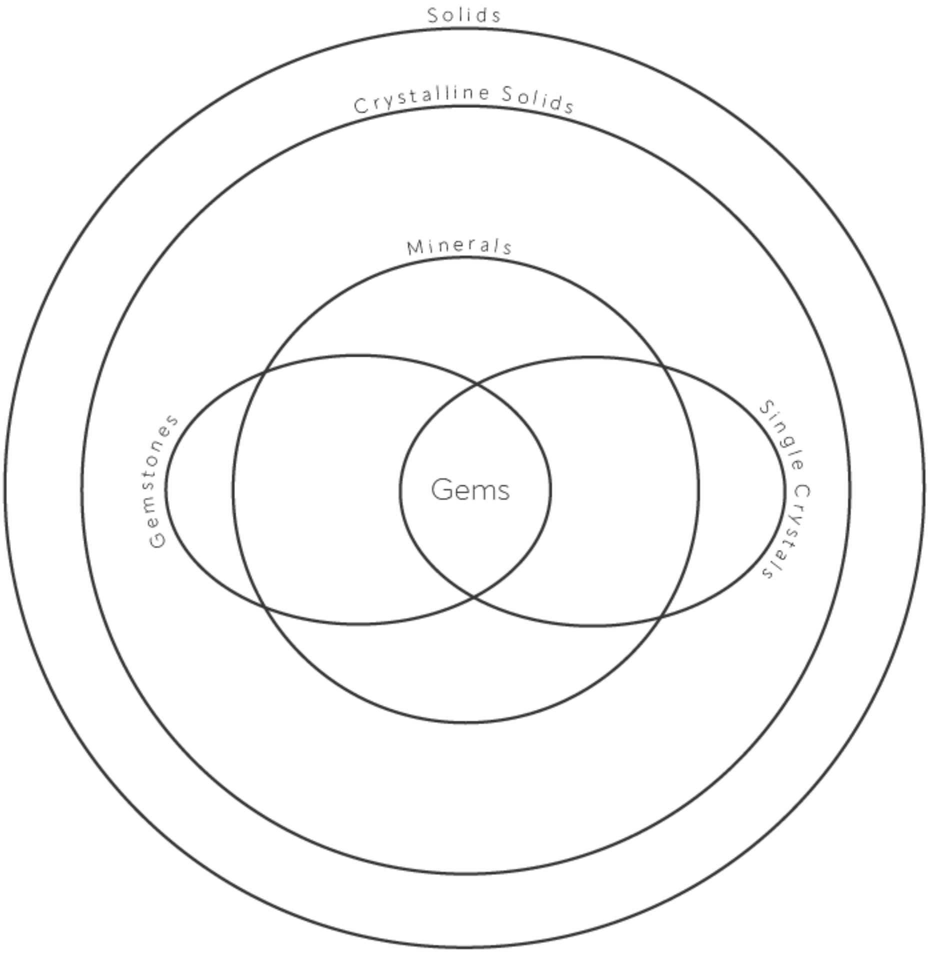
Figure 5.3. KTbW crystal grown in-situ in platinum ring by Sebastion Schwung and D. Rytz.

"I think the construct that is most overlooked now in the 21st century, and maybe the 20th century as well, is the power and importance of play. That's to say, how do I take an idea, and how do I play with it, how do I tinker with it, how do I come to make it personal, how do I come to own it, how do I indwell in the idea itself."
(Brown, 2011)

Several months of playful experimentation with sugar, salt and alum in jam jars in the home jewellery studio (Figure 5.2 on page 188) (Appendix 10) offered a hands-on introduction to solution growth and enabled the identification of a range of ideas that would be worth exploring with inorganic crystal growth technologies. When starting the collaborations with scientists (as documented in Chapter 4), there was a hope that, post-pandemic, there would be a possibility to venture into the lab and apply some of these ideas collaboratively. Whilst the in-situ crystal growth idea was considered interesting to the crystal growth partners, the execution of this idea did not become a priority. For the academic partner this was down to the outcomes of the tests they were running which focused on colour, and currently were not conducive to the growth of single crystals. For the industrial partner this could be attributed to the challenging schedule of growth runs the in-situ growth had to fit in with. Ultimately a test was attempted in collaboration with Rytz (Figure 5.3) but only towards the end of PhD research, after individually achieved outcomes had been shared. Further collaborative work in this area will take place post-PhD, as industrial adaptation of the techniques proposed could provide additional options, since industrial crystal growth provides greater control and therefore changes the methodology.

"Building upon an arts and crafts legacy, DIY culture is typically based on an explicit or implicit critique of disembodied an alienated industrial or institutional production for which it creates hands on alternatives."
(Cramer, 2022, p.268)

Having seen the Bristol University team apply the identified low temperature crystal growth process successfully to their production of small sapphires (Formula/Process 1), and a similar furnace to the one used by the team was available at the University of the West of England, a decision was made to conduct independent DIY experiments too. When speaking to the scientific collaborators about the idea to bring the laboratory closer to the studio environment, and approach the scientific technology with a neo-alchemical approach, their reaction was perceived as slightly apprehensive. Since no jeweller had ventured there before, their apprehension was perhaps well-founded. With determination, however, the journey towards applying the technique in a DIY manner outside the traditional scientific lab became a focus of the research project.



5.4

crystal

noun (MINERAL)

/ˈkrɪs.təl/

A piece of a substance that has become solid, with a regular shape.

Any solid consisting of atoms or molecules that are arranged in a regular structure.

Clear, transparent rock that is used in jewellery, or a piece of this.

5.5

Figure 5.4. The classification of solids, crystalline solids, minerals, gemstones, single crystals and gems.

Figure 5.5. Crystal, as defined in the Cambridge Dictionary.

5.3. Materia Prima

"It is a stone and yet not a stone,
in this lies the art alone:
Nature has made it so,
though not to perfection brought:
Its like will not on earth be found,
It grows in mountain and in ground,
Materiam Primam ought one to call it:
He is wise, if he knows it."
German Poem cited by Wamberg (2006, p.49)

The word 'crystal' (Figure 5.5) has Greek roots and used to mean clear ice, and still today is called upon for a range of confusing uses, from signifying cut glass and a clear ball to predict the future, to a gem in a piece of jewellery (Holden and Morrison, 1982). To physicists and chemists, however, a crystal is a solid material with atoms arranged in an orderly way. Not all gemstones are crystals (Arem, 1977) and, even though a range of the minerals considered gemstones can be classed as single crystals (gems), there are exceptions: for example opal, which is a non-crystalline material; and agate, which is a micro-crystalline material. Furthermore, not all single crystals are considered gemstones (Figure 5.4), since the minerals generally considered suitable for jewellery designs are usually expected to be adequately resistant to the conditions in which jewellery is worn. Therefore most crystals used for jewellery are durable in addition to displaying appealing optical properties (Boons, 2022a, 2021a).

ALUM, SALT AND SUGAR

Alum, salt and sugar are not considered gemstone quality, and evidently have only been used by a limited number of jewellery designers to date (Boons, 2022a) (Appendix 10). Because the growth of gemstone grade crystals (for example ruby, emerald, amethyst, quartz and citrine) generally requires more elaborate and high cost equipment, the first experiments set to test the methodology of 'Crystal Growing Design' for jewellery (Boons, 2021a) were conducted with sugar, salt and alum (Appendix 10).

5.6

Figure 5.6. Ruby crystal grown by Chatham. Photography by Tom Chatham. Image used with kind permission of Tom Chatham.

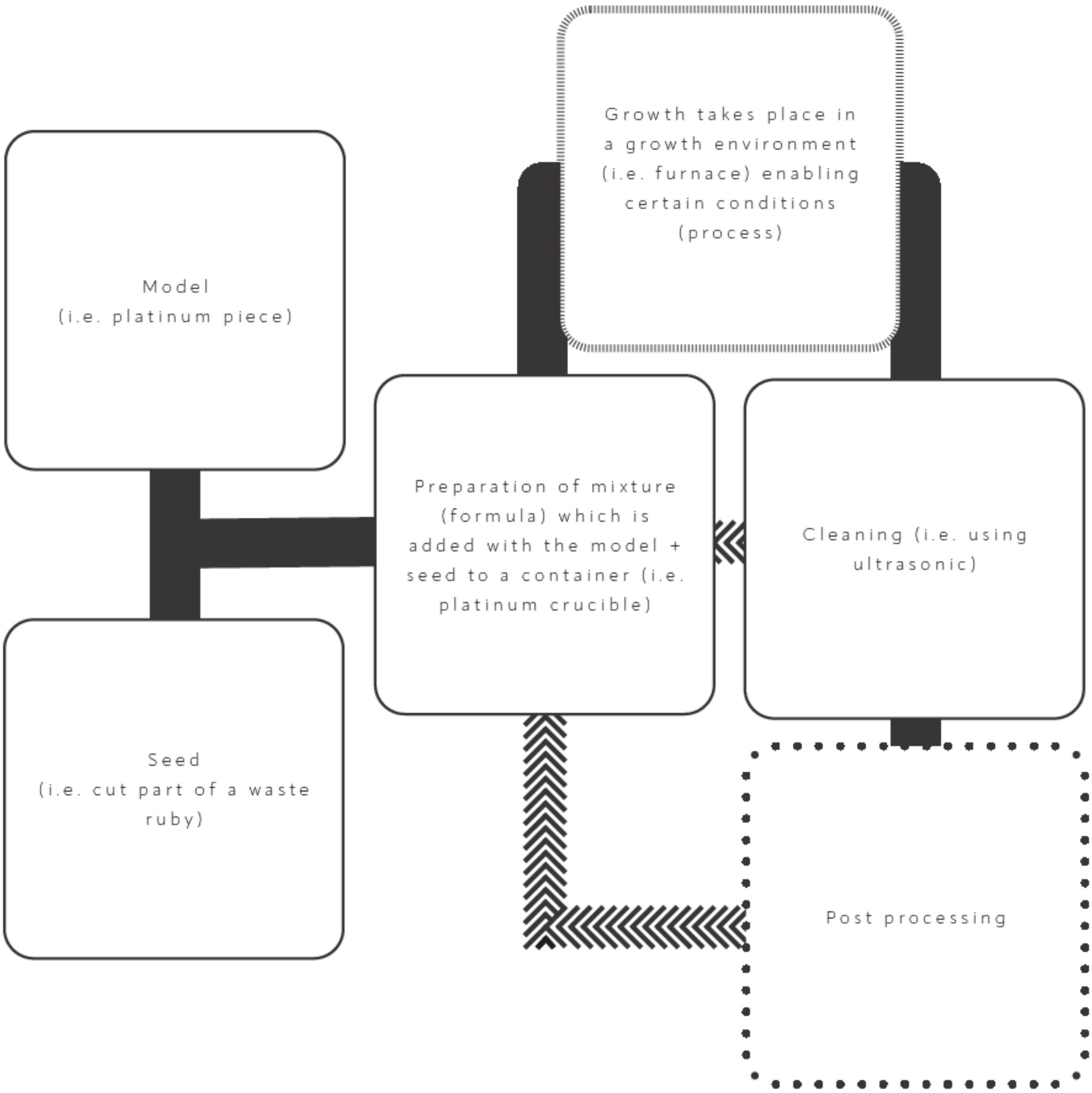
RUBY

Ruby (Al_2O_3:Cr), the jewellery field's term for chromium doped aluminium oxide (Al_2O_3), is the crystal that plays the leading role at the centre of the story illustrating the birth of crystal growth science. Building on the knowledge that heating ammonium alum enabled the production of pure aluminium oxide ascertained in 1817 by Gay-Lussac, and the understanding shared by Rose in 1840 that sapphire and ruby consisted mainly of aluminium oxide, the contest to crack the code of growing corundum began.

As documented in Chapter 2, regardless of the many who were experimenting with crystal growth in the 19th and early 20th centuries, it is A. Verneuil, Doctor of Science and Professor of Applied Chemistry at the Museum of Natural History in Paris, who is commonly considered the father of the technology. Moving away from the work of his mentor Edmond Frémy, who published *Synthèse du Ruby* summarising his achievements resulting in polycrystalline aggregates and small platy ruby crystals of rhombohedral form using ceramic crucibles, Verneuil created his own apparatus. The crystal growth technology he developed in 1902, generally referred to as flame-fusion growth, led to the first commercial production of lab-grown gemstones. His technique was so effective it is still in use today and led to the development of a plethora of other techniques based on growth from the melt, including those of Czochralski, Kyropoulos and Stockbarger.

Numerous methods have been applied to the growth of ruby since, including Czochralski, Hydrothermal, and vapor-phase, and even the technique experimented with by Fremy, flux growth, has now been perfected to result in single ruby crystals (Figure 5.6). Due to its mechanical, chemical and optical properties, today the faceted lab-grown ruby gemstones that can be bought around the world are but a small percentage of the diverse applications the material now enables, for which the bulk is used in industry for machinery, optics and electronics.

The material was deemed most interesting to explore because of its historical significance, resulting in a large amount of literature available documenting various formulas and growth processes. The chemicals needed to grow ruby (aluminium oxide and chromium) are also, when handled correctly, considered safer than those needed to grow other gemstones, making it the most attractive to explore in a Do It Yourself (DIY) manner in an alchemical laboratory/studio hybrid. Furthermore, its status as one of the most desirable gemstones was deemed interesting to leverage too.



5.7

Figure 5.7. Crystal growth process schematic.

5.4. Transmutation

"The orderliness of the atomic arrangement in a crystal is certainly its most important feature. But another feature, almost as important, is the fact that a crystal does not suddenly spring into being; it grows into being."
(Holden and Morrison, 1982, p.32)

Focusing here on the growth of single crystals, these techniques enable the perpetuation of a pattern or order of atoms either through vapour growth, melt growth, flux growth or solution growth (Arem, 1977). Since crystal growth is theoretically simple to do (Holden and Morrison, 1982), some of these processes lend themselves well to a DIY material practice (Boons, 2021a, 2022a; Karana and Camere, 2017; Rognoli et al., 2015). [redacted] To support growth and speed up the process, a seed was added to the experiment, as was done with experiments conducted with organic crystal growth (sugar, salt and alum), which differed from the approach the Bristol University team were taking. When fully cooled, the crucible and grown seed crystals were cleaned by submersion into water with a small addition of citric acid in a digital sonicator. In line with the process documented for sugar, salt and alum (Appendix 10), seeds were subjected to multiple growth cycles until the desired size was achieved. Figure 5.7 shows a schematic representation of the process, in which seed(s), and in some cases models, are added to a mixture (formula) in a container (platinum crucible), which is subjected to a growth environment (process). Then the outcomes are cleaned, and a decision is made to either subject the outcome to another growth cycle, leave it as is, or subject it to post-processing. The latter was not explored during the PhD project but has been identified as an area for further investigation.

5.8

5.9

5.10

Figure 5.8. Chipped faceted brilliant cut ruby seed, diameter = 3 mm (right), ruby grown from seed using Formula/Process 1 (left).

Figure 5.9. Chipped faceted brilliant cut ruby seed, diameter = 3 mm (right), ruby grown from seed using Formula/Process 2 (left)

Figure 5.10. Platinum crucible following growth of ruby pictured in Figure 5.8.

"The ambition of alchemy, as expressed by 12th and 13th century philosophers, was not bent on making gold. Gold was part of it, but most important was the ability to understand and imitate that invisible process, which occurred visibly in nature. To achieve that, one has to understand in detail how nature works, and hence alchemy was expressed as the art, whose aim is most precisely directed to the understanding of natural processes. No more, and no less."
(Haaning, 2006, p.30)

The above-mentioned mixture was first tested to grow a chipped 3 mm brilliant cut faceted ruby larger (Figure 5.10 and Figure 5.8). This was to test and ultimately demonstrate whether growth from faceted ruby material classed as waste in the gemstone industry was feasible for use in the process. This was the preferred option as it could provide additional avenues of use for this type of material, beyond cutting it into a smaller stones, or discarding it. [redacted]

Whilst high purity materials could likely result in even higher quality crystals following growth, the results achieved with waste materials were considered more than sufficient to warrant their further use. Further perfecting of the formula would remain the preferred option, over introducing highly specialist and pure seed crystals, which do not provide an opportunity for waste to be re-valued and re-used.

Organic Crystals (sugar/salt/alum)	Crystal Growing Design	In-organic Crystals (ruby)
	(1) Bespoke Inclusions	
→	Growing around	←
	(2) In-Situ Growth	
→	Hosting growth (single seed)	←
→	Hosting growth (multiple seeds)	←
	(3) Grow-ability	
→	Directing single crystal growth	
	(4) Polycrystaline configurations	
→	Directing polycrystaline growth	
	(5) Nucleation	
	Considering crystal agency	←

Table 5.1

Table 5.1. Taxonomy of the experiments created with Crystal Growth.

5.5. Solve et Coagula

"The artistic researcher works through theory-practice entanglements. This is to say, not by using practise as an illustration of theory or vice versa, but by exploring ways in which theory and practice are mutually implicated."
(Wesseling, 2022, p.169)

Since jewellery designers usually do not have a working knowledge of crystal growth, as previously documented, to gain a first-hand understanding of the process, experiments were conducted using salt, sugar and alum. A detailed review of the experiments conducted with non-gemstone crystals has been shared in two published papers: *Crystals as Co-creators: An investigation of growing crystals as a methodology for jewellery designers* (Boons, 2021a) and *Crystal Growing Design method: An investigation into the growing of crystals for jewellery designs* (Boons, 2022a) (Appendix 10). These papers provide a short overview of the method's overlap with bio-design/art, and reflect on the opportunities and challenges the growing of these non-gemstone crystals posed for the author. Furthermore, by providing an account of the hands-on experience of DIY growing crystals in the jewellery studio, and an insight into this material-driven process, it was demonstrated that the DIY growth of crystals is expected to be a valuable tinkering process to investigate design ideas involving the technique of gemstone quality crystal growth in the development of jewellery (Boons, 2022a).

When incorporating gemstone growth into the jewellery design process, the artist has to consider that the gemstone will grow into a shape that, in the processes applied, cannot be pre-determined, inviting an element of uncertainty into the process. The unpredictability of the growth, in direction and through the appearance of facets determined by the material's crystal structure, means that each time a seed is grown a different outcome will be materialised. This methodology, which shares commonalities with bio-design (Boons, 2021a, 2022a), requires a mindset-shift of the designer, who is unlikely to be able to ideate their designs with traditional methods, such as sketching or CAD modelling. Ideation using models exposed to organic crystal growth processes proved to be a suitable alternative, and ultimately informed the choice of experiments conducted with ruby growth. The opportunities identified comprised: (1) growing around metal structures to achieve bespoke inclusions, (2) growing in-situ in metal structures, (3) utilising the grow-ability of the process as a feature, and (4) the opportunity polycrystalline formations offer.

5.11

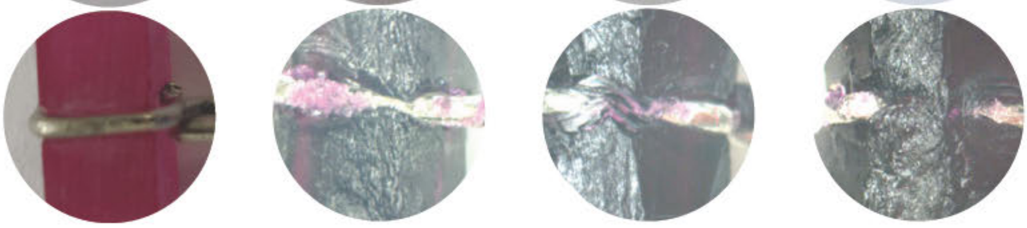
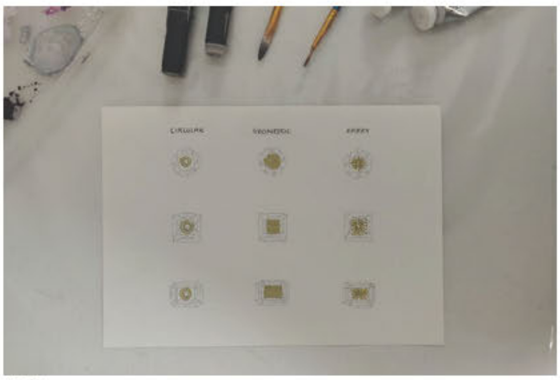
	Pre-growth	Growth 1	Growth 2	Growth 3
Top				
Side				
Detail				
Grams	1.5338	1.9766	2.1358	2.4338

Table 5.2



5.12

5.13

Figure 5.11. Sugar crystal grown on brass wire from 4 different views (front, right, left and top).

Table 5.2. Growth cycle record of ruby earrings.

Figure 5.12. Drawing of bespoke inclusions.

Figure 5.13. Ruby earrings grown from seeds, half encapsulating platinum wire.

Following hands-on engagement with the technique a further theme of interest developed that could not have been experienced or foreseen when experimenting with organic crystals. The nucleations that appear randomly on metal, following its exposure to the heat cycle as part of the crystal growth process, was therefore added as an additional area of exploration (5). The opportunities identified are listed in table Table 5.1 on page 200 and are discussed below.

BESPOKE INCLUSIONS

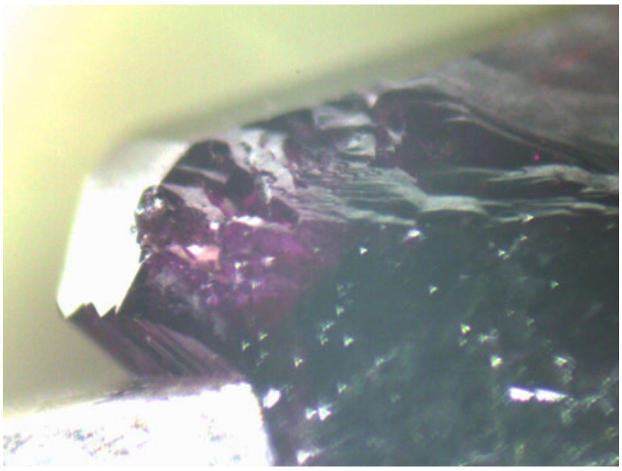
The fact that crystals can contain impurities by, for example, growing around obstacles, was discovered and identified as an opportunity whilst testing the growing of a single sugar crystal, suspended in its saturated solution through a brass wire (Figure 5.11). Since the crystal faces exposed continued to connect with sugar molecules in the saturated solution, the wire eventually became encapsulated by the crystal. This experiment was later also replicated using the growth of ruby, to create a pair of earrings (Figure 5.13 and Figure 5.38 on page 220), where the ruby crystal grew to such an extent that it started to encapsulate parts of the wire that was bent around the seeds (Table 5.2).

The idea was not as simple to translate from organic crystal growth (sugar) to inorganic crystal growth (ruby) since the growth rate of the latter was much slower than the growth rate of the former. Future plans would include repeating this experiment with Formula/Process 2, which is known to result in higher quality crystals. Furthermore, the control of the colour and translucency of the ruby crystal, by controlling the chromium percentage in the formula, will also be important to progress the idea. Further encapsulation, should it have been pursued with this piece through further growth cycles, would have resulted in the wire being encapsulated without it remaining visible. The opportunity to see the encapsulated metal segment could, however, be of interest from a creative perspective. Within gemmology, inclusions are generally considered 'faults', however, the design opportunity present with growing crystals incorporating designed inclusions, is promising (Figure 5.12). Furthermore, where the growth encapsulates the wire fully without this being visible in the crystal, due to its lack of translucency, the setting will become fully invisible, which could also hold opportunities for jewellery makers.

The decision to stop the growth of the pieces at the stage described above was both practical and aesthetic. Encapsulation of the wire had started to appear, and compelling growth patterns had emerged that would have likely become invisible should growth have been continued. Having proved the point that growth could set a stone in the earring wire, further growth would have been scientifically interesting yet functionally would not have contributed to the artefact, particularly as the weight of the stone would have increased, making the earrings less feasible to be worn. Small nucleations that formed on the studs of the earrings have not been removed, as they inspired further ideas, this is however a possibility, as small free-formed nucleations can be removed with tweezers or tongs. Whilst the experiments described aimed to celebrate the crystal formations that appeared, and post-cutting (faceting) was not of interest, this also remains a possibility, particularly for crystals grown as demonstrated here.

5.14

5.15



5.16

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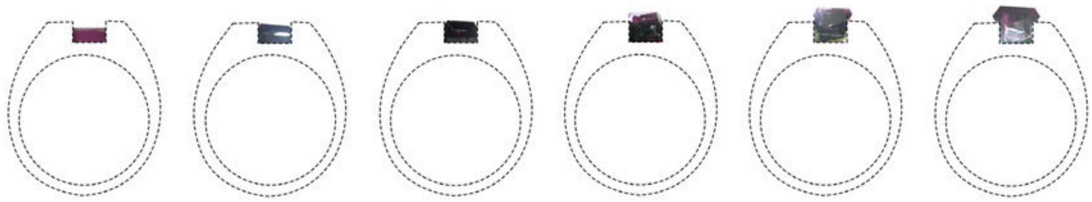


5.18

Figure 5.14. Alum crystal grown in-situ in silver ring. Ring with seed (left), grown ring from front, top and side (right).

Figure 5.15. Sugar crystal grown in-situ in silver ring.

Figure 5.16. Microscope image of *Ring #1*.

Figure 5.17. Platinum crucible containing *Ring #1* following growth.

Figure 5.18. Graphic representation of growth rate of *Ring #1*.

IN-SITU GROWTH

Generally, gemstones are incorporated in designs by setting. The art and craft of setting gemstones in jewellery has mostly revolved around the creation of a setting, or creating a suitable space in the metal where a stone is held into place in the design. Growing a stone in-situ in a piece gives an artist the opportunity to re-imagine how stones could be incorporated and fixed into their work. This proved to be possible and resulted in striking outcomes when tested with alum and sugar (Figure 5.14). Since the melting point of platinum is below the temperature needed to grow ruby crystals with the low temperature growth formulas and processes, it was considered feasible to test in-situ growth with ruby in a platinum ring. The first tests with ruby were planned in line with the learnings from those tests (Appendix 10). With the intention to grow a single crystal in a pre-determined open space, the shape of test pieces was kept simple to allow close monitoring of the crystal growth and enable the crystal to firmly grow itself into place (Figure 5.14 and Figure 5.15). The shape chosen proved to be simplest to encourage growth with organic crystals, so this shape was taken forward in the next part of the research project, when the gained knowledge was applied to the growth of ruby in a platinum ring (Figure 5.19 on page 206). The platinum ring, designed with Rino and 3D printed in castable resin, was cast in platinum using a Hatton Garden caster. Whilst the casting of printed models was financially most interesting and also reduced the manufacturing time, it was mainly chosen as a technique for its benefits in relation to the crystal growth process. To manufacture the ring without casting it from a 3D printed model would have required soldering. Platinum solders have lower melting temperatures, 1300 °C, 1400 °C, and 1500 °C (also referred to as easy, medium, and hard), and are usually composed of a mixture of metals that may not react well to the chemicals in the growth environment. Whilst this is an area of investigation that is recommended to be pursued post-PhD, ideally as part of a funded project, with limited funds available to purchase platinum test pieces, casting, resulting in pieces without solder seams, appeared the safest and most logical option.

The ruby seed, created from an offcut of ruby material (likely Verneuil grown), was positioned in the ring and subsequently exposed to the growth environment five times, using Formula/Process 2. The ring was positioned flat on its side in the crucible (Figure 5.17), which did not affect growth as the orientation of the crystal (which was not pre-determined) meant that growth was favoured upwards rather than sideways, as had happened with the growth of the alum crystal (Figure 5.14).

Evident in these experiments is the individual shapes each crystal displays, and the unpredictable direction the growth of the crystal has (Figure 5.16), since the crystal's orientation was not determined and considered in positioning the seeds. The unpredictability of the growth, in direction and through the appearance of facets determined by the material's crystal structure, means that every time a seed is grown a different outcome will be materialised. Sugar atoms grow in a monoclinic structure resulting in a hexagonal prism shape, alum atoms grow in a cubic structure resulting in octahedra with flattened corners, and salt grows in a cubic structure resulting in cube-like crystals. As a result of their trigonal crystal structure rubies grow in a hexagonal shape. The naturally occurring facets are beautiful and considered a feature of the pieces, which poses a stark counternarrative to the current appreciation of man-made gemstones as synthetic, celebrating the beauty of this natural phenomena.

5.19

Figure 5.19. *Ring #1*, ruby grown in-situ in platinum ring.

Figure 5.20. *Ring #2*, polycrystalline rubies grown in-situ in platinum ring.

5.20

5.21

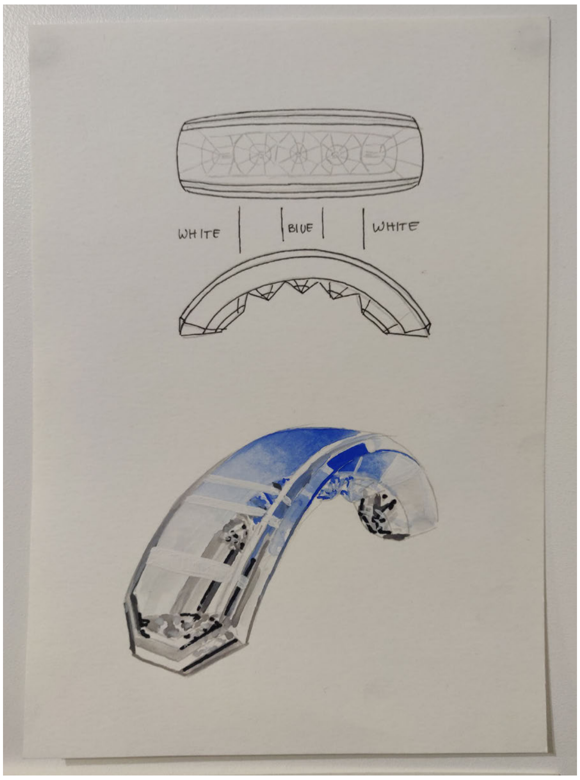
5.22 a.

5.23

5.22 b.

5.24

5.25



5.26

Figure 5.21. 3D printed ring model with multiple salt crystals grown in predetermined geometrical pattern.

Figure 5.22. Close up detail of *Ring #2, grown with Formula/Process 2*: (a.) after second growth cycle, (b.) after third growth cycle.

Figure 5.23. 3D printed ring model with multiple sugar crystals grown as a polycrystalline mass.

Figure 5.24. Testing grow-ability of sugar crystals using silicone mould in sugar/water solution.

Figure 5.25. Sugar crystals grown using a ring-shaped silicone mould.

Figure 5.26. Render and drawing of fantasy cut for a crystal grown in a curve.

In further experiments with sugar, salt and alum, 3D printed bio-resin base models were created to allow multiple seed crystals to be grown simultaneously, in order to incorporate a range of crystals in an organised or unorganised pattern and study the formation of polycrystalline crystals (Boons, 2022a, 2021a) (Figure 5.21, Figure 5.23 and Figure 5.28 on page 210). Since the results (Appendix 10) were considered aesthetically appealing and would lend themselves well to the re-use of small ruby offcuts and even the spontaneous nucleations that appear on the side of the crucible during growth, a platinum piece was created to conduct a similar experiment with the inorganic growth of ruby (Figure 5.20 on page 206 and Figure 5.22). Since platinum is an expensive material, limitations in budget for the research directed the shape and size of the piece that was ultimately produced. Whereas larger structures were deemed visually and technically more interesting, a simpler and less weighty design was ultimately chosen to be taken forward into the ruby growth experiment. Growth was conducted in a manner identical to the process applied for the single crystal experiment, with the main difference being the incorporation of multiple seed crystals instead of one, in predetermined spaces in the ring. The platinum ring was purposefully designed, in order to juxtapose the natural growth with the geometric appearance of the platinum host ring.

Following the first growth cycle, it became clear that, whilst the single crystal in *Ring #1* had grown itself stuck in the hollow spaces designed for this purpose, it is speculated that the process, whilst having some similarities with the solution growth process tested with organic crystals, may have behaved slightly differently (Whitehurst and Hall, 2023), causing the crystals to fall out of *Ring #2* during growth. Perhaps the lack of access of the solution to the bottom of the crystals in the structure additionally did not sufficiently enable growth there. Further research will have to determine how these challenges (both surviving a tumultuous growth environment and ensuring that growth solutions, expected to be viscous, can access crystals inside the structure) can be overcome.

GROWABILITY

The third hypothesis at the basis of experiments with sugar, salt and alum was the grow-ability of the crystals, which is comparable to the grow-ability (Karana and Camere, 2017) of materials generally associated with bio design/art. Since crystals keep growing until something gets in their way, stopping nourishment from reaching a blocked face of the crystal (Holden and Morrison, 1982), it seemed possible to shape the crystal by restricting growth in certain locations (Boons, 2022a, 2021a). Whilst this idea appeared to be simple from a theoretical point of view, in practice, when testing the concept with alum and sugar, it proved to be much more challenging to achieve. To date it has been possible to use this method to achieve single crystals that have been grown in a predetermined shape (Figure 5.24 and Figure 5.25), however, since growth required the use of moulds (in order to prevent the growth of the crystal in certain directions), and the cost of platinum is high, this could not be tested with ruby within the PhD project. Further experiments with bespoke platinum moulds could however test this theory with the inorganic crystal growth of ruby at low temperatures. This could lead to crystals formed in predetermined shapes, which would then enable innovative cuts to be explored that currently would not be financially viable and would result in a large amount of waste (Figure 5.26).

5.27

Figure 5.27. 3D printed ring model with multiple alum crystals forming on geometric pattern.

Figure 5.28. Polycrystalline alum structure grown in mould.

5.28

5.29 a.

5.29 b.

5.30

5.31

Figure 5.29. Earrings containing nucleations retrieved from platinum crucible wall following growth: (a.) hoop earrings, (b.) stud earrings.

Figure 5.30. Render of polycrystalline growth idea.

Figure 5.31. Detailed image of nucleations retrieved from platinum crucible wall following growth.

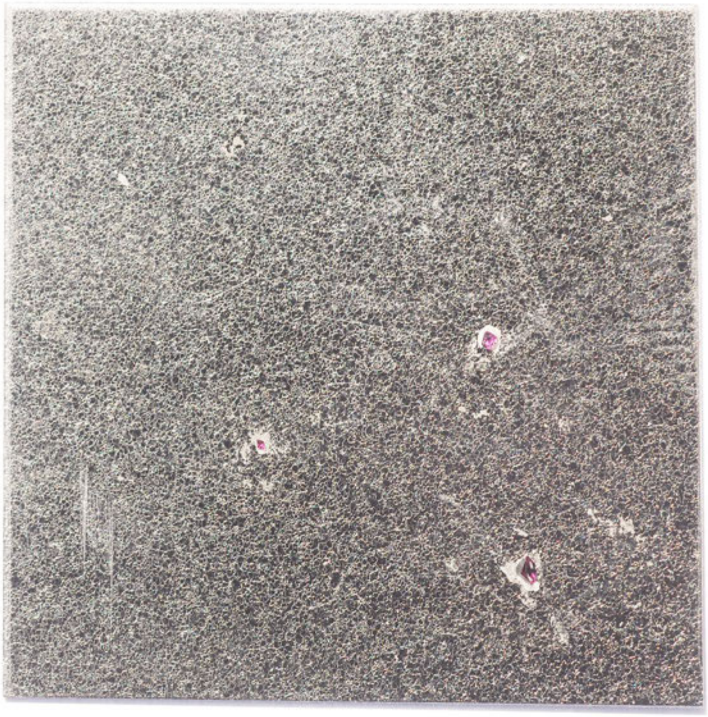
POLYCRYSTALLINE CONFIGURATIONS

> *"Usually, both in nature and in man's manufacturing processes, a great many crystals of the same material start growing at about the same time in many different places. They grow until something gets in their way, or until they get in one another's way, and then they stop. Since they start with no knowledge of one another, they all have different orientations, and when they meet they cannot join to form a single big crystal. The result is a polycrystalline mass."*
>
> *(Holden and Morrison, 1982, p.33)*

Unlike the practice outlined in growing ruby, using seeds produced from waste ruby material, when growing sugar, salt and alum, one needs to grow seeds. The technique to grow such organic seeds involves allowing a small amount of a supersaturated solution to deposit crystals on the bottom of the container in which the solution is contained. In the growth of organic crystals, as the water evaporates, more and more material is deposited on spontaneously forming nucleations at the bottom of the jar, and well-formed single crystal seeds can be harvested from the solution (Boons, 2022a, 2021a). A supersaturated solution (one containing more solid material than water) is unstable and wants to deposit its excess solid.

So, even when you are not intending to grow seeds, if one does not have full control over the saturation level of your solution (which is unlikely in DIY settings), seeds will likely be deposited on the bottom and edges of containers, and these are referred to as crystal debris. The crystal debris, formed of multiple seed crystals that continue growing until they no longer can, ultimately forms a polycrystalline mass. Whilst the growth of ruby with both formulas and processes did not result in polycrystalline masses, many seeds, grown from deposited solid on the bottom of the platinum crucible, were harvested following growth runs (Figure 5.31). This shimmering grit, not dissimilar to the grit used in the 'Bling It' project by its participants, can be used as seeds, or can be used as a material in its own right.

Opportunities for investigation include incorporating it into pieces of jewellery (Figure 5.29), embedding it in enamel, and using it with electroforming techniques. While it has not been possible to pursue all these ideas within the PhD, this is an additional avenue for exploration in the future (Figure 5.30). Furthermore, having grown many polycrystalline masses with sugar, salt and alum, some so beautiful they were preserved rather than re-melted for another growth run, the idea of growing a polycrystalline mass with ruby is another avenue of exploration scheduled post-PhD.



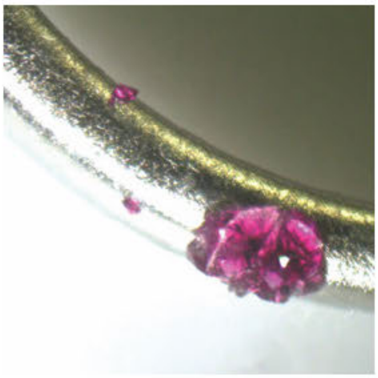
5.32

Figure 5.32. *Nucleation #2*, rubies grown through spontaneous nucleation on platinum sheet.

Figure 5.33. *Nucleation #1*, rubies grown though spontaneous nucleation on platinum sheet.

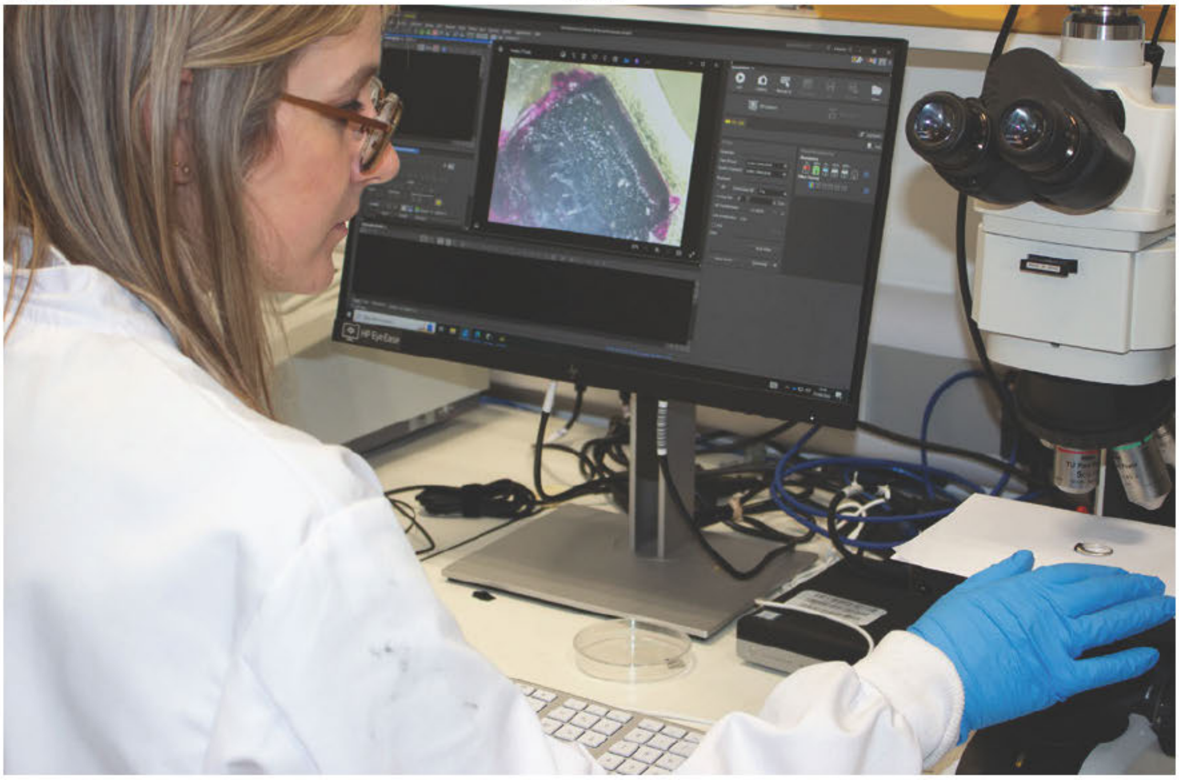
5.33

5.34 a.



5.34 b.

5.34 c.



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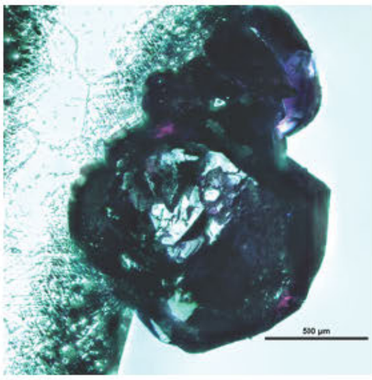
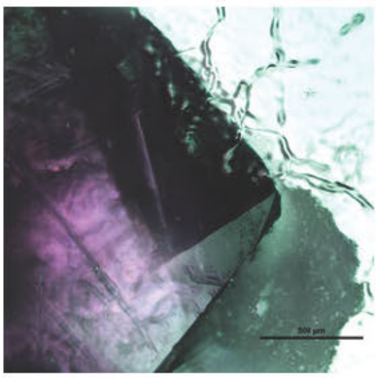


5.36 a.



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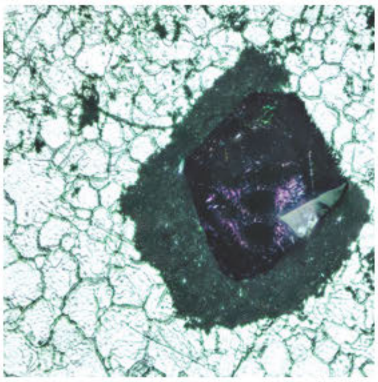


5.36 c.

Figure 5.34. Microscope images of spontaneous nucleations growing on platinum pieces: (a.) on *Ring #1*, (b.) on *Outgrown*, (c.) on *Ring #2*.

Figure 5.35. Author reviewing piece under microscope. Photography by Kate Rutsch for the University of the West of England. Image used with kind permission of the University of the West of England.

Figure 5.36. Microscope images of spontaneous nucleations growing on platinum pieces: (a.) on *Outgrown*, (b.) on *Nucleation #1* 20x magnification, (c.) on *Nucleation #1* 5x magnification.

NUCLEATIONS

An interesting development that did not present itself when growing organic crystals at low temperatures on metal pieces was the, what appeared to be spontaneous, growth of small ruby crystals, self-nucleating at various locations on the platinum pieces during the growth cycle. Upon closer inspection of the metal, it appeared that the platinum, exposed for a relatively long period of time to a high temperature (1100 °C), had undergone its own transformation. Large metal crystals, previously not visible, were clearly identifiable following growth Where these metal crystals met, also referred to as grain boundaries, appeared to be ideal locations for the spontaneous nucleation of ruby crystals (Figure 5.36).

These little ruby crystals randomly appearing on the metal structures (Figure 5.34) resulted in a reconsideration of the co-creative nature of the technique once more. Where significant amounts of control had already been given up, the position of seed crystals did not quite determine what the crystal would look like or in which direction it would grow, it did however provide control over where on the metal piece growth should take place.

Spontaneous nucleation, crystals growing in a pattern aligned with the host metal's crystal structure, happened without human intent when using Formula/Process 2. Whilst spontaneous nucleation is expected to be able to be encouraged, by for example applying engravings, or roughening up the metal texture prior to exposure (exemplified by the spontaneous nucleations that appeared on the bottom of the multiple seed experiment ring (Figure 5.34 c.) showing a rougher texture), its random appearance was considered a beautiful and poetic reminder of the agency of the materials.

As humans we gain the illusion we can control natural processes, but as a Neo-alchemist it is important to appreciate and celebrate that which is not controlled too. For these reasons an experiment was set up in which unaltered platinum metal was used in the process without seed crystals present (Figure 5.32 and Figure 5.33 on page 214). The metal, responding as seen previously, invited spontaneous nucleations, and the resulting piece is a shimmering reminder of our place in the universe – one of wonder.

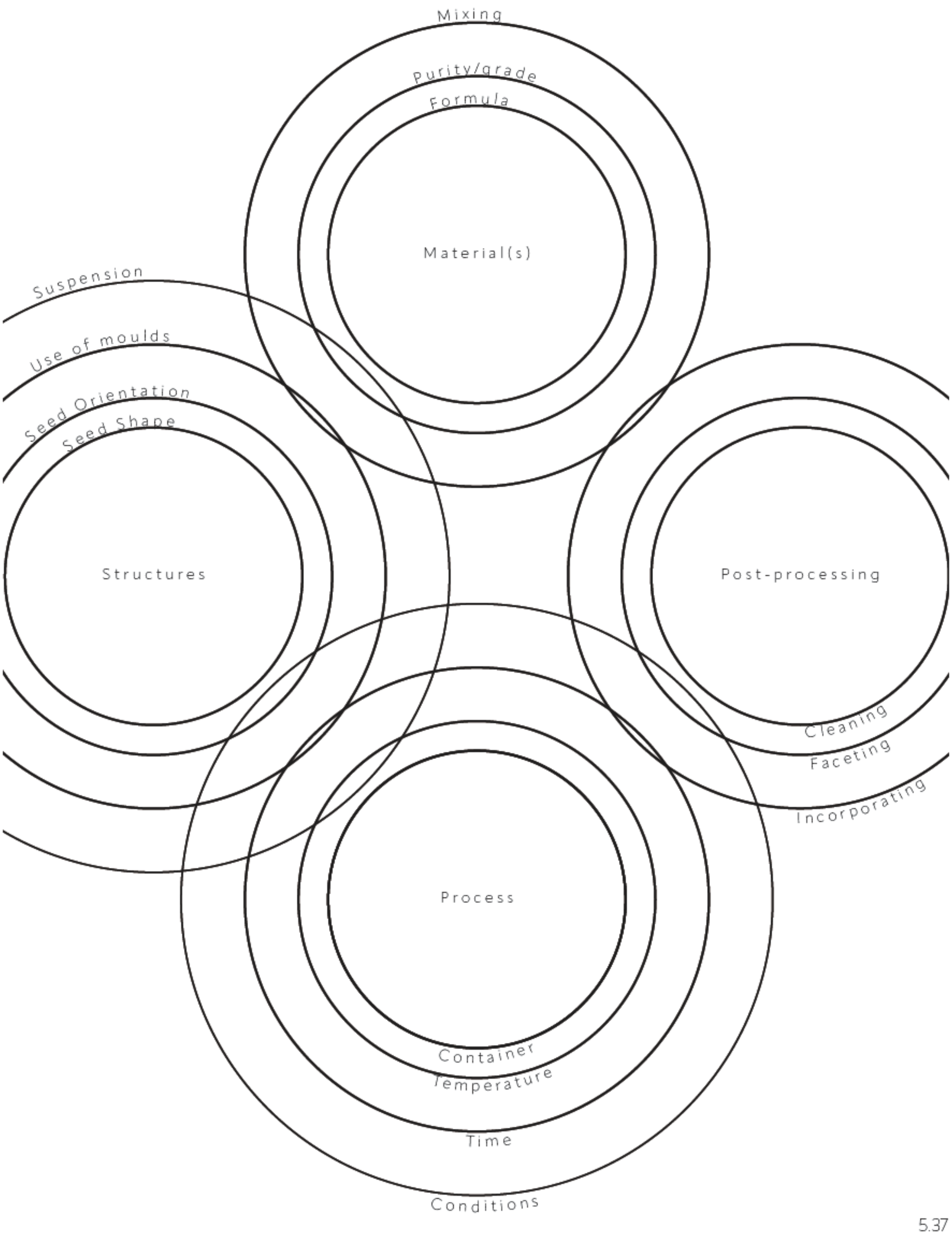


Figure 5.37. Diffraction of crystal growth method.

5.6. Ouroboros

"The joint properties of two objects exist only in relation to the third. To say that two objects are correlated means to articulate something with regard to a third object: the correlation manifests itself when the two correlated objects both interact with this third object, which can check."
(Rovelli, 2022, p.87)

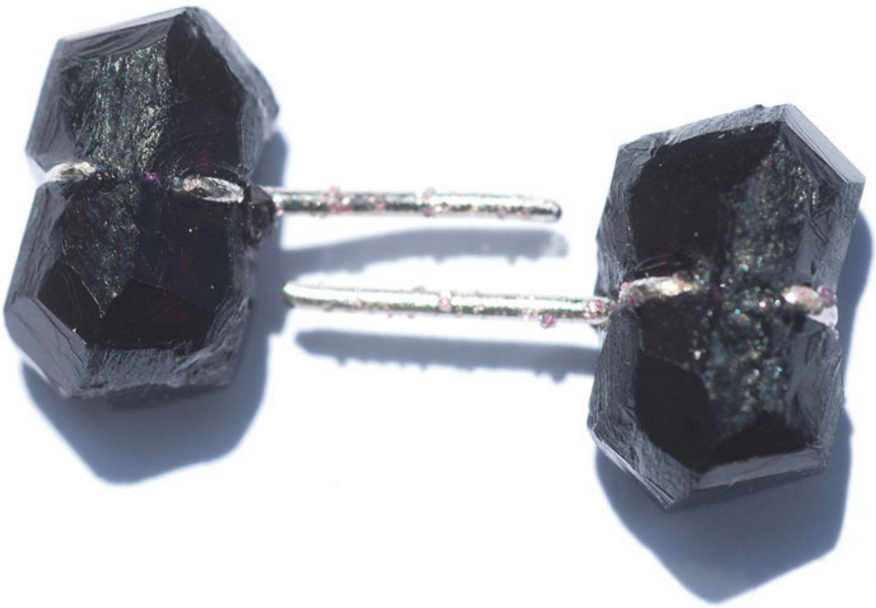
As a jewellery designer/maker, techniques and processes are generally learnt by experiencing and practising (Untracht, 1982). The more traditional techniques (forming, finishing, etc) require constant hand-eye coordination. This process, in which models are investigated by touch and both visual and haptic information, inform the further development of the piece, and give the jeweller more or less full control. When reflecting upon the general use of gemstones in jewellery, it is evident that this is no different. The stone is often purchased from a dealer and it is generally a known element prior to the production of the piece. In growing crystals, the shape of the crystals is significantly less predictable though, and hands-on tactile feedback from the stone as well as measuring it can only be done once the stone has been removed, washed and dried. Similarly to Growing Design (Karana et al., 2018; Karana and Camere, 2017; Rognoli et al., 2015), the growing of crystals is influenced by a number of factors (Figure 5.37), which ultimately will affect the outcome.

Controlling these factors can only be done to a certain extent, inviting an element of chance into a practice that traditionally is quite controlled. The opportunity to co-create with nature (Karana and Camere, 2017) could, however, lead to unique outcomes. The lack of control over the direction of growth, as well as the delay in achieving results, separating the production of the pieces and final (tactile) evaluation process (Karana and Camere, 2017), all posed challenges to the usual making practice. A significant period of time dedicated to tinkering (Karana et al., 2015, 2018; Barati, Karana and Hekkert, 2015) with the material to consider the process' impact on quality and its constraints, led to a greater understanding and acceptance of the uncertainty. All designers who would in future wish to implement the growing of crystals in their practice would be recommended to dedicate time to explorative and evaluative tinkering with organic crystals prior to starting work with inorganic crystals.

The growing of crystals as a method for jewellery holds great potential, but also poses a number of challenges. With some control of conditions, designers could influence the process significantly which could lead to opportunities for the creation of innovative crystals that cannot be found in nature. To gain additional control over the growing conditions, additional equipment and resources would have to be brought into the studio environment, which could be costly. The alternative, growing at a location that resembles a lab, would further distance the growing process from the making process, unless such a lab was able to accommodate various trades, resembling more an alchemical workshop than a scientific lab. Furthermore, the grow-ability of the material, influenced by the use of models/moulds, the characteristics and attachment of the seed and the suspension method, also give designers opportunities to re-think the way crystals can be incorporated into designs and how the process could be optimised for sustainability. The integration of the method into a hybrid studio/lab environment allowed for model designing and making to take place with growth simultaneously. When certain problems were observed, model redesign and development enabled the set-up of additional experiments faster, this was particularly evident when growing sugar, salt and alum. Distancing these processes from the studio environment would disadvantage this flow. For alternatives to be considered, such as a collaborative approach where a jeweller works with a company providing the growth of crystals as a service, or where a jeweller uses an alternative location for the growth of crystals, mitigations in order to increase the seamless interaction between studio practice and crystal growth processes would have to be considered.

Even though the growing of crystals can be a lengthy process for the jewellery artist and maker, who generally does not need to spend this time when purchasing a stone from a dealer, the process could be significantly more sustainable when compared to the supply chain of most stones extracted from the earth. The carbon footprint and impact of growth cycles, once perfected, could be calculated and analysed in detail and it is expected that it would be significantly more sustainable to grow stones locally using waste materials as seeds. Ultimately the growing of crystals offers a range of advantages and challenges similar to those of Growing Design (Karana and Camere, 2017) and, in a future where sustainability and unique designs are highly valued characteristics, the application of the methodology of growing crystals for jewellery designers warrants continued research.

Figure 5.38. Ruby earrings grown from seeds, half encapsulating platinum wire.



5.38

5.39 a.

Figure 5.39. *Outgrown*, ruby grown in platinum ring: (a.) side view, (b.) alternate side view. on page 225

5.7. Macrocosm

"Quantum field theory allows for something radically new in the history of Western physics: the transience of matter's existence. No longer suspended in eternity, matter is born, lives, and dies."
(Barad, 2012, p.209)

Even though crystals were historically considered to have magical powers, and even today there is a belief in the quintessence of crystals, they are in most scientific contexts conversely not considered to be living materials. Outside the jewellery industry, the democratisation of science has led to an increasing number of designers becoming interested in Do-It-Yourself (DIY) approaches to growing materials (Karana and Camere, 2017). Bio design/art applies biotechnological methods in order to manufacture artefacts with living organisms (Hamnele, 2005). Even though the materials used in bio design/art are not crystals, the processes used to grow crystals have clear commonalities with those related to the growth of living materials in bio design/art.

Also referred to as The New Artisans (Collet, 2013), these makers consider nature as co-creator and utilise natural growth for fabrication (Karana and Camere, 2017), taking advantage of the self-controlled production process (Rognoli et al., 2015) and the diverse forms of expressions that are achievable (Antonelli, 2012). Scholars in the field (Collet, 2021; Kac, 2020; Karana and Camere, 2017; Van Dijk, 2016; Rognoli et al., 2015; Myers, 2012) have commented on and documented the opportunities the methodology of growing materials holds for designers, ranging from achieving novel aesthetics, to their grow-ability, and their sustainability credentials.

The artist Kac coined the term 'bio art' in 1997 and has created and described the processes deployed as well as their aesthetic and social ramifications (Kac, 2020). Venturing beyond art, with the number of product designers involved with growing materials expanding, the emerging practice of DIY growing is also evolving (Karana and Camere, 2017; Van Dijk, 2016; Rognoli et al., 2015). DIY biology is described by Van Dijk (2016) as a global movement that aims to spread and popularise the use of biotechnology beyond academic and industrial contexts and those operating within them.

This paradigm shift promises to open up new possibilities for bio fabricating future intelligent materials as well as for engaging with new sustainable processes as described by Collet (2021), who examines the approaches to designing with living systems and proposes a framework for design to engage with a prospective future bio-materiality.

In their article *Growing Materials for Product Design*, authors and experts in bio design Karana and Camere (2017) reflect on the distinct characteristics and advantages of Growing Design. They suggest that designers should employ living organisms to achieve specific design purposes and materials for their use in products. Their outcomes bring higher sustainability, not only because what they are made of is often biodegradable, but also since the way they are produced is more efficient than using materials that have often taken ages to form. Additionally, the grow-ability of the material provides new opportunities for designs, for example through the growing of the material directly in a pre-determined shape. The article also highlights the importance and opportunities linked to time and scale as a characteristic of Growing Design. Often requiring weeks instead of days, and working on a microscopic level, designers have to adapt to working methods generally applied by scientists which has the benefit of enabling them to increase control over the qualities of the material and the fabrication process. Considering the symbiotic relationship between the designer and nature as co-creators they assert that: "*Growing Designers forge the conditions for the invention of new matter, which would not exist otherwise*" (Karana and Camere 2017). Designers set up processes in which nature as co-creator, with some degree of unpredictability, completes some key elements of the process.

> *"When the artist has to learn how nature works, and from this knowledge be able to produce the Philosophers' Stone, he is occupied with the study of stones, minerals, and plants and the very phenomenology of nature as well - his senses are open to what he sees and touches. But at the same time his mind - and that might not only be his conscious mind - is at work too. This means that some kind of introspection accompanies the work of alchemy, and it seems that at least some of the earlier alchemists were perfectly aware that also man himself - or the spontaneous workings of the mind of man - was a part of nature and therefore a source of knowledge of nature."*
> *(Haaning, 2006, p.32)*

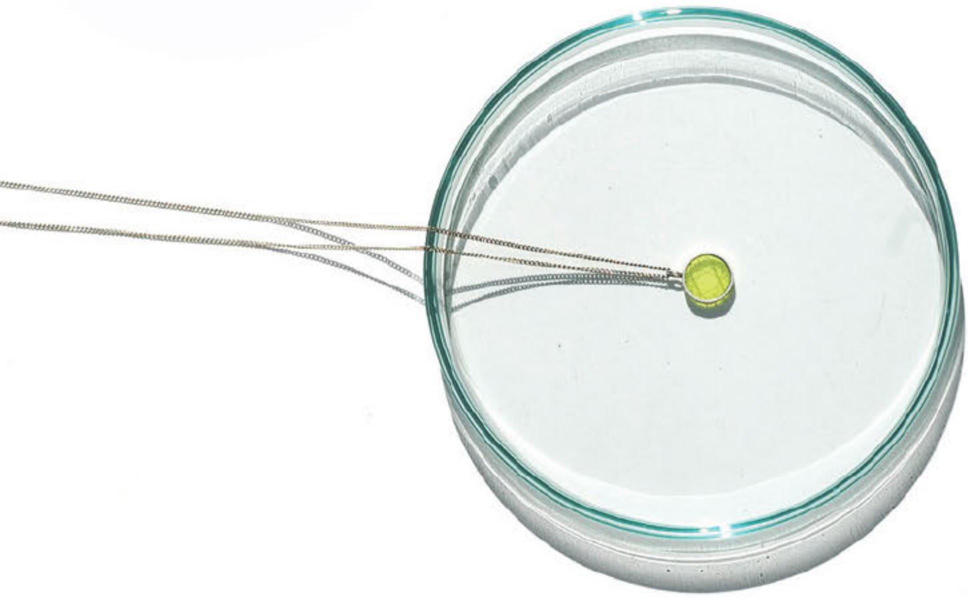
Another key author on the subject is Collet, who established a framework for designing with the living which has informed the Design and Living Systems Lab at Central Saint Martins at the University of the Arts London. This framework aims to portray a hierarchy: nature as model, where designers explore biomimicry principles; nature as co-worker, where designers combine biomimicry approaches with husbandry techniques resulting in a designer cultivator; and nature as a 'hackable' system, where designers use the advances of synthetic biology to create bespoke genetic engineered simple living organisms resulting in a designer biologist (Collet, 2020). Anchoring her framework within the changing cultural perception of nature, she highlights a divergence of position: nature as model acknowledges the supremacy of natural models; nature as co-worker endorses a partnership with nature; nature as a 'hackable' system aligns with values of dominance over nature, which is inherent to contemporary thinking, positioning nature as an exploitable commodity.

The growth of crystals using DIY methods aligns comfortably with nature as co-worker, however, those growing bespoke crystals in the lab, altering their chemical composition (see Chapter 4), could be situated under nature as a 'hackable' system. Growing rubies at low temperature, using comparably safe chemicals and equipment known to most jewellery makers enables the introduction of crystal growth technologies into the jewellery production process. Integrating the growth of gemstones into the designing and making of jewellery is a highly unique and very different approach to the common methods employed for the production of gemstone jewellery pieces, opening up opportunities for innovation, whilst challenging the standard processes within which each discipline operates.

The piece *outgrown* (Figure 5.39) how the stone has outgrown traditional setting practices, by literally outgrowing its setting. Furthermore, incorporating the technique into the studio environment, enabling access to the technology for jewellery artists turned Neo-alchemists, has enabled the identification of a range of opportunities for innovation. Continuing the diffractive exploration of the technique, in which various influencing factors are adapted, such as introducing moulds, adjusting the crucible and experimenting with other high melting metals is expected to lead to applications with interest to the jewellery field, and possibly beyond, as crystal growth in-situ in metal structures, which had not been attempted before, could have applications in the wider industry.

5.39 b.

6.1 a.



6.1 b.

6.1 c.

Figure 6.1. Petri dish with: (a.) diamond grit. (b.) Petri dish with Pooling Light necklace, BRG Type 2, silver. (c.) Petri dish with grit earrings, ruby seeds, silver, glass.

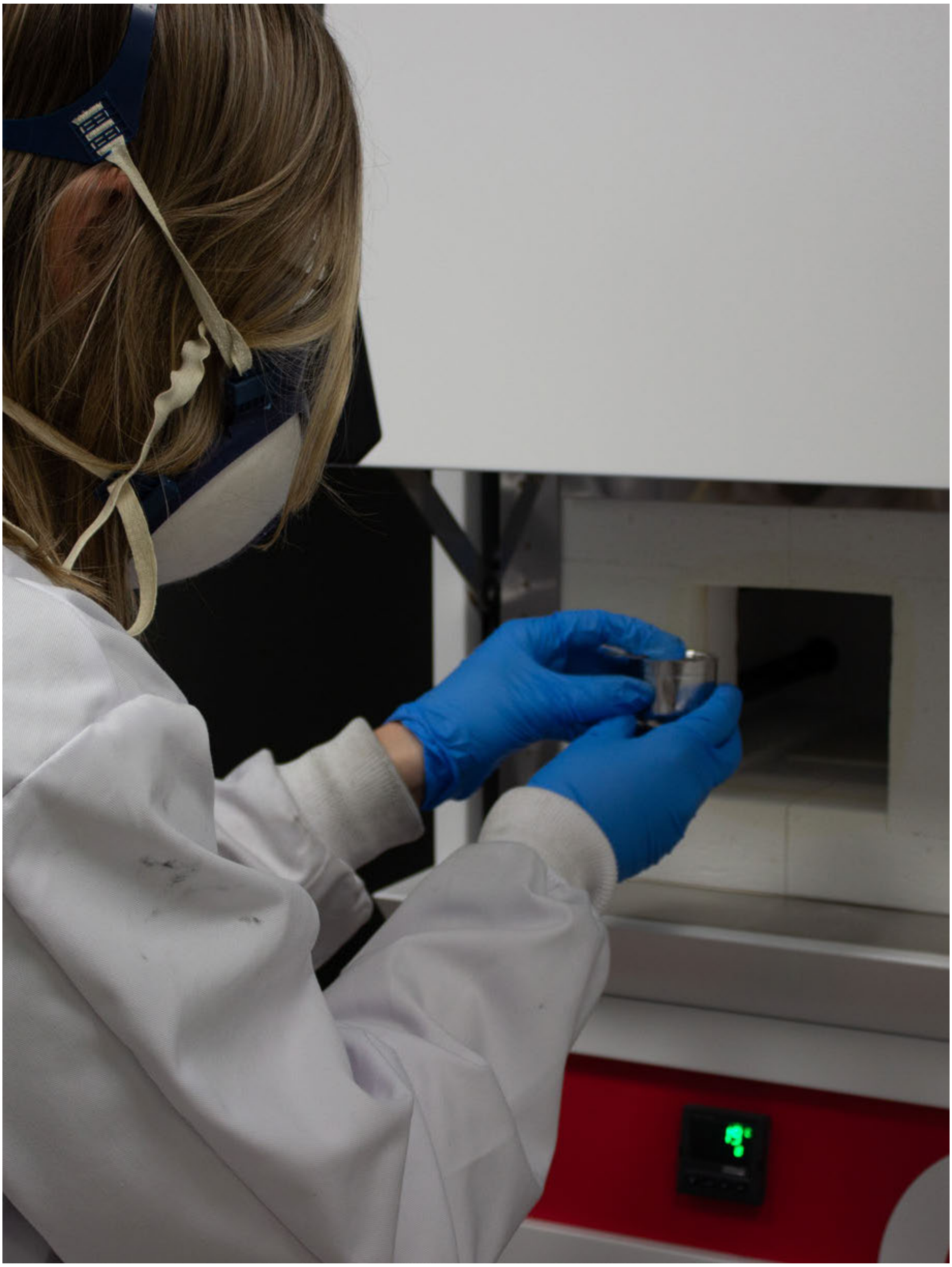
Chapter 6. Conclusion

"I believe that one of the greatest mistakes made by human beings is to want certainties when trying to understand something. The search for knowledge is not nourished by certainty: it is nourished by a radical absence of certainty."
(Rovelli, 2022, p.130)

Accompanying the objects created as part of the research project (Figure 6.1), this PhD thesis has narrated the answer to the research questions at the heart of the practice-based enquiry. By finding and using lab-grown waste gemstone materials (Chapter 3: Case Study 1), collaborating with scientists based in industry and academia on the development and usage of novel crystal materials (Chapter 4: Case Study 2) and incorporating crystal growth into a Neo-alchemical jeweller's practice (Chapter 5: Case Study 3), the creative opportunities the incorporation of man-made crystal materials and/or related crystal growth processes provide artists have been presented (Research Question 1, Objective 3).

These three case studies evaluated the feasibility and practicality of incorporating the researched man-made crystals and their design process and overarching methodology into a contemporary jewellery practice (Objective 4). Furthermore, the diverse approaches taken towards engaging with the material, ranging from no involvement and limited knowledge of their formation and use (urban mined waste materials), to collaborating with scientists to achieve innovations and to grow crystals using a methodology closely related to bio-design/art, were investigated to provide insights into the most multiplicitous approaches possible.

A historical and contemporary contextual review was used to support a hypothesis as to why, despite the technology and resulting materials having been around since the late 19th century, innovations with man-made crystal materials within a jewellery context remain sparse (Research Question 2). This contextual review, investigating the culture and context surrounding man-made crystals, explored the differences between man-made crystals and their mined counterparts used in the production of jewellery, and visualised findings through Critical Design (Objective 1).



6.2

Figure 6.2. Author adding crucible to furnace. Photography by Kate Rutsch for the University of the West of England. Image used with kind permission of the University of the West of England.

The alchemical exploration of lab-grown crystals and related technologies was utilised to underscore innovations whilst simultaneously challenging context, terminology, and underlying assumptions. The determination of the implications, possibilities, and limits of utilising man-made crystals in the development of jewellery designs was situated within a context where their usage remains highly debated. The proposition of the term 'Neo-gemstones' as an alternative terminology for labelling novel man-made crystal materials was a response to the identified need for the re-framing and re-naming of enhanced and designed crystal materials when used in a contemporary jewellery context (Objective 2). Below a diffraction of the contribution to knowledge presented in this thesis and the overarching research project is narrated documented in Table 6.1.

	Contribution to knowledge	Chapter
1	Demonstration of the application of a Practice-led research framework. Embedding Art, Dialectic, Conceptual and Contextual practices.	1
2	Demonstration of a Neo-alchemist practice, applying alchemical processes in a contemporary context, using techniques such as diffraction to investigate and analyse outcomes.	1
3	Contextual review of lab-grown crystals and the reasons why innovations have remained limited in a jewellery context (Research Question 2)	2
4	Proposal of new term 'Neo-gemstone(s)' for the description of novel man-made crystal material	2
5	Demonstration of the innovation potential of lab-grown gemstones when using waste materials (Research Question 1).	3
6	Demonstration and insight into the practice of Urban Mining and how it can be applied by creative practitioners.	3
7	Demonstration of the innovation potential of lab-grown gemstones when collaborating with crystal growth experts (Research Question 1).	4
8	Exemplar of art-science collaborations with industry and academia on the subject of crystal growth, documenting challenges and opportunities.	4
9	Demonstration of the innovation potential of lab-grown gemstones when incorporating DIY crystal growth into the jewellery production process (Research Question 1).	5
10	Development of crystal growing design method, including tinkering possibilities with organic crystals, and the growing of ruby crystals at low temperatures to achieve novel outcomes (such as growing in-situ in metal structures).	5

Table 6.1

Table 6.1. Overview of contributions to knowledge.

6.1. Contribution to Knowledge

INNOVATION POTENTIAL (RESEARCH QUESTION 1)

> *"In a crystal we have clear evidence of the existence of a formative life principle, and though we cannot understand the life of a crystal, it is nonetheless a living being."*
> *(Tesla, 1900, p.27)*

Whether or not one believes in the quintessence of crystals, the innovation opportunities present with laboratory-grown crystals are magnetic to those seeking to create unique artistic work. As documented in Chapter 5, crystal growth, when applied in a hybrid studio/laboratory setting, and experimented with playfully, can result in outcomes that challenge traditional setting practices by growing in-situ in metal structures and the current appreciation of these materials as synthetic. On display are natural facets that illustrate the intricacies of the building blocks and underlying lattice structure they follow. No crystal is ever the same, this is particularly true for technologies where less control is exercised over the process, such as the processes employed for the creation of the work document in Chapter 5. Spontaneous nucleation reminds us of the randomness in contrast to the order of the universe, a side effect that can be applied to create unexpected and countlessly unique outcomes. Aside from engaging and providing jewellery artists as Neo-alchemists with an opportunity to play with these techniques in order to achieve aesthetic applications of the technology, the usage of waste ruby material in a locally controlled low temperature environment could lead to jewellers providing a new, more sustainable service.

Outside the jewellery field crystal growing technologies have resulted in countless innovations in technology, medicine, electronics, and even nuclear-physics experiments now use grown gems (Scheel, 2003). Man-made crystals are nearly everywhere, and expertise on the subject can therefore be found in numerous research centres and in fewer European companies. Productive art-science collaborations, as documented in Chapter 4, require a significant investment of time and funds, and the differences in language and approach can be challenges to overcome. Whilst the scientists in academia may not currently have funding to enable contributive works, the newly-appointed PhD student at Bristol University investigating the colours achievable with low-temperature corundum growth is a sign that this could change, and her contributions will undoubtedly lead to innovations that will benefit enamelling and glazing artists and companies.

Developing novel materials takes time, according to industrial partner Rytz, around 20 years. The speed at which scientific progress is rigorously pursued does not always align with creative practitioner expectations. Regardless, as the fruitful collaboration and large number of phosphorescent prototypes and artefacts exemplify, when artists and scientists engage in discussions around material properties, functionality and aesthetical qualities, material, product and artistic innovations can be developed.

With all the benefits and opportunities available when growing crystals in innovative ways, there is also a large amount of material already present, often sitting idle in industrial companies and classed as waste. Urban mining these materials and incorporating them back into a jewellery creation process can encourage a reconsideration of waste, the agency of materials and lead to unique creative works that both have less impact on the planet and can engage viewers in a re-consideration of our material values and throwaway culture. A critique jewellery objects that align with Critical Design can perform. This is exemplified in the text of Chapter 3 and through the objects created with CVD-grown diamond waste. A methodology applicable to other creative disciplines, urban mining holds great potential for artists, when challenges of communication, technical knowledge and access are overcome.

6.3

Figure 6.3. Sugar crystal grown in 3D printed bio-resin model.

DIVERSE OPINIONS AND VESTED INTERESTS (RESEARCH QUESTION 2)

"For present-day artists, to position themselves as researcher rather than as producer of marketable goods offers an alternative to the dominance of economic liberalism in the art field and to the capitalist exploitation that is tied to the production of goods. The artist-as-researcher problematizes, contextualises, and re-enacts social, political, and environmental issues."
(Wesseling, 2022, p.169)

When starting this research project, it became evident that very few texts in the vast amount of literature dedicated to documenting techniques, reporting research and exploring applications in relation to crystal growth, focused on the innovation opportunities these materials and technologies could achieve in a jewellery context. Whilst there are research centres, conferences and journals on the subject, where subject specialists are working or reporting on crystal growth in a myriad of manners and for a range of applications, due to its scientific nature, this literature remains largely inaccessible to most jewellery designers. This thesis has made a first attempt at filling this gap, which is considered to be one of the reasons why innovations with crystals in a jewellery context remain sparse. After all, why would a scientist know what a jewellery artist would be interested in?

Another reason identified is the jewellery industry's negative response in the past to innovations as they entered the market. With the investment needed to conduct most crystal growth experiments, and challenging fierce obstacles from the jewellery industry, scientists should not be blamed for directing their attention elsewhere. Whilst current sentiments around sustainability are driving larger corporations to consider lab-grown gemstones as an alternative, the battle of wills and words continues to play out in the popular press (Boons, 2021b, 2022b, Appendix 10).

In contrast to the gemmological literature, which was established to support those interested in identifying and differentiating between lab-grown and mined gems, this thesis challenges the negative and often confusing discussion of these materials in such contexts and offers a new term for enhanced and designed crystal materials when used in a contemporary jewellery context. The term 'Neo-gemstone(s)' is suggested as a suitable alternative to the current usage of synthetic, artificial and fake. Chapter 2 reviewed the historical and contemporary context, highlighting that sentiments towards lab-grown materials remain diverse and are fuelled by extensive marketing campaigns. The chapter concluded that context is everything when it comes to categorising and valuing objects and materials. When context is everything, it is more important than ever that value systems and the social constructs holding them in place are questioned, not only by those with a vested interest commercially, but also by those appropriating the materials as designers and those buying them as consumers. This intention was attempted by producing Critical Design in response to the contextual review.

NEO-ALCHEMIST (METHODOLOGICAL CONSIDERATIONS)

With the rise of paradigmatic figures such as the Cyborg, emergence and self-organisation, the modern ontological gap between nature and what art and technology make out of her is seriously challenged, a challenge perhaps giving alchemy a chance for rehabilitation or at least an important place in the genealogy of what is happening in our hyper-complex culture.
(Wamberg, 2006, p.17)

The deliberate integration of an alchemical approach into the research and this thesis has emphasised that the rich methodological principles of alchemy remain relevant to interdisciplinary practice today. Alchemists traditionally sought knowledge through a dual approach: studying written texts and engaging in hands-on experiments. This dual approach not only facilitated a comprehensive understanding of material transformations but also fostered innovative practices in creating new knowledge.

By adopting this alchemical methodology in a contemporary context, this thesis bridges the gap between theoretical research and practical experimentation, aligning with contemporary theories such as Karen Barad's Agential Realism, which emphasises the intertwined nature of human and non-human, material and discursive elements in scientific practices. Agential Realism challenges traditional binary thinking and promotes a holistic understanding of knowledge creation, which resonates with alchemical principles. The concept of diffraction, as proposed by Barad, complements the cyclical and transformative processes inherent in alchemical experimenting, writing and thinking.

By adopting diffraction over reflection, the thesis encourages an iterative and dynamic engagement with knowledge. This approach not only enriches the research methodology but also invites readers to engage with the text in a non-linear, interactive manner, thus promoting a more playful and realistic engagement with, and understanding of, the material. The adoption of alchemical practices in the thesis underscores the importance of interdisciplinary collaboration and hands-on experimentation in the pursuit of knowledge, offering a framework for others interested in conducting research in a similar Neo-alchemical manner.

6.2. Limitations

"Science, we say, is only an extension of the way in which we see: we seek out discrepancies between what we expect and what we gather from the world. We have visions of the world and, if they don't work, we change them. The whole of human knowledge is constructed in this way."
(Rovelli, 2022, p.163)

Whilst this thesis has tried to provide an answer to the questions underpinning the research, it has not been possible to address all the additional questions that arose along the way. Sustainability is an area of this PhD project and the methods employed within it that could not fully be documented. Due to a limited background in ecological studies and the complexities that underpin sustainable practice, it was not possible, nor has been the intention, to make robust claims about the sustainability of the discussed technologies, materials and processes discussed. There is, however, a strong belief that localised manufacturing and the use of waste materials could have significant sustainability benefits. For this to be proven unequivocally, further research will have to be conducted, likely by numerous partners from various disciplines. Knowledge is constructed through collective efforts and it is recommended that the included hypothesises are tested following publication of this research.

6.4

Figure 6.4. Author delivering a lecture at Sint Lucas Antwerpen, Belgium. Photography by Elise Hoebeke. Image used with kind permission of Studio sieraad.

6.3. Dissemination

> *The artist-as-researcher distinguishes herself from other artists by taking it upon herself to gain a deeper understanding of the production of the work and the thinking process through a continuous dialogue with others. The artist researcher allows others (peers, colleagues) to participate in their creative process, entering into a discussion with them and opening herself up to critique. In this context, the public dimension of research, in the sense of making the artistic process public and explicating the so-called 'tacit knowledge' embodied in the work and the practise, is at its core. (Wesseling, 2022, pp.171–172)*

As part of the research project contributions have been made to numerous conferences and through the additional delivery of guest lectures and writing of publications it has been the intention to disseminate the research (Appendix 1). Following completion of the project, plans have been made to disseminate the findings of the research through multiple exhibitions, both in the UK and in Germany. Moreover, as a lecturer and researcher, it is the aim to further disseminate the unpublished segments of this thesis in papers and conference presentations (to reach academics), during lectures and guest lectures (to reach students) and in trade shows (to reach the industry). Having previously discussed the opportunity to transform the thesis into a monograph, this opportunity will also be explored.

	Further Work	Building on chapter
1	Run further Urban Mining projects/workshop to test the impact of the practice on other creative disciplines.	3
2	Create work with other lab-grown gemstone materials sourced through Urban Mining.	3
3	Support the exploration of pigment colours achieved by M. Whitehurst for enamelling and glazing applications.	4
4	Apply for funding to support contributive work with the Bristol University team.	4
5	Expand the exploration of BRG in doublet form from transparent YAG to other coloured materials.	4
6	Create work with BRG in larger formats, following the creation of larger boules.	4
7	Continue the collaboration with Brevalor to support the use of BRG and BRB by jewellers and their commercial viability as products.	4
8	Continue the collaboration with D. Rytz to investigate the growing of other crystals in-situ in platinum structures in laboratory settings.	4/5
9	Investigate the use of different shapes/materials (Figure 6.5) in the DIY growth of ruby, including the impact of solder on metal models.	5
10	Investigate the growth of polycrystalline ruby masses.	5
11	Investigate the growth of other crystals in a DIY manner (i.e. low temperature diamond growth).	5
12	Optimise the DIY growth of ruby by investigating the ideal shape, size and positioning of seeds to achieve desired effects in the most sustainable way.	5

Table 6.2

Table 6.2. Overview of further work.

6.4. Further Work

"The conceptual clarity of classical physics has been swept away by quanta. Reality is decidedly not how it is described by classical physics. This was an abrupt awakening from the pleasant sleep in which we had been cradled by the illusion of Newton's success. But it was a reawakening that connects us back to the beating heart of scientific thinking, which is not made up of acquired certainties: it is thinking constantly in motion, the power of which is precisely the capacity to always question everything and begin over again, to be fearless of subverting the order of the world in the search for a more efficient one, only to then put a further question mark over everything, to subvert it all over again."
(Rovelli, 2022, p.66)

Francastel (2000) conducted a study on how art and technology developed at the end of the 19th and beginning of the 20th century, establishing that art and technology can influence each other, not standing in opposition, but inspiring each other. Even though this may be true for the technologies considered in his study, there is some catching up to be done when it comes to the technology of crystal growth, and enabling artistic influence on it. This research project, and the present thesis, therefore, only mark the beginning of an exciting journey in which lab-grown crystals are used to innovate within a jewellery context. The discussed methodologies, technologies and materials are just a small selection of a larger spectrum. Follow-on funding has been secured through an Early Career Vice Chancellor Grant at the University of the West of England, which will focus on the DIY growth of crystals.

The collaboration with Rytz is scheduled to continue beyond this PhD research project, with the intention to: (a) further explore the creative opportunities these materials provide, (b) promote the novel materials to jewellery artists and makers, and (c) support their commercial viability by offering products that can be incorporated by jewellers. A project in collaboration with the British Academy of Jewellery will see a group of Bachelor's students have access to a selection of sponsored materials for incorporation into their designs.

Urban mining, as a practice, will continue to be a topic for discussion and dissemination. In 2024 a project on the theme engaged 20 Royal College of Art students as part of an 'Urgency of the Arts' module, which saw a number of students shift their practices from using virgin materials to embracing found and urban mined materials. Whilst this thesis has documented the practice in a jewellery context, its application to other practices has now been demonstrated, and will remain a topic of exploration for the author and hopefully for all those who take part in any of the planned future urban mining projects.

The collaboration with the Bristol University team is expected to continue, at least for the duration of Whitehurst's PhD study, during which we intend to collaboratively publish findings and support the application of findings in industry. There are plans to apply for a grant to fund this and further collaborative work too. Ultimately it would be the intention to build a Neo-alchemical Crystal Growth hub, where research in crystal growth in relation to pigments, glazes, enamels and gemstones can be conducted in a hybrid science/art setting.

6.5

Figure 6.5. Sugar crystals grown on stone ring.

6.5. Afterword

When embarking on this PhD journey, naïve alchemical desires around growing novel crystals and innovating in the field surpassed the ever-present 'cannot-use' and 'cannot-do' narratives surrounding laboratory grown crystals and their associated technologies. As an alchemist and stubborn conceptual artist critical of socially constructed contexts and eager to unpick theses narratives, a research project involving iterative cycles of reading, discussing, trying, failing, re-trying, making and diffracting was embarked on. These materials can be used, and may have imperative benefits when used. These materials can be grown, both in collaboration and in a DIY manner, bringing the studio and laboratory closer together. This thesis therefore not only meets the qualification descriptor criteria for the award of PhD, but also provides new knowledge in an area that many with vested interests have aimed to control.

It is the author's hope that the increasingly savvy consumer, creative practitioner, and collaborative scientist will read this thesis and continue working towards the subject, or find another subject that similarly could benefit from critical reflection and creative playful exploration.

Bibliography

American Institute of Physics (2017) *Engaging Diamond for Next-era Transistors*. ScienceDaily. Available from: https://www.sciencedaily.com/releases/2017/05/170516121646.htm [Accessed 15 June 2020].

Angus, J. C., Argoitia, A., Gat, R., Li, Z., Sunkara, M. K. and Wang, Y. (1993) Chemical Vapor Deposition of Diamond. *Philosophical Transactions of the Royal Society of London. Series A: Physical and Engineering Sciences* [Online]. 342, pp. 195-208. [Accessed 29 July 2024].

Antonelli, P. (2012) Vital Design. In: Meyers, W. ed. (2012) *Bio Design: Nature, Science, Creativity.* High Holborn: Thames & Hudson, pp. 6–7.

Arem, J.E. (1977) *Encyclopedia of Gemstones*. 2nd Edition. New York: Van Nostrand Reinhold Company Inc.

Arem, J.E. (1973) *Man Made Crystals.* Washington: Smithsonian Institution Press.

Arem, J.E. (2011) *Understanding Gem Synthetics, Treatments and Imitations*. International Gem Society. Available from: https://www.gemsociety.org/article/guide-to-gem-synthetics-treatments-and-imitations/ [Accessed 29 June 2024].

Astfalck, J. (2005) Jewellery as a Fine Art Practice. In: Astfaclk, J., Broadhead C. and Derrez, P. (2005) *New Directions in Jewellery*. London: Black Dog Publishing, pp. 18-24.

Astfaclk, J., Broadhead C. and Derrez, P. (2005) *New Directions in Jewellery*. London: Black Dog Publishing.

Ayuzawa, S., Yamada, T., Katsuta, N., Suzuki, S., Shiiba, H., Oishi, S. and Teshima, K. (2020) Form Design of Bulky Ruby Crystals with Well-Developed $(11\bar{2}3)$ Faces - Epitaxial Growth of Crystal Films on Sapphire Substrates via MoO_3 Flux. *Crystal Growth & Design* [online]. 20 (10), pp. 6283–6289. [Accessed 24 April 2023].

Ayuzawa, S., Yamada, T., Miyagawa, H., Oishi, S. and Teshima, K. (2024) Low-temperature Ruby Crystal Growth Via a Supersaturation Process Based on Flux Decomposition. *Small* [online]. 20 (18), p. 2308047. [Accessed 3 April 2024].

al-Azīz, A. (1942) *The Imperial Treasury of the Indian Moghuls*. Internet Archive [online]. Available from: https://archive.org/details/in.gov.ignca.19313/ [Accessed 29 June 2024].

Bain & Company (2019) *Diamonds in the Rough: Global Diamond Industry Experiences Challenges Across Value Chain Leading Up To Holiday Season*. Available from: https://www.prnewswire.com/news-releases/diamonds-in-the-rough-global-diamond-industry-experiences-challenges-across-value-chain-leading-up-to-holiday-season-300972912.html [Accessed 10 June 2020].

Barad, K. (2014) Diffracting Diffraction: Cutting Together-Apart. *Parallax* [online]. 20 (3), pp. 168–187. [Accessed 4 July 2024].

Barad, K. (2007) *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* Durham London: Duke University Press.

Barad, K. (2012) On Touching - The Inhuman That Therefore I Am. *Differences: A Journal of Feminist Cultural Studies* [online]. 25 (5), pp. 206–223. [Accessed 4 July 2024].

Baraniuk, C. (2021) Why is there a chip shortage? *BBC News* [online]. 26 August. Available from: https://www.bbc.com/news/business-58230388 [Accessed 1 October 2021].

Barati, B., Karana, E. and Hekkert, P. (2015) A case of designing with an underdeveloped computational composite for materials experience. In: Bang, A. L., Buur, J., Lonne, I. A., Nimkulrat, N. eds. (2015) *Proceedings of the International Conference of the DRS Special Interest Group on Experiential Knowledge (EKSIG)*. Kolding: Design School Kolding, pp. 118–132.

Barnard, A.S. (2000) *The Diamond Formula Diamond Synthesis: a Gemmological Perspective.* Oxford: Butterworth-Heinemann.

Bates, R. (2024) France Says Diamond Growers Must Stick to "Synthetic". *JCK* [online]. 15 February. Available from: https://www.jckonline.com/editorial-article/france-diamond-growers-synthetic/ [Accessed 29 June 2024].

Bergstein, R. (2016) *Brilliance and fire: a biography of diamonds.* New York: Harper.

Biesheuvel, T. and Burden, L. (2018) Lab-Made Diamonds for Less: Why De Beers's Plan Worries Rivals. *Bloomberg UK* [online]. 1 September. Available from: https://www.bloomberg.com/news/articles/2018-09-04/lab-made-diamonds-for-less-why-de-beers-s-plan-worries-rivals [Accessed 15 June 2020].

Boons, S. (2022a) Crystal Growing Design method: An Investigation into the Growing of Crystals for Jewellery Designs. *Craft Research* [online]. 13 (2), pp. 303–326.

Boons, S. (2021a) Crystals as Co-creators: An Investigation of Growing Crystals as a Methodology for Jewellery Designers. *FormAkademisk* [online]. 14 (2). pp. 1-18.

Boons, S. (2021b) Man-made Crystals: A Review of their Historic and Contemporary Context and Use. In: I*nternational Journal of Design in Society* [online]. 15 (2), pp. 63–71. [Accessed 21 July 2024]

Boons, S. (2022b) Pierres Precieuses Artificielles: Une Bataille de Mots – Man-made Gemstones: A War of Words. In: *Raddar* 4, pp. 162-236.

Boonzaier, S. and Gediga, J. (2021) *Research-Based Sustainability Brief on Lab-Grown Diamonds from Chemical Vapor Deposition Technology* [online]. Sphera. Available from: https://pandoragroup.com/-/media/Files/Sustainability/Brilliance/Sphera-statement.pdf [Accessed 29 June 2024].

Bremner, S. (2018) 110 Years of Gemmology. *The Gemmological Association of Great Britain.* Available from: https://gem-a.com/gem-hub/gem-a-news/110-years-gemmology-education-barnett-2 [Accessed 10 September 2021].

Bring Diamonds (2024) *Bring Diamonds*. Available from: https://bringdiamonds.com/ [Accessed 1 July 2024].

British Academy of Jewellery (2017) *A Ring is A Ring is A Ring*. Available from: https://baj.ac.uk/ring-ring-ring-2/ [Accessed 13 August 2020].

Brown, J. S. and Sarkar, C. (2008) John Seely Brown: Tinkering as a Mode of Knowledge Production. YouTube [video]. 21 December 2008. Available from: https://www.youtube.com/watch?v=9u-MczVpkUA [Accessed 4 July 2024].

Buxton, W. (2007) *Sketching User Experience : Getting the Design Right and the Right Design*. San Francisco : Morgan Kaufmann. Internet Archive [online]. Available from: https://archive.org/details/sketchinguserexp0000buxt/ [Accessed 4 July 2024].

Caley, E. R. and Richards, J. F. (1956) Theophrastus On Stones: Introduction, Greek Text, English Translation and Commentary [online]. Columbus, Ohio: The Ohio State University. [Accessed 31 July 2024].

Calvão, F. (2015) Diamonds, Machines and Colours: Moving Materials in Ritual Exchange. In: Darzin, A. and Kurchler, S. eds. (2015) *The Social Life of Materials: Studies in Material and Society* [online]. London; New York: Bloomsbury Academic. [Accessed 20 September 2021]

Cambridge Dictionary (2024a) Gemstone. In: Cambridge Dictionary [online]. [Accessed 5 July 2024].

Cambridge Dictionary (2024b) Neo. In: Cambridge Dictionary [online]. [Accessed 5 July 2024].

Cambridge Dictionary (2024c) Waste. In: Cambridge Dictionary [online]. [Accessed 5 July 2024].

Cermak-Sassenrath, D. and Møllenbach, E. (2014) Teaching to Tinker: Making as an Educational Strategy. In: Roto, V. ed. *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational* [online]. Helsinki, 26-30 October 2014. Association for Computing Machinery, pp. 789–792.

Chatham, T.H. (2017) Chatham Created Gems and Diamonds. Interview with Alan Olsen. *American Dreams*, 2 September [online]. Available from: https://www.youtube.com/watch?v=7tkMhU687LY [Accessed 15 June 2020].

Chatham, T.H. (2023) *The Chatham Legacy: An American Story*. San Diego: Chatham.

Cheung, L., Clarke, B., Clarke, I. (2006) *New Directions in Jewellery II*. London: Black Dog Publishing.

Collet, C. (2020) Alive. Available from: http://thisisalive.com/about/ [Accessed 14 September 2020].

Collet, C. (2021) Designing our future bio-materiality. *AI & Society* [online]. 36 (4), pp. 1331–1342. [Accessed on 1 May 2022].

Collins, H.M. and Evans, R. (2002) The Third Wave of Science Studies: Studies of Expertise and Experience. *Social Studies of Science* [online]. 32 (2), pp. 235–296. [Accessed on 8 July 2024].

Cramer, F. (2022) DIY. In: Wesseling, J., ed. (2022) *Making Matters: a Vocabulary for Collective Arts*. Amsterdam: Valiz, pp. 263–268.

Daston, L. (2005) Fear and Loathing of the Imagination in Science. *Daedalus*. 134 (4), pp. 16–30.

Deleuze, G. (1988) *Foucault.* Minneapolis: University of Minnesota Press. Internet Archive [online]. Available from:https://archive.org/details/foucault0000dele/ [Accessed 5 July 2024].

Delgado, T., Rytz, D., Cai, G., Allix, M., Veron, E., di Carlo, I. and Viana, B. (2023) Highly Transparent Ce^{3}+,Cr^{3}+ Co-doped GYAGG Single Crystals with Enhanced Persistent Luminescence. *Ceramics International* [online]. 49 (24), pp. 41031–41040. [Accessed on 8 July 2024].

den Beste, L. (2011) *On Jewellery: A compendium of international contemporary art jewellery.* Stuttgart: Arnoldsche Art Publishers.

Dieulafait, L., Herbert, G.F., Foshag, W.F., Pearl, R.M., Webster, R. and Church, A.H. (2011) *Artificial Gemstones: a Collection of Historical Articles on the Production of Synthetic Gemstones*. Alcester: Read Books Ltd.

Dragons Den (2024), Series 21, Episode 4, Dragons Den [online]. BBC, 25 January. Available from: https://www.bbc.co.uk/iplayer/episode/m001vnlp/dragons-den-series-21-episode-4 [Accessed 9 February 2024].

Dubinsky, E.V., Stone-Sundberg, J. and Emmet, J.L. (2020) A Quantitative Description of the Causes of Color in Corundum. *Gems & Gemology*. 56 (1), pp. 2–28.

Dunne, A. ed. (2005) *Hertzian tales: electronic products, aesthetic experience, and critical design.* Cambridge, Massachusetts: MIT Press.

Dupre, S., ed. (2006) *Art & Alchemy*. Copenhagen: Museum Tusculanum Press, University of Copenhagen.

Dupre, S., ed. (2014a) *Art and Alchemy: The Mystery of Transformation*. Munich: Hirmer.

Dupre, S., ed. (2014b) *Laboratories of Art. Alchemy and Art Technology from Antiquity to the 18th Century.* Cham: Springer International Publishing.

Eaton-Magaña, S. and Shigley, J.E. (2016) Observations on CVD-Grown Synthetic Diamonds: A Review. *Gems & Gemology* [online]. 52 (3), pp. 222–245. [Accessed 16 July 2024]

Effgen Lapport Schleiftechnik (2019) *History Effgen Lapport Schleiftechnik.* Available from: https://effgen.com/en/history/ [Accessed 1 July 2024].

Elwell, D. (1979) *Man-made Gemstones.* Chichester: Ellis Horwood Ltd.

Ethica Diamonds (2019) The Catastrophic Effects Of Mining Diamonds. *Ethica Diamonds* [Blog]. 10 July 2019. Available from: https://www.ethica.diamonds/diamond-mining-effects/ [Accessed 21 October 2021].

Federal Trade Commission (2018) Guides for the Jewelry, Precious Metals, and Pewter Industries In: *Federal Register* [online]. 83 (159), pp. 40665–40675. [Accessed 4 February 2021].

Ferguson, J. and Fielding, P.E. (1971) The Origins of the Colours of Yellow, Green and Blue Sapphires. In: *Chemical Physics Letters* [online]. 10 (3), pp. 262–265. [Accessed on 6 July 2024]

Foshag, W.F. (2011) Minerals from the Earth and Sky. In: Dieulafait, L., Herbert, G.F., Foshag, W.F., Pearl, R.M., Webster, R. and Church, A.H. (2011) *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones.* Milton Keynes: Read Books Ltd, pp. 24–25.

Francastel, P. and Francastel, P. (2003) *Art and Technology in the Nineteenth and Twentieth Centuries*. New York: Zone Books.

Fremy, E. (1891) *Synthese Du Rubis.* Paris: Vve. Ch. Dunod. Internet Archive [online]. Available from: https://archive.org/details/SyntheseDuRubis/Fremy-e-synthese-1891-rtl010139-lowRes/ [Accessed 21 July 2024]

Gaspar, M. (2013) Jewelry in the Expanded Field: Between Applied Social Art and Critical Design. In: Skinner, D. ed. (2013) *Contemporary Jewellery in Perspective*. Asheville: Lark Crafts, pp. 228–233.

Gem Rock Auctions (2019) *When Will Gemstones Overtake Diamond Sales?* Available from: https://www.gemrockauctions.com/learn/news/when-gemstones-overtake-diamond-sales [Accessed 9 June 2020].

Gemmological Institute of America (2024a) *Why Doesn't GIA Issue Grading Reports for Colored Stones?* Available from: https://www.gia.edu/gia-faq-analysis-gradinggrading-report-colored-stone [Accessed 28 June 2024].

Gemmological Institute of America (2024b). Does GIA grade laboratory-grown diamonds? Available from: https://www.gia.edu/gia-faq-gia-grade-laboratory-grown-diamonds [Accessed 29 July 2024].

Gemporia (2019) *The Story of Idar-Oberstein.* Available from: https://www.gemporia.com/en-gb/gemology-hub/article/1470/the-story-of-idar-oberstein/ [Accessed 13 August 2020].

Gillham, B. (2000) *Case Study Research Methods.* London: Continuum.

Groten, A. (2022) Workshop. In: Wesseling, J. and Cramer, F., eds. (2022) *Making Matters: A Vocabulary for Collective Arts.* Amsterdam: Valiz, pp. 149–156.

Gundermann, K. D. (2023) Luminescent Materials and Phosphor Chemistry. *Encyclopedia Britannica* [blog]. 29 June. Available from: https://www.britannica.com/science/luminescence/Luminescent-materials-and-phosphor-chemistry [Accessed 16 July 2024].

Haaning, A. (2006) The Philosophical Nature of Early Western Alchemy: the Formative Period c. 1150-1350. In: Wamberg, J., ed. (2006) *Art & alchemy.* Copenhagen: Museum Tusculanum Press, University of Copenhagen, pp. 23-40.

Hall, S. (2024) *Professor Simon R Hall*. Available from: https://research-information.bris.ac.uk/en/persons/simon-r-hall [Accessed 6 July 2024].

Halpern, M.K. and Rogers, H.S. (2021) Art–Science Collaborations, Complexities and Challenges. In: Bucchi, M. and Trench, B., eds. (2021) *Routledge Handbook of Public Communication of Science and Technology.* Milton Park; Abingdon; Oxon; New York: Routledge, pp. 214–237.

Heinich, N. (2018) Contemporary Art as a New Paradigm? In: Sormani, P., Carbone, G. and Gisler, P., eds. (2018) *Practicing Art/Science: Experiments in an Emerging Field.* London; New York: Routledge, pp. 45–55.

Helwig, B. (1991) Lead Bearing and Lead Free Enamels. Glass on Metal. *Ganoskin* [blog] Available from: https://www.ganoksin.com/article/lead-bearing-and-lead-free-enamels/ [Accessed 6 July 2024].

Herbert, G.F. (1912) *Gemstones*. London: Methuen and Co Ltd.

Holden, A. and Morrison, P. (1982) *Crystals and Crystal Growing.* 1st edition. Cambridge, Massachusetts: MIT Press.

JCK Magazine (1997) *Germany's Jewelry Centers*. Available from: https://www.jckonline.com/magazine-article/germanys-jewelry-centers/ [Accessed 27 June 2024].

Johnson, J.M. (2001) In-Depth Interviewing. In: Holstein, J. A. ; Gubrium, J. F. (2001) *Handbook of Interview Research* [online]. California: SAGE Publications, pp. 103–119. [Accessed 29 November 2021].

Josephs, J. (2021) Pandora says laboratory-made diamonds are forever. *BBC News* [online]. 4 May 2021. Available from: https://www.bbc.com/news/business-56972562 [Accessed 10 September 2021].

Jung, C. (1968) *Psychology and Alchemy*. 2nd edition. London: Routledge.

Kac, E. (2020) Bio Art. *AI & Society* [online]. 36, pp. 1367-1376. [Accessed 26 August 2020].

Karana, E., Barati, B., Rognoli, V. and Zeeuw Van Der Laan, A. (2015) Material Driven Design (MDD): A Method to Design for Material Experiences. I*nternational Journal of Design* [online]. 9 (2), pp. 35–54. [Accessed 19 September 2020].

Karana, E., Blauwhoff, D., Hultink, E.-J. and Camere, S. (2018) When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials. *International Journal of Design* [online]. 12 (2), pp. 119-136.

Karana, E. and Camere, S. (2017) Growing Materials for Product Design. Karana, E., Giaccardi, E. & Nimkulrat, N., Niedderer, K. and Camere, S. (2017). *Alive.Active.Adaptive [EKSIG2017 Proceedings].* Rotterdam: Delft University of Technology. Delft: TU Delft Open, 19-20 June 20017. pp. 101–115.

Kula, D., Ternaux, E., Hirsinger, Q., Jannelle, M., Gomez, B., Matério, and Atelier MAJi (2009) *Materiology: the Creative's Guide to Materials and Technologies* [online]. Basel; London; Amsterdam: Frame. [Accessed 15 June 2020].

Hamnele, K. (2005) Bio Design Products: Co-design with Nature. In: *Joining Forces*. University of Art and Design Helsinki, Helsinki, 22-24 September 2005. p. 4.

Lab Grown Diamonds Magazine (2023) Tom Chatham in a Candid Conversation with Sandhya Valecha. *Lab Grown Diamonds Magazine Podcast* [podcast]. Available from: https://www.youtube.com/watch?v=K9BTw1wGVfk [Accessed 9 February 2024].

Lastusaari, M., Bettinelli, M., Eskola, K.O., Hölsä, J., Jungner, H., Laamanen, T., Malkamäki, M. and Welter, E. (2012) The Bologna Stone: History's First Persistent Luminescent Material. E*uropean Journal of Mineralogy* [online]. 24, p. 5. [Accessed 16 July 2024].

Latour, B. (2005) *Reassembling the Social: An Introduction to Actor-Network-Theory.* 1st edition. Oxford: Oxford University Press.

Leslie, E. (2005) *Synthetic worlds: nature, art and the chemical industry.* London: Reaktion.

Levin, I. H. (1913) Synthesis of Precious Stones. *Journal of Industrial & Engineering Chemistry* [online]. 5 (6), pp. 495–500. [Accessed 6 February 2024].

Linde, O., Kravchenko, S., Epstein, A., Rentmeesters, K. and Pinkney, D. (2022) *The Global Diamond Industry 2021–22* [online]. Bain & Company. Available from: https://www.bain.com/globalassets/noindex/2022/bain_report_diamond_report-2021-22.pdf [Accessed 28 June 2024].

Lindemann, W., ed. (2016) *Edelstein/Kunst: renaissance bis heute.* Stuttgart: Arnoldsche Art Publishers.

Lindemann, W. (2020) Gemstones - The Crystalline: From Natural Sciences Paradigm to Art Symbol. In: *Thinking Jewellery Two.* Stuttgart: Arnoldsche Art Publishers, pp. 41–108.

Lindemann, W. and FH Trier/Idar-Oberstein eds. (2011) *Thinking Jewellery*. Stuttgart: Arnoldsche Art Publishers.

Lindemann, W. and Smeets, T. eds. (2020) *Thinking Jewellery Two.* Stuttgart: Arnoldsche Art Publishers.

London Diamond Bourse (2024) *NAJ, NDC and LDB write open letter to the BBC following Dragons Den Misconceptions.* Available from: https://londondiamondbourse.com/2024/02/naj-ndc-and-ldb-write-open-letter-the-bbc-following-dragon-dens-misconceptions/ [Accessed 9 February 2024].

Mader, A. and Dertien, E. (2016) Tinkering as Method in Academic Teaching. In: Bohemia, E., Buck, L., Eriksen, K., Kovacevic, A., Ovesen, N. and Tollestrup C. eds. *DS: 83 Proceedings of the 18th International Conference on Engineering and Product Design Education (E&PDE16), Design Education: Collaboration and Cross-Disciplinarity*, Aalborg, Denmark, 8-9 September 2016. pp. 240–245.

Malpass, M. (2017) *Critical Design in Context: History, Theory, and Practices.* London: Bloomsbury Academic.

Manzini, E. (1989) *The Material of Invention.* Cambridge, Massachusetts: MIT Press.

Martin, A. (2011) A Man-Made Diamond Is Forever, Too: Nitty-gritty. *Stanford Magazine* [online]. 31 August. Available from: https://stanfordmag.org/contents/a-man-made-diamond-is-forever-too-nitty-gritty [Accessed 12 August 2020].

McClure, T. (2022) Jewellery Industry Accused of Silence over Russian Diamonds. *The Guardian* [online]. Available from: https://www.theguardian.com/world/2022/mar/19/jewellery-industry-accused-of-silence-over-russian-diamonds [Accessed 27 June 2024].

McNiff, J., Lomax, P. and Whitehead, J. (2003) *You and your action research project* [online]. 2nd edition. London: RoutledgeFalmer. [Accessed 26 June 2024].

Merleau-Ponty, M. (2011) *Phenomenology of Perception* [online]. London: Routledge. [7 July 2024].

Merriam Webster (2024), Neo-. In: Merriam Webster [online]. [Accessed 21 July 2024]

Miller, A.I. (2014) *Colliding Worlds: How Cutting-edge Science is Redefining Contemporary Art.* New York: W. W. Norton.

Myers, W. (2012) *Bio Design: Nature, Science, Creativity.* London: Thames & Hudson.

Nassau, K. (1980) *Gems Made by Man*. Radnor: Chilton Book Company.

Natural Diamond Council (2020a) *Diamond Terminology Guideline*. Available from: https://www.naturaldiamonds.com/council/assure-testing-program/ [Accessed 28 June 2024].

Natural Diamond Council (2020b) *The 5 C's of Diamonds (Yes, 5): How to Select the Perfect Engagement Ring Only Natural Diamonds.* Available from: https://www.naturaldiamonds.com/love-diamonds-romance-symbolism/how-to-select-the-perfect-engagement-ring/ [Accessed 1 October 2021].

Neele, A. (2022) Idar-Oberstein and the Gemstone Road Adam Neeley. *Adam Neely* [blog]. 19 October 2022. Available from: https://www.adamneeley.com/idar-oberstein-and-the-gemstone-road/ [Accessed 27 June 2024].

Northdata (no date) *Electro-Optics Technology GMBH, Idar-Oberstein, Germany*. Available from: https://www.northdata.com/Electro-Optics+Technology+GmbH,+Idar-Oberstein/Amtsgericht+Bad+Kreuznach+HRB+10625 [Accessed 30 April 2024].

Mandeville J. (1900), *The Travels of Sir John Mandeville*. London: Macmillan and Co. Limited. Internet Archive [online]. Available from: https://archive.org/download/travelsofsirjohn00manduoft/travelsofsirjohn00manduoft.pdf [Accessed 29 July 2024].

O'Donoghue, M. (2007) *Artificial Gemstones.* London: NAG Press.

O'Donoghue, M., ed. (2006) *Gems: their Sources, Descriptions, and Identification.* 6th edition. Amsterdam; Boston: Elsevier.

O'Donoghue, M. (2008) *Synthetic, Imitation and Treated Gemstones.* London: NAG Press.

Ogden, J. (1992) *Ancient Jewellery.* Berkeley, Los Angeles: University of California Press.

Ogden, J. (2018) *Diamonds: An Early History of the King of Gems.* Yale: Yale University Press.

Oishi, S., Kondo, H., Kobayashi, T., Watanabe, S., Wakabayashi, S. and Sumiyoshi, Y. (1997) Flux Growth of Ruby Crystals. *The Chemical Society of Japan* [online]. 2, pp. 107–111. [Accessed 24 November 2021].

Oishi, S., Teshima, K. and Kondo, H. (2004) Flux Growth of Hexagonal Bipyramidal Ruby Crystals. *Journal of the American Chemical Society* [online]. 126 (15), pp. 4768–4769. [Accessed 18 March 2021].

Oluleye, G. (2021) *Environmental Impacts of Mined Diamonds* [online]. London: Centre for Environmental Policy, Imperial College London. Available from: https://skydiamond.cdn.prismic.io/skydiamond/364c98ae-8ec8-41b0-909c-1d6756635360_environmental-Impacts-of-mined-diamonds.pdf [Accessed 21 October 2021].

Pedersen, M.C. (2004) *Gem and Ornamental Materials of Organic Origin.* Oxford: Elsevier Butterworth-Heinemann.

Philips, C. (2012) *Jewelry: From Antiquity to the Present.* London: Thames & Hudson.

Pliny the Elder (1962) *Natural History*. Attalus [online]. Available from: https://www.attalus.org/info/pliny_hn.html [Accessed 31 July 2024].

Price, O. (2024) Mined Diamond Industry Faces Turmoil as Lab-Grown Gems Capture Market. Business Insider [online]. 11 March 2024. Available from: https://markets.businessinsider.com/news/stocks/mined-diamond-industry-faces-turmoil-as-lab-grown-gems-capture-market-1033152414 [Accessed 28 June 2024].

Principe, L.M. (2014) Spaces of Wonder and Ruin: Alchemical Laboratories in Early Modern Painting. In: Dupre, S., ed. (2014) *Art and Alchemy: The Mystery of Transformation.* Munich: Hirmer, pp. 60–81.

Pringle, S. (2017) Synthesizing the Future. *Perfumer & Flavorist* [online]. 42 (12), pp. 38–45. [Accessed 24 September 2021].

Pyne, L. (2019) *Genuine Fakes: How Phony Things Teach Us About Real Stuff.* London: Bloomsbury Sigma.

Queensmith (2024) *Lab Grown Diamonds Price & Value Queensmith.* Available from: https://www.queensmith.co.uk/diamond-guides/lab-grown-diamonds/lab-grown-diamonds-price-and-value [Accessed 28 June 2024].

Read, P.G. (1982) *Dictionary of gemmology.* London: Butterworth Scientific.

République Française (2002) *Décret n°2002-65 du 14 janvier 2002 relatif au commerce des pierres gemmes et des perles* [online]. Available from: https://www-legifrance-gouv-fr.

translate.goog/loda/id/JORFTEXT000000593364/?_x_tr_sl=fr&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp [Accessed 29 June 2024].

Resnick, M. and Rosenbaum, E. (2013) Designing for Tinkerability. In: Honey, M., ed. (2013) *Design, Make, Play: Growing the Next Generation of STEM Innovators.* [online] New York: Routledge, p. 19. [Accessed 4 July 2024].

Rheinberger, H.-J. (2018) Epistemics and aesthetics of experimentation. In: Sormani, P., Carbone, G. and Gisler, P., eds. (2018) *Practicing Art/Science: Experiments in an Emerging Field.* London; New York: Routledge, pp. 236–249.

Roden, A. (2021) The lab-grown diamond report: All that Glitters. *Jeweller Magazine* [online]. 5 November 2021. Available from: https://www.jewellermagazine.com/Article2/10133/The-lab-grown-diamond-report-All-that-glitters [Accessed 24 June 2024].

Rognoli, V., Bianchini, M., Maffei, S. and Karana, E. (2015) DIY materials. *Materials & Design* [online]. 86, pp. 692–702. [Accessed 26 August 2020].

Rovelli, C. (2022) *Helgoland: The Strange and Beautiful Story of Quantum Physics.* London: Penguin Books.

Rozin, P. (2005) The Meaning of 'Natural': Process More Important Than Content. *Psychological Science* [online]. 16 (8), pp. 652–658. [Accessed 24 September 2021].

Scheel, H.J. (2003) *Crystal Growth Technology.* West Sussex: John Wiley & Sons Ltd.

Singh, L. (1958) The Colour Problem of Ruby. *Nature* [online]. 181 (4618), pp. 1264–1265. [Accessed 6 July 2024].

Skains, R.L. (2018) Creative Practice as Research: Discourse on Methodology. *Media Practice and Education* [online]. 19 (1), pp. 82–97. [Accessed 8 July 2020].

Sky Diamond (2021) *Skydiamond.* Available from: https://skydiamond.com/ [Accessed 3 March 2021].

Smith, H. and Dean, R.T. (2009) *Practice-Led Research, Research-Led Practice in the Creative Arts.* Edinburgh: Edinburgh University Press.

Sormani, P., Carbone, G. and Gisler, P. (2018) *Practicing Art/science: Experiments in an Emerging Field*. London; New York: Routledge.

Stadtverwaltung Idar-Oberstein (2014) *HartSproede Kompetenzregion Idar-Oberstein.* Stadtverwaltung Idar-Oberstein

Stone, S. (2016) The Most Brilliant Advertising Campaign of All Time: A Diamond is Forever *Steven Stone* [blog]. 9 July 2016. Available from: https://www.stevenstone.co.uk/blog/our-blog-1/post/the-most-brilliant-advertising-campaign-of-all-time-a-diamond-is-forever-952 [Accessed 24 August 2021].

Stone-Sundberg, J. (2013) Sapphire Series Part 3: Modern Synthetic Sapphire Applications. *GIA* [blog]. 21 August 2013. Available from: http://www.gia.eduhttps://www.gia.edu/gia-news-research-sapphire-series-modern-applications [Accessed 15 June 2020].

Sullivan, G. (2010) *Art Practice as Research: Inquiry in Visual Arts.* 2nd edition. California: SAGE Publications, Inc.

Sullivan, G. (2009) Making Space: The Purpose and Place of Practice-led Research. In: Smith, H. and Dean, R.T., eds. (2009) *Practice-Led Research, Research-Led Practice in the Creative Arts.* Edinburgh: Edinburgh University Press, pp. 41–65.

Sundström, P. and Höök, K. (2010) Hand in Hand with the Material: Designing for Suppleness. In: Wixon, D. ed. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* Atlanta, 10-15 April 2010. New York: Association for Computing Machinery, pp. 463–472.

Sybel, H. (2024) "Diamonds are a Girl's Best Friend?" Diamanten, De Beers und die Vermarktung von Brillantschmuck in den USA, 1939-1960. *Historische Zeitschrift.* 318 (1), pp. 64–98.

Tesla, N. (1900) Problem of Increasing Human Energy. With Special Reference to the Harnessing of the Sun's Energy. *The Century Magazine* [online]. 60 (2), pp. 175–211. [Accessed 20 October 2020].

The MVEye (2021) *New Tech Meets Old World - Lab-Grown Diamonds Awareness & Acceptance in Western Europe* [online]. MVI Marketing LLC. Available from: https://www.themveye.com/reports/new-tech-meets-old-world/ [Accessed 28 June 2024].

The World Jewellery Confederation (2021) *Diamond Terminology Guideline CIBJO*. Available from: https://www.cibjo.org/diamond-terminology-guidelines/ [Accessed 24 September 2021].

Unger, M., Van Leeuwen, S. (2017) *Jewellery Matters.* Rotterdam: nai010 publishers Rotterdam Rijksmuseum Amsterdam.

Untracht, O. (1982) *Jewelry concepts and technology.* London: Robert Hale.

Van der Heggen, D., Joos, J.J., Feng, A., Fritz, V., Delgado, T., Gartmann, N., Walfort, B., Rytz, D., Hagemann H., Poelman D., Viana, B. and Smet, P. (2022) Persistent Luminescence in Strontium Aluminate: A Roadmap to a Brighter Future. Advanced Functional Materials [online]. 32 p. 2208809. [Accessed 30 July 2024].

Van der Heggen, D., Joos, J.J., Rytz, D., Viana, B. and Smet, P.F. (2023) Strontium Aluminate Persistent Luminescent Single Crystals: Linear Scaling of Emission Intensity with Size is Affected by Reabsorption. *The Journal of Physical Chemistry Letters* [online]. 14 (45), pp. 10151–10157. [Accessed 3 May 2024].

Van Der Wal, S. and Haan, E. de (2010) Rough Cut: Sustainability Issues in the Coloured Gemstone Industry. *SSRN Electronic Journal* [online]. Available from: http://www.ssrn.com/abstract=1557705 [Accessed 12 August 2020].

Van Dijk, E.S. (2016) *Bio Art, DIY Biology, and Academics* [online]. Leiden: Leiden University. [Accessed 11 December 2020].

Vaupel, E. (2015) Edelsteine aus der Fabrik. Technikgeschichte [online]. 82 (4), pp. 273–302.

Verneuil, A. (1904) Mémoire Sur la Reproduction Artificielle du Rubis par Fusion. *Annales de Chimie et de Physique.* 8 (3), pp. 20–48.

Verneuil, A. (1902) Production artificielle du rubis par fusion. *Comptes Rendus Hebdoma-Daires des Séances de l'Académie des Sciences.* 135, pp. 791–794.

Vicenzaoro (2020) TV Talk: What is the Future of Diamonds? *YouTube* [video]. 22 January 2020. Available from: https://www.youtube.com/watch?v=06E1uGdHTtY [Accessed 23 October 2021].

Wamberg. (2006) *Art & Alchemy*. Copenhagen: Museum Tusculanum Press, University of Copenhagen.

Wang, W., Moses, T., Linares, R.C., Shigley, J.E., Hall, M. and Butler, J.E. (2003) Gem-quality Synthetic Diamonds Grown by a Chemical Vapor Deposition (CVD) Method. *Gems & Gemology.* 39 (4), pp. 268–283.

Wesseling, J. (2022) Artistic Research. In: Cramer, F., ed. (2022) *Making Matters: a Vocabulary for Collective Arts.* Amsterdam: Valiz, pp. 167–172.

Whitehurst, M.E. (2022) *The Effect of a Dopant on the Colour of Synthetic Corundum.* BSc Thesis, University of Bristol.

Whitehurst, M.E. and Hall, S.R. (2023) New and Unforeseen Crystal Growth Processes for a Metal Oxide. *ACS Omega* [online]. 8 (51), pp. 49327–49333. [6 July 2024]

Xavier, L.H., Ottoni, M. and Leonardo, A. (2023) A Comprehensive Review of Urban Mining and the Value Recovery from E-waste Materials. *Resources Conservation and Recycling* [online]. 190 (10), pp. 106840 [Accessed 21 July 2024].

Xu, J. and Tanabe, S. (2019) Persistent Luminescence instead of Phosphorescence: History, Mechanism, and Perspective. *Journal of Luminescence* [online]. 205, pp. 581–620. [16 July 2024]

Yin, R.K. (2018) *Case Study Research and Applications: Design and Methods.* 6th Edition. Los Angeles: Sage Publications.

Zimmerman, J., Forlizzi, J. and Evenson, S. (2007) Research through Design as a Method for Interaction Design Research in HCI. Wixon, D. ed. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* Atlanta, 10-15 April 2010. New York: Association for Computing Machinery, pp. 493–502.

Zoellner, T. (2007) *The Heartless Stone: a Journey through the World of Diamonds, Deceit, and Desire.* New York: Picador.

Appendices

Appendix 1: Previous Presentation

Elements of this research have been presented in workshops, conferences, books and journals over the past 4 years.

In 2020 I presented early stages of the research at the *Art of Research 2020* Conference in Finland.

At the end of 2020 I co-organised the Crafts Council and CFPR seminar *Touch: Reflections on Making*, where I presented early stages of my research in a talk titled: Touch for Luck, a Jewellers Perspective on Touch.

In 2021 I was selected as emerging scholar and funded to present the early findings of my research at the *15th International Conference* on *Design Principles and Practices* conference in Mexico. The paper (Boons 2021) presented at this conference was later published by the International Journal of Design in Society.

I was invited to present the early stages of my research at the PhD event in the *Nordes* Conference in Copenhagen in 2021.

On the 24th of March I was a guest on The Futurist Forecast, streamed live on Instagram.

During the *Craft and Science* 2021 Conference in Sweden I presented my crystal growing methodology. The paper (Boons 2021 b) was selected for publication in the journal FORMAkademisk.

In 2021 I was awarded a Deutscher Akademischer Austauschdienst (DAAD) scholarship to complete a 2-month residency at the Hochschule Trier in Idar Oberstein. During this residency I presented my research to the department and delivered an industry lecture as part of the *SteinZeit* at the Kasino Gesellschaft.

I was invited as guest lecturer to deliver the 2021 Art Lecture organised by the Institute of Materials Minerals and Mining (IOM3) SECC.

At the end of 2021 I was invited to present my research at the ninth Congress of the *International Association of Societies of Design Research* (IASDR) in China. The short paper submitted was selected to be published as a chapter in the book *[ ] With Design: Reinventing Design Modes*

I was a guest presenter at the *Future Materials Conference* in Birmingham organised by the Institute of Materials Minerals and Mining (IOM3) SECC in 2021.

In 2022 I presented my research at the *16th International Conference* on *Design Principles and Practices* in Australia.

In 2022 was invited to deliver a guest lecture as part of the Birmingham University LANS Lab Seminar.

In 2022 the paper (Boons 2022 a) was published in the *Craft Research* journal.

My paper (Boons 2022 b) was published in the 4th issue of RADDAR titled Faux/Fake in 2022.

In 2023 I authored the UWE Blog Post (Boons 2023) reviewing the history of crystal growth through 10 key stones.

I have presented my research to art and design departments at the University of the West of England during 2020-2023 through guest lectures.

In 2023 I was awarded the Mary-Somerville-Lehrbeauftragtenprogramms which enabled me to deliver the Bling-It workshop at the Hochschule Trier in Germany in collaboration with Julia Wild, and with support of the diamond tooling company Effgen and Medidia.

In 2023 I was invited by the *Intergem Fair* in Idar Oberstein (Germany) to present my work in a seminar. Pieces of the 'Glow' collection were also presented at the stand of Klein & Becker for the duration of the fair.

In 2023 I participated in the recording of the Free Thinking Episode by BBC Radio 3 on Victorian Colour, Jewellery and Metalwork.

In 2024 I delivered a guest lecture about my work and research at St Lucas in Antwerp.

I presented a lightning talk at the Festival of Futures in Lancaster University in 2024.

In 2024 I delivered a guest lecture for the Colour Group in London.

My research was covered in the May episode of the Podcast 'This is Lancaster' titled 'The Transformative Power of Design'

Appendix 2: Ethics Documents

Participant Information Sheet:

Study Title:

Man-made Crystals: an investigation into the design implications, possibilities, and limits of utilising cultured crystals and related processes in contemporary jewellery practice.

Outline of invitation:
You are being invited to take part in a research study concerning the current and future creative use of man-made crystals in jewellery. Before you decide to participate, it is important you understand why the research is being conducted and what it will involve. Please take time to read the following information carefully and review the list of interview questions enclosed. Please take the opportunity to discuss it with others if you wish and do not hesitate to ask for further clarification or information.

What is the purpose of the study?
The main aim of this enquiry is to explore the design implications, possibilities, and limits of utilising man-made crystals and related processes in contemporary jewellery practice. The research seeks to extend the current uses of these materials into more innovative and design led applications.

Why have you been chosen?
You have been identified as a key contact in a sector relevant to this particular research.

Do you have to take part?
It is completely up to you to decide whether or not to take part. If you do decide to participate you will be given this information sheet to keep for your records and be asked to sign a consent form. If you decide to take part you are still free to withdraw your consent at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not have any effect outside of this research project.

What will happen to me if I agree to take part?
I will get in contact with you to arrange a suitable time to undertake the interview. The information sheet and consent form will be sent to you a week in advance of the interview and you will be asked to return the signed consent form prior to the interview.

What will be the structure and format of the interview?
The interview will be conducted as an informal conversation, semi-structured with topics that have been identified as of relevance to the research and your particular area of expertise. These topics will be outlined prior to the interview. Please feel free to make notes for the interview to remind yourself of certain areas or topics that you consider relevant to the study.

How long will the interview last?
The interview is expected to last 40 - 90 minutes.

Will the Interview be transcribed?
The interview will be recorded and a recording of the interview will be supplied to you. The researcher will primarily use the interview to gain industrial and sector insights to direct the

practical research of this study. The researcher will make notes during and after the interview but the interview will not be wholly transcribed as such. You will be provided with the option of anonymising your responses.

What are the possible disadvantages of taking part?
There should not be any notable disadvantages in taking part in the research.

What if you have a concern about anything after the interview has been conducted?
If you have any concerns about anything regarding this project you can contact me. My contact details can be found on the consent form and below.

How and when can I withdraw from participating?
You can withdraw from participating at any point by using the contact details supplied below. If you would like to withdraw or postpone a scheduled interview we ask you to give us at least two days' notice. Once the interview has been completed you can withdraw consent within up to 4 weeks of receipt of transcriptions and copies.

Will taking part in this study be kept confidential?
All information which is collected from you during the course of the research will be kept strictly confidential and saved on a secure drive. Your details will not be passed on to any other persons for any reason, and the project will be subject to the guidelines of the Data Protection Act.

What will happen to the results of the research study?
Both raw data as well as the results of the research will be stored on a secure and encrypted RAID storage server. Quotes and other results from the research study might be used in the final outcomes of the PhD project.

Who is organising and funding the research?
This research project is funded by Research England.

Contact details for further information:

Sofie Boons
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PARTICIPANT CONSENT FORM

Title of Project: *Man-made Crystals: an investigation into the design implications, possibilities, and limits of utilising cultured crystals and related processes in contemporary jewellery practice*

I ______________________________[print name] agree with the terms as described in the accompanying Participant Information Sheet, and I am a willing participant in the above named UWE research project.

Address:

Phone:

Email address:

Signed: **Date:**

Contact details for further information:

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Appendix 3: Research Visits

Table A 1 List of Research Residencies

#	Date From	Date To	Duration	Funder	Actions
1	31/8/2021	1/11/2021	2 months	DAAD	Interviews, Making, Archive Visit, Company Visits, Intergem Fair Visit, Roundtable Event
2	22/10/2022	18/12/2022	2 months	Erasmus +	Interviews, Making, Company Visits, Intergem Fair Visit
3	11/6/2023	22/6/2023	10 days	Mary Somerville	Bling It Project, Making
4	11/7/2023	23/7/2023	12 days	Mary Somerville	Bling It Project, Making
5	29/9/2023	6/10/2023	1 week	N/A	Intergem Presentation, Making

Appendix 4: Interviews

The interview method was chosen to elicit 'insight into the situation' by industry professionals (Yin, 2018) in order to collect 'richer' data' (McNiff, Lomax and Whitehead, 2003). This appendix will provide further information and where relevant a record or summary of the data collected.

Following the construction of a database of potential persons and locations of interest who could offer a professional opinion or provide an insight on the suitability of the use of man-made crystals in a cross section of contexts in Idar-Oberstein a selection was based on the following criteria:

- Working or located within a 50-mile radius of Idar-Oberstein in Germany.
- Expertise of the interviewee or company/other research location in the field (wider jewellery and gemstone manufacturing context).
- Likelihood that the interviewee or company/location could provide an opinion/relevant insight into the use of man-made crystals in a jewellery context.
- Possibility of being introduced, ability to contact, ability to visit.

With the support of Research Fellow Julia Wild at the hosting institution (Hochschule Trier' Gemstone and Jewellery Department) a database of contacts was established by week two of the first residency. A selection of the contacts/companies included in the database were professional contacts of Julia Wild, who, as a native to Idar-Oberstein, is closely connected to a large section of the industry in the city. The list was then supplemented with contacts identified during a visit to the trade fair Intergem and from an online search of relevant businesses in the valley. In total 19 contacts listed in the constructed database were chosen for initial contact. The selection aimed to include a cross section of professional roles in the industry and was constructed to provide a balance between those who do and do not use lab-grown gemstones. Of those contacted 10 consented to an in-person interview, 1 consented to a written interview and 3 declined, the remaining contacts did not respond to interview requests sent via email. Table A 2 lists the interviewees with their professional role and whether they work with, handle or sell man-made gemstones. Names of interviewees were replaced with numbers to preserve anonymity.

Table A 2 List of Interviews

Interviewee Name [Redacted]/ Date	**Professional Role**	**Works/Handles/Sells Man-Made Gemstones**
Interviewee #1 23 September 2021	Business Manager/Engineer	Yes
Interviewee #2 29 September 2021	Business Owner/Gemstone Cutter	No
Interviewee #3* 4 October 2021	Professor/Jewellery Designer	No
Interviewee #4* 7 October 2021	Employee/Jewellery Designer	No
Interviewee #5 10 October 2021	Writer/Researcher	N/A
Interviewee #6* 21 October 2021	Employee/Gemstone Dealer/Gemstone Cutter	No
Interviewee #7 22 October 2021	Business Owner/Gemstone Carver	Yes
Interviewee #8* 24 October 2021	Employee/Gemstone Cutter	Yes
Interviewee #9 26 October 2021	Business Owner	Yes
Interviewee #10* 27 October 2021	Gemologist/Lecturer/Jewellery Designer	N/A
Interviewee #11 12 December 2022	Business Owner	Yes
Tom Chatham** 8 March 2024	Business Owner/Crystal Grower	Yes

**Interviewed at Hochschule Trier*

***Interviewed online, interviewee not located in Germany*

The majority of those who declined or did not respond to the invitation to be interviewed were business owners of gemstone cutting and dealing companies that worked exclusively with mined gemstones. This category is therefore not equally represented in the shortlist. The Venn Diagram below (figure A 1) pictures the distribution of interviewees across the following categories: Gemstone Company, Industrial/Tooling Company and Independent/Other. Some interviewees, particularly those with multiple roles within the industry, fall within more than one of the categories.

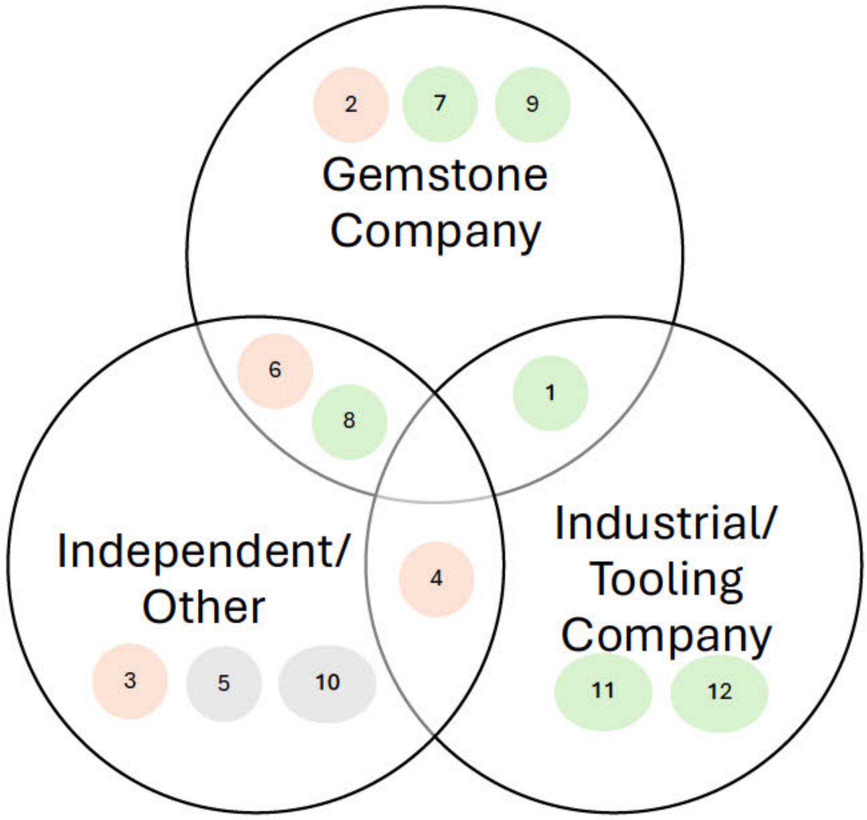

Figure A 1 Venn diagram of interviewees (listed by their number as documented in table A2). Numbers in green indicate the interviewees works/handles or sells man-made gemstones, numbers in red indicate the interviewees do not, and numbers in grey relate to those for who this question does not apply.

An additional interview was organised separately at a later time with a crystal grower based in America over Zoom. This additional interviewee had retired from directorship of highly influential crystal growing companies focused on the growth of crystals for the gemstone industry. With his respective company having played an instrumental role in the development of gemstone crystal growth for commercial use in the jewellery industry, his insights seemed instrumental to the project. This source of additional data beyond the data collected from industry experts in Idar-Oberstein, which no longer has a crystal growth company serving the gemstone industry, filled that gap.

All participants, except interviewee #5, were interviewed in person, either at their location of work or at the Hochschule Trier with each conversation lasting between 45 minutes to 1 hour and 30 minutes. The conversations were loosely based on draft open interview questions and interview guidance that was shared with participants prior to the interview. All interviews were recorded and transcribed. Full permission was given for the recording of these transcripts in accordance with my ethics procedure (Chapter 1 section 1.4.). After transcription, a thematic analysis approach was used to reflect on the data and collate initial findings. Following transcription, they were read in full again. Then important quotes were highlighted following the key listed below (table A 3), which is aligned with the sections listed in chapter 2 section 2.

Table A 3 Thematic analysis highlighting key

Highlight	Theme
Yellow	quotes with relevance to use or non-usage of lab-grown gemstones
Green	quotes with relevance to the discussion around knowledge and understanding of lab-grown gemstones
Blue	quotes with relevance to the discussion around terminology
Grey	quotes with relevance to the discussion around authenticity and value

In summary, the main drive behind the choice to conduct interviews as part of the practice-based overarching research project was to capture industry professionals' opinions in relation to the use of man-made crystals in a jewellery context, and investigate the practices in which they are incorporated in the region, which is representative as the largest gem-dealing and cutting center in Europe. Whilst it was not the intention to establish conclusive facts, which as an outsider with limited time in the region would not be a feasible endeavor, the various conversations supported the conclusion proposed in the thesis.

Appendix 5: Organisation Visits

Direct observations were another method employed for data collection throughout the research project. As highlighted by Yin, “relevant social or environmental conditions will be available for observation” (2018). These observations were documented informally through observational notes, which including text and reflective writing. Images/photos have been taken and saved to supplement the notes. Direct observations were conducted of a range of companies and organisations, some following a guided visit (table A 4), others following an unguided visit (table A 5-6). The selection of companies and organisations to visit was based on similar principals as listed above with the interviews, and therefore based on the following criteria: based on the following criteria:

- Company or organisation is located within a 50-mile radius of Idar-Oberstein in Germany or within reasonable travelling distance in the United Kingdom.
- Expertise of the company/organisation in the field (wider jewellery and gemstone manufacturing context).
- Likelihood that the company/location visit could provide an opinion/relevant insight into the use of man-made crystals in a jewellery context.
- Possibility of being introduced, ability to contact, ability to visit.

Table A 4 List of guided company visits.

Organisation Name [redacted] / Date	**Type of Organization**	**Works/Handles/Sells Man-Made Gemstones**
Bring Diamonds 13 August 2021	Crystal Growing Company	Yes
Company #2 23 September 2021	Industrial Tooling Manufacturing	Yes
Company #3 29 September 2021	Artistic Gemstone Cutter/Dealer	No
Effgen 19 October 2021	Industrial Tooling Manufacturer	Yes
Company #5 22 October 2021	Artistic Gemstone Carving	Yes
Company #6 22 October 2021	Gemological Association	Yes
Company #7 25 October 2021	Crystal Growing Company	Yes
Company #8 26 October 2021	Gemstone Cutter/Dealer	Yes
Company #9 3 November 2022	Gemstone Cutter/Dealer	No
Company #10 12 December 2021	Industrial Tooling Manufacturer	Yes

*Not located in Idar-Oberstein

The companies visited through guided visits represented a broad range of relevant companies, ranging from gemstone companies to industrial (mainly tooling) companies, companies focussing on crystal growth or those providing education on the topic (Figure A 2).

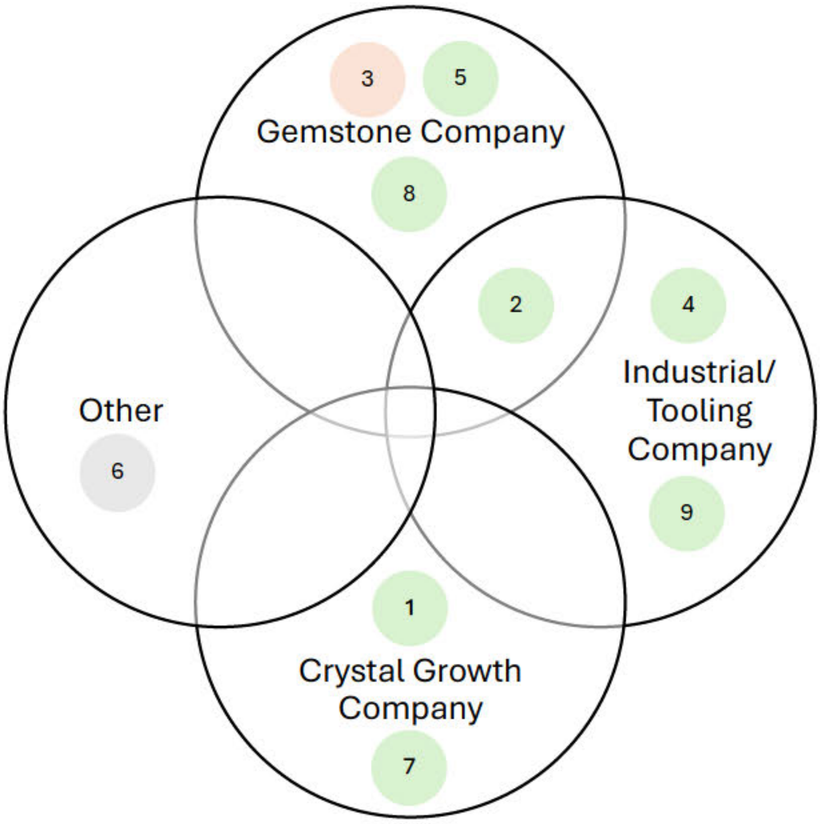

Figure A 2 Venn diagram of guided company visits (listed by their number as documented in table A 4). Numbers in green indicate the company works/handles or sells man-made gemstones, the number in red indicates the company does not, and the number in grey relate to the organisation to which this question does not apply.

When it was not possible to organise a guided visit to a company which was open to be visited independently and deemed interesting for the research, this was organised too.

Table A 5 List of unguided company visits.

Organisation Name [redacted]	**Type of Organization**	**Works/Handles/Sells Man-Made Gemstones**
Company #1 16 September 2021	Mineral and Rough Gemstone Dealer	Yes
Company #2 4 October 2021	Mineral and Rough Gemstone Dealer	No
Company #3 18 October 2021	Mineral and Rough Gemstone Dealer	No
Company #4 22 October 2021	Tool Reseller	Yes
Company #5 23 October 2021	Tool Reseller	Yes
Company #6 6 November 2022	Mineral and Rough Gemstone Dealer	Yes

This also applies to a range of museums on the topic of gemstones and jewellery.

Table A 6 other organisation visits.

Organisation Name	Date	Type of Organization	Displayed Man-Made Gemstones
Natural History Museum London	17 October 2020	Museum	Yes
Steinkaulenberg Mine Idar-Oberstein	5 September 2021	Discontinued Mine turned museum	No
Mineralien Museum Idar-Oberstein	16 September 2021	Museum	Yes
Gemstone Museum Idar-Oberstein	22 October 2021 & 20 November 2022	Museum	Yes

The note-taking method underpinning the direct observation approach was also applied to documenting visits to relevant gemstone and jewellery fairs (table A 7). All data was collated to triangulate with the other data collected.

Table A 7 List of fair visits.

Fair Name	Location	Displayed Man-Made Gemstones
Vincenzaoro 2020	Venice, Italy	Yes
Intergem 2021	Idar-Oberstein, Germany	Yes
Schmuck Denken 2021	Idar-Oberstein, Germany	No
Schmuck 2022	Munich, Germany	Yes
Intergem 2023	Idar-Oberstein, Germany	Yes

Appendix 6: Open Survey

In order to conduct a more widespread thorough analysis (McNiff, 2016) and provide the wider jewellery community an opportunity to participate in the research project, an online survey was produced using Qualtrics. It was launched on the 31st of January 2021 via sofieboons.com (figure A 2) and associated social media profiles on Twitter, Instagram, Facebook and LinkedIn (figures A 3-6). The survey was reposted to a range of industry relevant pages, including the 'Jewellery Appreciation Group', 'The Society of British Jewellers', 'Jewellery Group'. In total 51 participants responded to the survey. Even though the survey remained open for four years, all responses to the survey were received in the first two months of its launch. The survey questions were structured similarly to the interview. Closed questions were supplemented by a comment box for participants to provide commentary on their response. The data was extracted from Qualtrics and reviewed in Excell. A similar thematic analysis was conducted as was applied to the review of the interview data, using the same colour coding key.

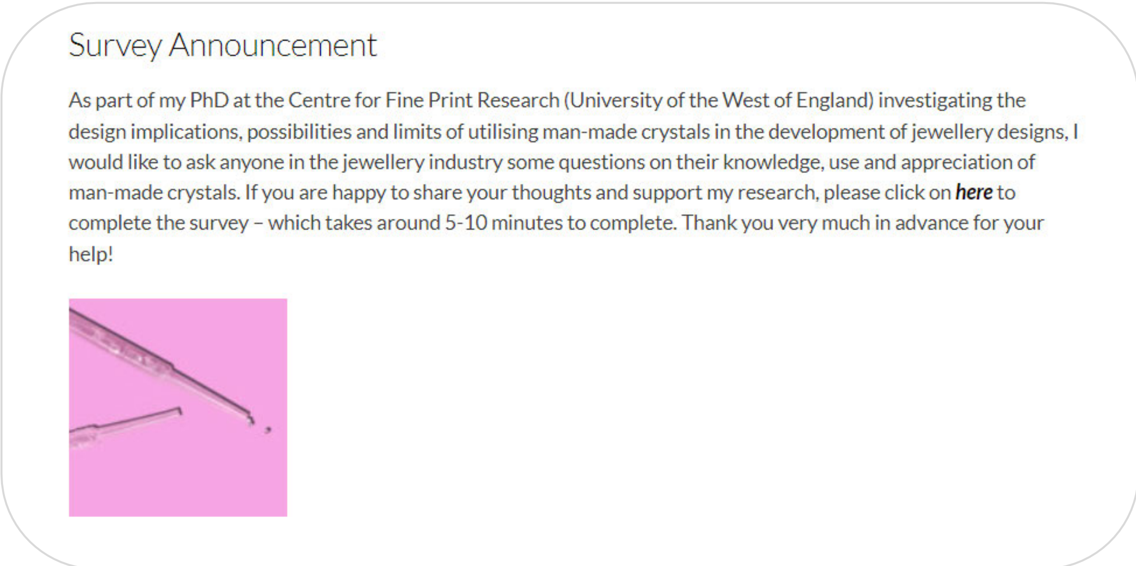

Figure A 3 Survey announcement on sofieboons.com

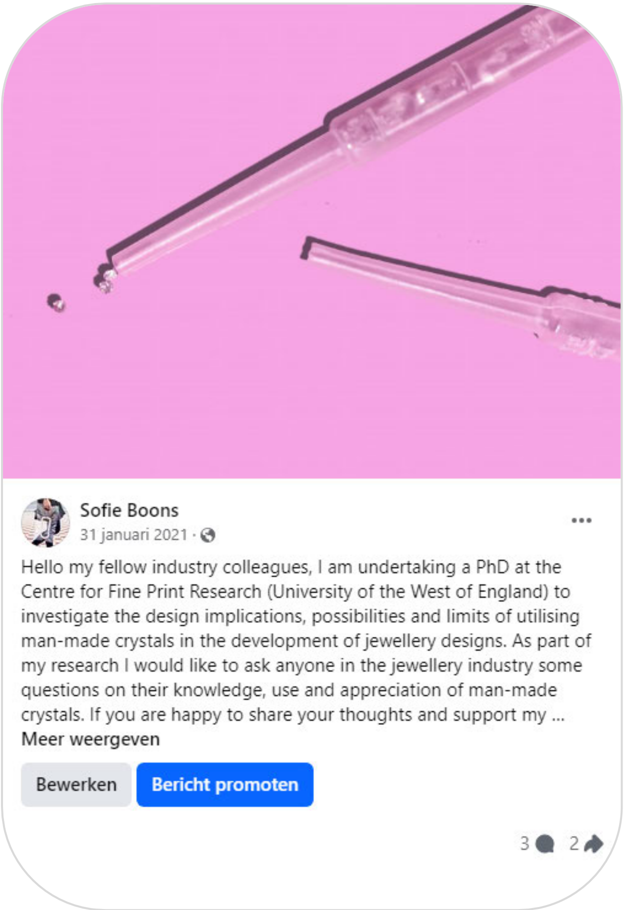

Figure A 4 Survey announcement post on Facebook

Figure A 5 Survey announcement post on Instagram

Figure A 6 Survey announcement post on Twitter (now X)

Figure A 7 Survey announcement post on LinkedIn

A list of the questions and detailed responses, including where relevant a percentage breakdown of the received responses has been included below (table A 5).

Table A 8 Survey summary

Participant Consent	
Yes	51
No	0
	51

Participant Consent	
Yes	100%
No	0%
	100%

Role	
XDesigner	29
Retailer (SME)	1
Service Provider	3
Trade Person	7
Other	11
	51

Role	
Designer	57%
Retailer (SME)	2%
Service Provider	6%
Trade Person	14%
Other	22%
	100%

How long have you been part of the jewellery industry?	
more than 10 years	22
5-10 years	19
less than 5 years	10
	51

How long have you been part of the jewellery industry?	
more than 10 years	43%
5-10 years	37%
less than 5 years	20%
	100%
Where are you based?	

Africa	1
Asia	1
North America	18
Europe	5
South America	0
Oceania	1
United Kingdom	25
	51

Where are you based?	
Africa	2%
Asia	2%
North America	35%
Europe	10%
South America	0%
Oceania	2%
United Kingdom	49%
	100%

How would you rate your knowledge of man-made crystals?	
Extremely knowledgeable	3
Very knowledgeable	5
Moderately knowledgeable	20
Slightly knowledgeable	16
Not knowledgeable at all	7
	51

How would you rate your knowledge of man-made crystals?	
Extremely knowledgeable	6%
Very knowledgeable	10%
Moderately knowledgeable	39%
Slightly knowledgeable	31%
Not knowledgeable at all	14%
	100%

Comments:

⇒ I have cut synthetic stones and I work loosely with a synthetic manufacturer

⇒ I know virtually noting unfortunately!

⇒ I am aware of them and where to buy them. I haven't had cause to buy any. I have used stones that have been heated to change the colour.

⇒ About?

⇒ Studied synthetics in gemology school, now work exclusively with Moissanite

⇒ I'm familiar with Swarovski crystals and have used them in jewelry designs in the past

⇒ Use cubic zirconia in flameworked glass.

⇒ I have a background in geology and all took the GIA courses in colored stones and diamonds

⇒ I am currently performing a PhD on the Subject

⇒ I have used them and seen them in others' jewellery pieces
⇒ I have a diploma in gemmology and as part of this we study simulants and synthetics.
⇒ I use cubic zirconia, but don't know about any other man made crystals
⇒ aware of lab created stones, synthetics
⇒ I'm aware of their existence and have a general knowledge of how they are made, but nothing detailed. I would not be able to tell the difference between a man-made and natural crystal.
⇒ ! am a FGA and DGA
⇒ I have learned a bit of the processes of making diamonds and sapphires though a couple of seminars that Gia and debeers put out
⇒ I regularly advise my customers to consider lab-grown/synthetic gemstones so I've learnt a lot about what's available and most suitable
⇒ Know how they are made, always check when buy where they come from
⇒ Some knowledge from researching while sourcing stones.
⇒ I'm aware of the existence of several kinds, but haven't used any yet in a project.
⇒ As a maker I have considered using these rather than mined stones.

Do you agree with the following statement? 'A range of gemstones (including diamonds) can now be made in the lab, and these man-made crystals can be produced to be physically and chemically identical to mined gemstones.'	
Agree	44
Neither agree nor disagree	2
Disagree	4
I don't know	1
	51

Do you agree with the following statement? 'A range of gemstones (including diamonds) can now be made in the lab, and these man-made crystals can be produced to be physically and chemically identical to mined gemstones.'	
Agree	86%
Neither agree nor disagree	4%
Disagree	8%
I don't know	2%
	100%

Text input after 'Agree':

⇒ I know this is possible. I also know lots of jewellers don't like the idea of them
⇒ However an important aspect of value, rarity, is lost.
⇒ With some gemstone varieties it's become difficult sometimes to determine what's natural and what's synthetic
⇒ Close enough to where it no longer matters.

Text input after 'Disagree':

⇒ Man-made crystals are too *perfect*. If impurities are introduced it's certainly possible to make the two identical
⇒ Special flaws can't be replicated, individual stones can't be replicated.

Do you agree with the following statement? 'Man-made crystals are a more sustainable option than mined gemstones.'	
Strongly agree	15
Somewhat agree	19
Neither agree nor disagree	12
Somewhat disagree	2
Strongly disagree	0
I don't know	3
	51

Do you agree with the following statement? 'Man-made crystals are a more sustainable option than mined gemstones.'	
Strongly agree	29%
Somewhat agree	37%
Neither agree nor disagree	24%
Somewhat disagree	4%
Strongly disagree	0%
I don't know	6%
	100%

Comments:

⇒ What does more suitable mean?

⇒ This is only based on my very basic knowledge. I feel a bit awkward about commenting in some ways when I know so little!

⇒ Of course it’s more sustainable and stops awful working practices in mines and the destruction of environments.

⇒ In the sense that natural diamonds will eventually all have been mined, but they can be created in labs forever

⇒ Lab created gems are becoming increasingly popular in relation to ethics and environmental impact issues, though little research has been published about the energy requirements to grow synthetic crystals. The ‘ingredients’ needed to grow them are widely available, but depending on the type of energy used to power the pressure chambers, it could also be less ‘green.’

⇒ I’ve heard the environmental impact of creating lab/ man made diamonds is greater than mining them. I would have to research further.

⇒ No point mining diamonds if they can't be distinguished from manufactured.

⇒ I prefer mined but lab created have their uses as well

⇒ More sustainable than irresponsibly sourced stones. However, not sure they are a viable replacement for jewelry. You can make a synthetic dinosaur footprint that’s the same in every way as an authentic one, but it won’t be nearly as special.

⇒ I believe they can become even more sustainable, and it also depends which stones you are comparing.

⇒ I have heard that the amount of energy etc used to make a man-made diamond is just as bad for the earth

⇒ Synthetics have their own environmental impacts like the mining of pyrophyllite.

⇒ by prodoct, chem waste disposal needs to be clear in actice comparrison to end product. Out of the ground, is always going to be devastating for the earth, but, so are most human activities

- ⇒ I believe man-made is the future and should be more widespread and accepted.
- ⇒ As far as sustainability, I know it takes a great deal of energy to produce man made crystals, I dot know that they are more sustainable, but I know that mining is very bad for the world.
- ⇒ Sustantial energy is used in production of man-made crystals
- ⇒ My uneducated theory is that it depends. Making a stone takes energy. In a mined stone the energy used to make it was provided by the earth. The energy cost here is mining it. The cost of alluvial mining is quite low
- ⇒ Trying to encourage my future Daughters-in-law to get moissanite over natural diamonds for their engagement rings. Not successful so far.
- ⇒ There are times when synthetic gemstones are more appropriate for consumers who desire a more sustainable alternative to natural gemstones. This is not always the case however and sometimes natural gemstones can be reused from old jewellery which is just as sustainable as lab-grown gemstones if not more so.
- ⇒ Not sure about the consequenses on the overall production, energy needed to produce the stones, how much waist is produced while making and how the polishing-process looks like.
- ⇒ Fron what I've seen, the environmental impacts from man-made are less severe than mining.
- ⇒ Considering these are just high-pressure formed elements and minerals, there is no excuse to mine them unless it's necessary.
- ⇒ Produced crystals also draw on resources. I am not sure what impacts their use have.

Do you use/sell or work with man-made crystals?	
Yes	27
No	24
	51

Do you use/sell or work with man-made crystals?	
Yes	53%
No	47%
	100%

What are the main reasons for you to use or offer man-made crystals? (please select all that apply)	
Financial reasons	21
Aesthetic reasons	5
Supply reasons	5
Sustainability reasons	16
Other reasons	8
Participants	32
Blank	19

What are the main reasons for you to use or offer man-made crystals? (please select all that apply)	
Financial reasons	66%

Aesthetic reasons	16%
Supply reasons	16%
Sustainability reasons	50%
Other reasons	25%

Do you discuss man-made crystals with customers, and if so, how do they respond?	
Extremely positive	2
Somewhat positive	8
Neither positive nor negative	11
Somewhat negative	3
Extremely negative	1
N/A	12
Participants	37
Blank	14

Do you discuss man-made crystals with customers, and if so, how do they respond?	
Extremely positive	5%
Somewhat positive	22%
Neither positive nor negative	30%
Somewhat negative	8%
Extremely negative	3%
N/A	32%
Participants	73%
Blank	27%
	100%

Do you discuss man-made crystals with customers, and if so, how do they respond?	
Extremely positive	8%
Somewhat positive	32%
Neither positive nor negative	44%
Somewhat negative	12%
Extremely negative	4%
	100%

On average, how would you rate your customers understanding of man-made crystals, prior to your discussion?	
Extremely knowledgeable	0
Very knowledgeable	1
Moderately knowledgeable	2
Slightly knowledgeable	10
Not knowledgeable at all	14
N/A	11
	38
	13

On average, how would you rate your customers understanding of man-made crystals, prior to your discussion?

Extremely knowledgeable	0%
Very knowledgeable	3%
Moderately knowledgeable	5%
Slightly knowledgeable	26%
Not knowledgeable at all	37%
N/A	29%
Participants	75%
Blank	25%
	100%

On average, how would you rate your customers understanding of man-made crystals, prior to your discussion?	
Extremely knowledgeable	0%
Very knowledgeable	4%
Moderately knowledgeable	7%
Slightly knowledgeable	37%
Not knowledgeable at all	52%
	100%

How would you rate your own appreciation of man-made crystals?	
Extremely positive	13
Somewhat positive	13
Neither positive nor negative	17
Somewhat negative	7
Extremely negative	1
	51

How would you rate your own appreciation of man-made crystals?	
Extremely positive	25%
Somewhat positive	25%
Neither positive nor negative	33%
Somewhat negative	14%
Extremely negative	2%
	100%

Comments:

⇒ Neither positive nor negative As a gem cutter and gem seller I'm not interested. For those that want it or can't afford the real gems it's a good alternative.

⇒ Neither positive nor negative They have their place but there are a lot of implications. What happens to the price of diamonds if the process became easier so they were cheaper. Some people want particular gem stones for their "energy" and because they are "of the earth". Lab grown needs to be sold as such at all levels so that customers are aware of what they are buying. There are definitely merits to lab grown but it needs to be regulated.

⇒ Extremely negative They aren't quite the same. A natural crystal has a certain feeling to it, and a natural charm that a synthetic gem can never replicate.

⇒ Somewhat positive There isn't enough information available to be able to compare use of energy and CO_2 production. I feel that they probably don't do as much environmental damage (no huge mines) but better still would be to recycle whats already available or source diamonds direct from the miners

⇒ Somewhat positive The selling of synthetics as natural gems plagued the gem industry. The world is full of opportunists and synthetics often get a bad reputation because of dishonesty. When disclosed as such, synthetics offer a less expensive and beautiful alternative to mined gems.

⇒ Somewhat negative I work with semiprecious and precious stones only

⇒ Extremely positive I would never be able to use natural diamonds in my work.

⇒ Somewhat positive some customers need too much education on the subject

⇒ Somewhat negative I feel like they wind up in the hands of unscrupulous dealers who try to pass them off as natural.

⇒ Neither positive nor negative I like the beauty of natural stones, also the value it holds compared to man-made

⇒ Somewhat negative Synthetic diamonds are depreciating in value constantly and will likely become as cheap as synthetic moissanite. The false claims of being environmentally friendly are false.

⇒ Neither positive nor negative I would like to know more about it

⇒ Extremely positive If I used gemstones I would choose lab grown because I try to work sustainably

⇒ Extremely positive I think they're excellent.

⇒ Somewhat positive The technology is very exciting

⇒ Neither positive nor negative They are another option to be considered

⇒ Somewhat positive I think they have their place. As a designer I use them when I want to create an exceptional piece but the client may not have the budget for a mined diamond. Rather than settle for a smaller or ugly mined diamond we can get a beautiful lab diamond.

⇒ Extremely positive Just love the beauty and the price. Mostly use Cubic Zirconium.

⇒ Extremely positive I see the value in using synthetic gemstones and they are (to the client at least) indistinguishable from natural gemstones. I very rarely (if ever) have problems with synthetic gemstones.

⇒ Somewhat positive I would like to have more transparenty in the overall process

⇒ Extremely positive My customers tend to not be very knowledgable about man-made, frequently asking if they're like CZs. After discussion with them, they frequently respond more positively.

Would you value man-made crystals higher than mined crystals?	
Always	1
Most of the time	3
About half of the time	4
Sometimes	15
Never	28
	51

Would you value man-made crystals higher than mined crystals?	
Always	2%
Most of the time	6%
About half of the time	8%
Sometimes	29%
Never	55%

100%

Comments

- ⇒ Never Mined gems are precious and rare. This helps give them value. Synthetic gems are infinitely abundant which makes them about as valuable as plastic.
- ⇒ About half the time Again, not too sure on this, I feel like it would depend a lot on specific circumstances and specifications of the particular gem.
- ⇒ Never There's value in nature putting something together
- ⇒ Never Very subjective in terms of comparison of material
- ⇒ Never As they are less rare, I feel they would have a perceived lower value
- ⇒ Never In economic terms they are much cheaper
- ⇒ Sometimes Certain synthetics are widely available and produced also for industrial uses (laser glass, etc.) Other synthetics can actually be more rare.
- ⇒ Always Natural incredibly destructive to mine, trade.
- ⇒ Never probably an old school "snob" attitude
- ⇒ Never Rarity is a major factor in value (either through nature or other supply constraints). The only way synthetics should be rare is if there's an artificial anticompetitive constraint (monopoly).
- ⇒ Never They aren't in any way as valuable.
- ⇒ About half the time It depends what is done with them, not just the stone on its own
- ⇒ Sometimes I work in a jewellery shop and lab grown gems are not perceived to have the same value
- ⇒ Sometimes For example, I like moissanite better than real diamonds
- ⇒ Never China, mass production, plastics, glass, chemicals, etc - all have links to lab stereotypes
- ⇒ Never The value of mined crystals is paid in much more blood than man-made crystals, which automatically increases their financial value by whatever a life or two is worth.
- ⇒ Sometimes Each stone has particular properties and hence value
- ⇒ Sometimes When it comes to rarity, it's hard to beat mined stones. They have the opportunity to create interesting and delightful specimens. A great example are parti sapphires from Montana and Australia. Or the rare coloured diamonds.
- ⇒ Never Can't value it more myself until public sees it that way. Chicken and the egg conundrum.
- ⇒ Sometimes I'm not convinced that one can put a higher value on synthetic gemstones unless one is specifically considering sustainability factors. Yes, for all intents and purposes they are chemically the same stone but a natural stone will always have the sense of individuality and uniqueness that a lab-grown stone will not have. A naturally sourced stone could be one-of-a-kind and although you can grow it, you cannot refer to a lab-grown version as one-of-a-kind. For example, an original Van Gogh artwork will always have an exponentially higher value than a print of that same artwork. In the same way, one could grow a diamond with almost identical qualities and characteristics as the Hope Diamond but it will never come close to having the same value because of the historical value and sentiment attached to the natural diamond.
- ⇒ About half the time I have a great respect for natural stones, as they are a creation of time and just the right conditions in the volatility of nature. I respect and value

man-made because the science that allows for their creation is amazing and their environmental impact is less destructive.

⇒ Never Supply and demand. Indeed, that's probably the only reason why they're not popular in the luxury market yet.

⇒ Never No. Knowing something is not natural doesn't always have appeal. Part of the joy of natural gemstones is precisely that they are natural.

Appendix 7: Neo-Gemstone Trademark

TRADE MARKS REGISTRY

Trade Marks Act 1994 of

REGISTRATION CERTIFICATE

Great Britain and Northern Ireland

I certify that the marks shown below have been registered as a series of 2 marks under No. UK00004002101 effective as of the date 15/01/2024 and have been entered in the register on 12/04/2024

Signed this day at my direction

Adam Williams
REGISTRAR

Representation of Marks
Mark 1

Neo-Gemstones

Mark 2

Neo-Gemstone

The marks have been registered in respect of:
Class 14:
Gemstones;Jewellery.

Class 42:
Design of jewellery;Research relating to design;Scientific research and development;Development (Research and -) of products;Product design and development;Product research.

In the name of Sofie Boons

Intellectual Property Office is an operating name of the Patent Office

Appendix 8: Meetings Log Case Study 2

Meetings with D Rytz

#	Date	Location
1	7/8/2020	Online
2	13/10/2020	Online
3	9/11/2020	Online
4	7/12/2020	Online
5	18/1/2021	Online
6	15/2/2021	Online
7	22/3/2021	Online
8	3/5/2021	Online
9	7/6/2021	Online
10	19/7/2021	Online
11	9/8/2021	In person
12	22/9/2021	In person
13	27/9/2021	In person
14	11/10/2021	In person
15	27/10/2021	In person
16	29/11/2021	Online
17	20/1/2022	Online
18	24/2/2022	Online
19	5/5/2022	Online
20	16/6/2022	Online
21	4/8/2022	Online
22	30/8/2022	Centre for Print Research
23	6/10/2022	Online
24	26/10/2022	In person
25	19/11/2022	In person
26	22/11/2022	In person
27	27/11/2022	In person
28	29/11/2022	In person
29	7/12/2022	In person
30	10/12/2022	In person
31	13/12/2022	In person

32	16/12/2022	In person
33	11/1/2023	Online
34	25/1/2023	Online
35	8/2/2023	Online
36	23/2/2023	Online
37	29/3/2023	Online
38	13/4/2023	Online
39	3/5/2023	Online
40	24/5/2023	Online
41	14/6/2023	In person
42	17/6/2023	In person
43	5/7/2023	Online
44	12/7/2023	In person
45	14/7/2023	Klein & Becker
46	18/7/2023	In person
47	19/7/2023	In person
48	17/8/2023	Online
49	6/9/2023	Online
50	27/9/2023	Online
51	29/9/2023	In person
52	3/10/2023	In person
53	1/11/2023	Online
54	22/11/2023	Online
55	20/12/2023	Online
56	24/1/2024	Online
57	21/2/2-24	Online
58	3/4/2024	Online
59		Online

Meetings with BU Chemistry Team

#	Date	Location
1	28/9/2020	Online
2	19/10/2020	Online
3	16/11/2020	Online
4	30/11/2020	Online
5	11/1/2021	Online
6	8/2/2021	Online
7	10/3/2021	Online
8	7/4/2021	Online
9	12/5/2021	Online
10	1/6/2021	Bristol University
11	9/6/2021	Online
12	21/7/2021	Online
13	27/7/2021	Bristol University
14	25/8/2021	Online
15	29/9/2021	Online
16	24/11/2021	Bristol University
17	2/3/2022	Bristol University
18	7/12/2022	Online
19	26/1/2023	Bristol University
20	16/2/2023	Online
21	20/2/2023	Sofie Studio
22	11/5/2023	Centre for Print Research
23	3/11/2023	Centre for Print Research
24	22/3/2024	Centre for Print Research
25	15/4/2024	Bristol University
26	3/5/2024	Centre for Print Research

Appendix 9: Bling It Project

Project Brief

BLING IT

For many years the production of diamond tools has revolutionised industrial processes ranging from the automotive industry to the gem trade. Lab grown diamond powders used for faceting, for example, attract higher prices than the natural material. However, until today the techniques used to produce these tools have not been widely applied as creative techniques and its waste remains stored in small and large diamond tooling companies (see fig. 1-6). Furthermore, the use of lab grown diamonds (or 'synthetics' as they are called in the industry) remains a highly contested subject in the jewellery field.

Project Aims

The aim of the project is to provide students with the background necessary to engage in an initial critical investigation of the *concept and social construct of value in relation to material culture* in contemporary European society. This through the creation of a *jewellery design*, utilising diamond waste materials innovatively and by producing a supporting *artist manifesto*.

This project will provide students with a general overview of the use and value of man-made diamond through examples of industrial and aesthetic applications and context. The project will also cover a select example of the waste materials that result from the processes used in the creation or working of these materials. To provide students with an understanding of *urban mining concepts*, the students will be introduced to the techniques these materials could be used for, and will be encouraged to come up with their own (if possible) application.






Project Objectives

- To introduce the concept of 'value', 'authenticity' and investigate our fascination with 'bling'.
- To introduce an 'urban mining' practice using waste diamond.
- To develop basic knowledge of man-made diamond (production, use and application).
- To create a considerate and sustainable jewellery design.
- To develop skills in the writing of artist manifestos.
- To develop skills in the presentation and pitching of ideas to industry.

Timings

Project week 1: 12-15 June
Project week 2: 17-21 July

Preparation

Prior to the session:
Please read the following texts as chosen by Sofie and Julia for discussion:

- Pyne, L. (2019) 'Conclusion' in *Genuine Fakes***:** *How Phony Things Teach Us About Real Stuff.* London, Bloomsbury Sigma.
- Sudjic, D. (2009) 'Luxury' in *The Language of Things.* London, Penguin.
- Amato, J. A. (2000) 'Dust' in Lange-Berndt, P. ed. (2015) *Materiality*. London, Whitechapel Gallery.
- Diepeveen, L. & Van Laar, T. (2021) 'Introduction' in *Shiny Things: Reflective Surfaces and Their Mixed Meanings*. Bristol, Intellect.

On Monday 12 June:
Please bring 2 objects (or images of said objects): the first, the object you consider most valuable to you, and second the object you (currently) own, that is least valuable to you.

About Effgen - Lappaport Schleiftechnik

For over 100 years, Effgen Lapport Schleiftechnik has been offering its customers individual solutions for the most demanding grinding tasks. Effgen Lapport Schleiftechnik offers grinding applications for almost every sector of industry. The company's product portfolio extends from conventional and high-performance grinding tools to dressing tools.

About Sofie Boons

Sofie works as a Research Associate and Crafts Council Research Fellow at the Centre for Print Research (University of the West of England), where she is working towards the completion of a PhD investigating the design implications, possibilities, and limits of utilising man-made crystals in the development of jewellery designs.

Scheme of Work

BLING IT

WEEK 1

DAY 1 Monday 12 June

- 9 AM - 12 AM:
  - ⇨ Icebreaker Activity: Discussion of objects
  - ⇨ Presentation
  - ⇨ Discussion of value/real-fake text
- 2 PM: Effgen Visit

DAY 2 Tuesday 13 June

- 10 AM – 2 PM:
  - ⇨ Effgen Visit
- 3 PM: Discussion Brief/material selections

DAY 3 Wednesday 14 June

- 10 AM – 12:30 AM:
  - ⇨ Manifesto Brief Setting
  - ⇨ Testing and production of tests
- 1:30 PM – 4 PM:
  - ⇨ One to one discussion on ideas for project and technical feasibility
  - ⇨ Plenary: what have we learned from working with the materials?

DAY 4 Thursday 15 June:

- 10 AM – 12:30 AM:
  - ⇨ Icebreaker activity: discussion of bling it projects
  - ⇨ Testing and production tests
- 1:30 PM – 4 PM:
  - ⇨ Group presentation and discussion of ideas
  - ⇨ Plenary: project brief discussion

WEEK 2

DAY 1 Monday 17 July

- 10 AM – 12:30 AM:
  - ⇨ Presentation of Task 1
- 2:00 PM – 4 PM:
  - ⇨ Review of pieces returned from Effgen
  - ⇨ Group discussion of Effgen outcomes and agreement of further developments for Task 2
  - ⇨ Plenary: Discussion of Manifesto Presentations

DAY 2 Tuesday 18 July

- 10 AM – 12 AM:
  - ⇨ Icebreaker activity: 2 manifesto presentations + discussion
  - ⇨ Finalising objects
- 1:30 PM – 4 PM:
  - ⇨ Walk around one-to-one discussions
  - ⇨ Finalising objects

DAY 3 Wednesday 19 July

- 10 AM – 12 AM:
  - ⇨ Icebreaker activity: 3 manifesto presentations + discussion
  - ⇨ Finalising objects
- 1:30 PM – 4 PM:
  - ⇨ Scheduled one-to-one discussion
  - ⇨ Finalising objects

DAY 4 Thursday 20 July:

- 10 AM – 12 AM:
  - ⇨ Icebreaker activity: 3 manifesto presentations + discussion
  - ⇨ Finalising objects
- 1:30 PM – 4 PM:
  - ⇨ Group presentation of final outcomes

DAY 5 Friday 21 July:

- 10 AM – 12 AM:
  - ⇨ Icebreaker activity: 1 manifesto presentation + group discussion on manifesto exercise
  - ⇨ Finalising objects
- 1:30 PM – 4 PM:
  - ⇨ 1-1 discussions to agree plan of action

Effgen Technical Brief

<table>
<tr>
<td rowspan="3">Object Image(s)
Please label each image (e.g. object 1 top view, object 2 side vies, etc.)</td>
<td>Student Details
Name:
Email:</td>
</tr>
<tr>
<td>Object Details
Number of objects submitted:

Materials:
Please provide a list for each object, e.g. object 1: Plastic</td>
</tr>
<tr>
<td>Effgen Techniques
☐ Electroforming
Metal:
Tickness:
☐ Graphite layer has been applied/is not needed
☐ Graphite layer needs to be applied

☐ Grit application
☐Grit included
Please staple to brief
☐Grit nr:
Please provide a list for each object (e.g. object 1: CBN 25)

☐ Stopping lacquer has been applied
☐ Stopping lacquer needs to be applied (describe in notes below)</td>
</tr>
<tr>
<td colspan="2">Student instructions and notes:</td>
</tr>
<tr>
<td colspan="2">Effgen notes:</td>
</tr>
</table>

Appendix 10: Published Journal Papers

VOLUME 15 ISSUE 2

The International Journal of
Design in Society

Man-made Crystals

A Review of their Historic and Contemporary Context and Use

SOFIE BOONS

COMMON GROUND

DESIGNPRINCIPLESANDPRACTICES.COM

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https://designprinciplesandpractices.com
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Man-made Crystals: A Review of their Historic and Contemporary Context and Use

Sofie Boons,[1] University of the West of England, UK

Abstract: This paper reports on the history and use of man-made crystals for jewelry in a contemporary context. The cross-disciplinary contextual review traces human fascination with gemstones back centuries, and covers key developments in their "imitation." The infiltration of these man-made crystals in the market sparked the development of the discipline of gemology, through which they are often painted in a negative light. With innovations in the growth of man-made crystals revolutionizing other industries (engineering, technology, etc.), and their distinction from mined crystals increasingly more challenging, the paper reports on the terminology prescribed to the industry to describe man-made and mined crystals. These descriptions, which include "natural" and "real" versus "synthetic," are interrogated in relation to key texts and a need for the identification of an alternative terminology is proposed. The jewelry industry remains apprehensive about the influx of man-made crystals, and only a small number of man-made crystal suppliers are growing crystals for the purpose of creative exploration beyond the imitation of mined crystals for jewelry. Through the review of artifacts, where man-made crystals have been used, their ability to enable creativity is highlighted, and their further future creative possibilities explored.

Keywords: Man-made Crystals, Jewelry Design, Contextual Review

A History of Crystals Growth and the Birth of Gemology

Gemstones have long captivated human imagination. They have been greatly valued throughout time and their use can be traced back centuries (Ogden 1992), even inspiring many myths. When we speak of a treasure, we do not have to look far in popular culture to see gemstone-filled boxes, or a large crystal at the center of attention (e.g., The Pink Panther movies). Perhaps human ingenuity can be traced back as far as our fascination with gemstones. As the following examples will demonstrate, it has been a human desire to recreate and imitate that which is considered valuable, including gemstones. Pearls were imitated in great numbers by the Romans, and later Assyrian *paste*, a glass imitation for gemstones, was very popular in Europe (Pearl 2011; White 1961). Jack Ogden, in his book *Diamonds: An Early History of the King of Gems* (2018), documents and describes a range of examples, including crown jewels and pieces dating back to ancient India, where "imitation" diamonds were incorporated.

It is not until the nineteenth century that successful experiments resulted in the first man-made crystals. Even though knowledge of the nucleation of crystals can be traced back further, the necessary advancement of technology in the nineteenth century resulted in the first man-made crystals being successfully created (Arem 1973). Regardless of the many who were experimenting with crystal growth in the nineteenth and early twentieth centuries, it is A. Verneuil who is considered the father of the technology (Scheel 2003). His fusion growth method from 1902 led to the first commercial production of crystals, and even though the technique is still used today, it also led to the development of a range of other techniques, including growing from the melt, for example the Czochralski process, which was named after its inventor (Scheel 2003).

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The influx of these man-made crystals in the market ultimately inspired the development of the branch of mineralogy and geoscience we now know as gemology (Dieulafait et al. 2011), set up to distinguish the mined gemstones from imitations. The sharing of rudimentary principles of the practice began in the nineteenth century, with the first official qualifications being developed and accredited by the National Association of Goldsmiths of Great Britain (NAG) through their gemological committee called the Gemological Association of Great Britain (Gem-A). Not much after, in 1925, the first laboratory was set up in London, which provided a gemstone identification and authentication service to jewelers. Early gemology books, like *Gemstones* by G. F. Herbert (1912), clearly depict man-made crystals as less valuable and fake, even going as far as referencing the knowledge and techniques employed in the endeavor as "weapons." To date, the limited literature available that is dedicated to man-made crystals in a jewelry context (Arem 1973; Elwell 1979; O'Donoghue 2007; Pedersen 2004; O'Donoghue 2008) has mainly been produced in the field of gemology, with a clear aim to enable the continued distinguishing of mined stones from their man-made imitations.

Since the field of gemology was developed to support the identification of gemstones, it therefore also serves as authenticator of value. With certain gemstones assigned great value, classification systems and formulae for the valuing of gemstones based on size and quality ensured clarity of value. For diamond, for which there are records of its prices dating back over a millennium and price lists including formulae for calculating its value for at least half that time (Ogden 2018), a very recognizable system was introduced in 1940 titled the 4 Cs. Clarity, Cut, Carat (weight), and Color were identified as the quality beacons (Bergstein 2016). Even today, there is an option to buy a certified diamond, which comes with a report on its performance against these four characteristics, and the better the diamond scores, the higher value it is. This system, which certainly supported the rise in sales for diamonds, as it resolved the issues sellers of diamonds had explaining why certain stones cost more than others prior to its invention, is now, in certain instances, also being used for laboratory-grown diamonds. Since laboratory-grown diamonds are created to score as high as possible in the criteria, an alteration to the approach might now be on the way. Even though many news articles are currently circulating the jewelry trade press surrounding man-made materials and their quality and sustainability credentials, little literature in the jewelry context to date portrays man-made crystals in a positive light.

Modern Crystal Growth Science

In other industries, meanwhile, crystal growth is driving innovations, for example in technology, medicine, electronics, and even nuclear-physics experiments now use grown crystals (Scheel 2003). Tens of thousands of tons are produced annually, of which the bulk consists of the semiconductors silicon (Scheel 2003). Even though it is a small percentage of the amount of crystals grown annually, nearly all crystals commonly used for jewelry can now be reproduced in the lab and these imitations are making their way into the market. Year on year, statistics are indicating the segment is growing (Bain & Company 2019), particularly due to the more recent advancements and interest of a number of companies in the growth of diamond.

> It is generally accepted to-day that diamond has never yet been artificially formed, and, moreover, with the means at our disposal its production in the factory or laboratory is unlikely in the extreme. Jewellers may therefore rest assured that there is no risk of catastrophic disruption of their trade by the provision of a supply of cheap synthetic diamonds, and that any one claiming to have produced such stones is suspect.
> (Herbert 1912, 138)

In contradiction to the writing of Herbert (1912), it is now possible to grow diamonds. Grown most commonly using Chemical Vapor Deposition (CVD) or High Pressure High Temperature (HPHT) processes, these diamonds are chemically and physically identical to mined diamonds. There are a couple of books available that reference the story of the invention of man-made diamonds in a light-hearted way, including *The Heartless Stone* by Zoellner (2007) and *Brilliance and Fire* by Bergstein (2016). In addition, there is a large selection of literature that documents the techniques and the application of grown diamonds in a range of other industries, available through science journals and crystal-growth science literature.

With a serious interest in crystal growth in a variety of industries, there is a vast amount of literature dedicated to the documenting of techniques, reporting of research, and exploring of applications in relation to crystal growth. There are research centers, conferences, and journals on the subject, where subject specialists are working or reporting on crystal growth in a myriad of manners and for a range of applications. However, in line with the small percentage of man-made crystals that is annually produced for the jewelry market (Scheel 2003), there is little or no literature investigating the opportunities and innovations for the incorporation of man-made crystals in a jewelry context. It appears that the small amount of crystals produced that make their way into the jewelry market is mainly produced to imitate mined crystals, and hardly any of the innovations taking place across other fields lead to innovations within the field for which they were originally produced.

There are some exceptions where stones have been grown outside of the blueprint found in nature; for example, Swarovski's vibrance collection of Cubic Zirconiums (CZ), launched in 2020, contains four Cubic Zirconium (CZ) stones that display color combinations that would not be found in nature (Swarovski n.d.). Another example of an innovation in the use of laboratory-grown crystals was achieved by the company Lonite (Lonite n.d.), which is one of a number of companies who have been able to perfect the technique to grow diamonds from the carbon extracted from the ashes of a loved one who passed away. With most of the research in crystal growth conducted by trained scientists and a hostile jewelry market, it is perhaps no surprise there is little to no cross fertilization of developments innovating other fields and the jewelry industry.

Man-made Crystals for Contemporary Jewelry

Having identified the industry has been keen to clearly distinguish mined gemstones from man-made crystals, it is worth exploring how these crystals, which have become indistinguishable from mined crystals, are currently positioned, used, and valued outside of the realm of gemology.

Marketing Regulations for Man-made Crystals

Driven by the mined industry, spearheaded by the Natural Diamond Council (previously known as the Diamond Producers Association), which is composed of seven diamond mining corporations representing 75 percent of the diamond mining industry, legislation and guidelines to market and sell man-made crystals, and particularly diamonds, has been devised and published by the Federal Trade Commission.

> It is unfair or deceptive to use the word "ruby," "sapphire," "emerald," "topaz," or the name of any other precious or semi-precious stone, or the word "stone," "birthstone," "gem," "gemstone," or similar term to describe a laboratory-grown, laboratory-created, [manufacturer name]-created, synthetic, imitation, or simulated stone, unless such word or name is immediately preceded with equal conspicuousness by the word "laboratory-grown," "laboratory-created," "[manufacturer name]-created," or some

> other word or phrase of like meaning, or by the word "imitation" or "simulated," so as to disclose clearly the nature of the product and the fact it is not a mined gemstone. (Federal Trade Commission 2018, 40674)

The lobbying to achieve this guidance, in addition to large amounts of money spent on advertising, educational materials, and resources, are all part of the mined industry's strategy (of which the largest is the diamond industry) to ensure efforts to distinguish man-made from mined stones is now a matter of terminology and legality rather than gemology. Since methods to distinguish man-made crystals from mined stones have become less effective, their value is determined by social construct.

Material Perceptions and Authenticity

With legislation at hand, the mining industry has not only lobbied to have terminology prescribed for man-made crystals; it has also coined its own terms to use when describing their produce. A clear example of an attempt to connect the word "natural" to diamonds has been the rebranding of the Diamonds Producers Association (DPA) to the Natural Diamond Council in June 2020 (The National Association of Jewellers 2020). With the additional use of the adjective "real," the aim is transparent: depicting man-made crystals as unnatural, artificial, and fake.

With these changes having only taken place recently, little literature, outside the standard popular press reporting, has investigated the suitability of these terms in this context. The debate around the appropriate defining of materials as natural or artificial is, however, not new, and there are some key texts that aim to unpack these terms in relation to materials. Ezio Manzini's *The Material of Invention* (1989) calls for a scale of depth to be assigned to artificiality, which is in turn further explored by other writers like, for example, Lerma and Palù (2019) in their paper "Natural Materials: A Family on the Move, But Where Is the Last Stop?" The latter explores materials through a multicriteria analysis and aims to map the difference between a "natural material" and a "sustainable material." Following the writing of Esther Leslie in her book *Synthetic Worlds: Nature, Art and the Chemical Industry* (2005), all that is natural and can exist is natural, but when a material or product has been exposed to a specific process, it is considered synthetic.

If the process a material or product has been exposed to determines whether a material is "unnatural," "synthetic," and/or "fake," who decides which processes are acceptable and which are not? To illustrate the complexity, we could compare the production of cotton or extraction of gold with the growth of diamonds. Cotton is grown and seeds are harvested, which are refined into thread; a fabric is formed, which is shaped and dyed or other post processes are applied before it is used as a product. The laboratory-grown diamond is grown from a seed, cut, faceted, and polished into a shape, before it is incorporated into jewelry. Cotton is subjected to substantially more processes than the laboratory-grown diamond—so why is the one considered natural and the other artificial? Perhaps Lydia Pyne's (2019, 179) conclusion is a suitable one: "Objects don't have an intrinsic morality to them – context is everything.' If context is, in fact, what defines a material's authenticity and in turn the terminology that can be associated with it, then it is important that definitions continue to be challenged, not only by the industry when it could have commercial consequences, but also by those appropriating these materials as authors and those acquiring them as consumers.

The mined industry has been keen to align with the writings of Humberto Maturana (1980) promoting the ahistorical and autopoietic process with which mined crystals come into being, therefore distinguishing them as natural from their "artificial" competitors, whereas the laboratory-grown crystal companies have wanted to promote the sustainable nature of the laboratory-grown crystals. In marketing literature, there is plenty of work prescribing the benefits of aligning your product with the ongoing trend that sees consumers preferring natural produce over synthetic alternatives (Ormondroyd and Morris 2019). Yet paradoxically, since the impact of mined crystals, depending on the process applied, can be highly unsustainable, man-made crystals could prove to be a more sustainable option (Abrose 2020). Companies like Sky Diamond (Skydiamond n.d.), who claim to produce carbon-negative diamonds and are extracting carbon out of the sky for their production, is an example. With the free press readily reporting on these findings, particularly in relation to diamonds, and the market segment growing year on year (Danziger 2019), it remains to be seen how this will shift the social construct and its context and, in turn, affect the need for the terminology assigned to be reconsidered.

Examples of Innovations in the Creative Use of Man-made Crystals for Jewelry

Despite all controversy and the limited amount of innovation in the creation of man-made crystals for use in jewelry, they have been incorporated by an increasing number of designers, and have, for some, provided design options that previously would have not been considered feasible and/or acceptable. Some designers have taken liberties with the stones, bypassing “traditional conventions”; for example, by drilling large holes or cutting them in innovative shapes or even enclosing them in unusual materials like rubber. An example is the brand SOMA, whose designer drilled large holes in lower-cost lab-grown CZs to enable them to be hooked on hoop earrings. Another example is the all diamond ring produced by Jony Ive and Marc Newson’s cutting the material so it does not need to be set in a metal ring. Other designers, like Karl Fritsch, have used the lab-grown materials in their unaltered, uncut, and unpolished form.

When reviewing the innovative use of man-made crystals in jewelry, two distinct approaches have been determined as most promising for jewelry, and will be investigated in the overarching PhD currently being conducted. The first is the opportunities and liberties certain designers take with man-made crystal materials, likely related to their low cost. Whether it is cutting holes, cutting stones in half, or cutting them in new ways, that would not prove financially viable. These interventions become options for designers due to the currently low cost of some man-made crystals and the large format they can be acquired in. The other is the actual innovation in the material itself, as demonstrated by the new color combinations by Swarovski in their Vibrance collection. With designers like Karl Fritsch incorporating the material in its unaltered state as another example, perhaps with the opportunities for designers to be creative with the material when it is not reproduced to look like what we already know, innovations could be ample.

To date, the latter opportunity has already been explored by setting up a range of crystal-growth experiments in the jewelry studio environment. Even though the crystals being grown are not of gemstone quality (salt, sugar, and alum), the growing of crystals as methodology for the jewelry designer holds great potential (Boons 2021), as it could also be applied to the growing of gemstone-grade crystals in collaboration with partners or upon acquiring specialist equipment. Not unlike the materials used for bio-art and bio-design (Kac 2020; Koivumen 2005; Myers 2012), the growability (Karana and Camere 2017) of crystals, or in other words its ability to be grown in a certain shape or direction, could potentially enable designer to grow crystals in predetermined shapes (see Figures 1 and 2). Crystals grown in a predetermined shape could reduce material loss and cost, and lead to the development of new stone cuts.


Figure 1 (Left): Sugar Crystals Grown in Ring Mold over Eight Days
Figure 2 (Right): Alum Seed Crystals Distributed across a Ring Mold, Suspended in Saturated Solution
Source: Boons

Additionally, the growing of the crystal around designed inclusions (see Figure 3) could also provide aesthetic opportunities. In nature, crystals can contain impurities; often they grew around obstacles in their environment, resulting in inclusions. These are generally considered faults, and only on rare occasions within gemology are they valued. To design them, however, would offer new possibilities to embed patterns and elements, or introduce color and contrast to the crystal.

Figure 3: Various Views of a Grown Single Sugar Crystal with Brass Wire Inclusion
Source: Boons

Further experiments also proved the growing of crystals in a predetermined space in a design—or in situ growth—holds additional design opportunities. When a crystal is grown, control over growing conditions can give the designer sufficient ability to embed the process into the design practice. There are, however, limitations, as not all aspects of the growth can be controlled and a designer will have to approach the methodology as a co-design practice with nature. The individual shape the crystal displays, albeit always similar due to the underlying crystal structure the atoms will align in for each crystal, will still grow in somewhat unpredictable directions (see Figure 4).

Figure 4: Silver Ring with In Situ Grown Alum Crystal from Various Views:
Before-Growth Images on the Left and After-Growth Images on the Right
Source: Boons

As discussed in the paper "Crystals as Co-Creators: An Investigation of Growing Crystals as a Methodology for Jewelry Designers" (Boons 2021), the crystal-growing methodology poses challenges for the jewelry designer who is generally used to being in control of all aspects in relation to the incorporation of stones. Moreover, the delayed process and the additional equipment the growing of gemstone grade crystals requires, which could result in the distancing of the process from the studio environment, are challenges to be investigated further.

Nevertheless, the crystal-growing design methodology (Boons 2021) clearly offers additional opportunities for innovation, and the potential for an alternative and likely more sustainable option to traditional gemstone incorporations. The growing of gemstone-grade crystals is likely to be less sustainable than the growing of alum, sugar, and salt, but the impact of the growth could be analyzed in detail and it is expected to still be more sustainable should stones be able to be grown locally, eliminating the need for extraction practices and transportation.

Conclusion

To complete the cross-disciplinary contextual review on man-made crystals, this paper had to cover a diverse range of sources spanning a number of fields, including gemology, crystallography, humanities, etc. To report on the limited creative use of man-made crystals for the production of jewelry designs, the paper traced the desire for gemstones and their imitations in history and explored the development of the discipline gemology as a means to identify and value crystals. The paper showed that in gemology, man-made crystals are often painted in a negative light. By exploring the terminology appropriated by both mined and man-made crystal companies, a short review of the terminology used to describe man-made and mined crystals was conducted through a critical lens. Key texts investigating the distinction between the natural and artificial were referenced in order to sketch various approaches. Furthermore, although significant innovations in man-made crystals are revolutionizing other sectors (i.e., technology and engineering), the paper aimed to demonstrate that in the jewelry industries, where crystals are used in great numbers, there has been limited creative exploration of these grown materials. The jewelry industry, instead, has only a sparse number of jewelry crystal suppliers taking an interest in growing crystals for the purpose of creative exploration beyond the imitation of mined crystals. Jewelry designs and man-made crystals were reviewed, and a short discussion concluded the paper on how these materials enabled creativity in design. In the overarching PhD research, the design implications, possibilities, and limits of utilizing man-made crystals in the development of jewelry will be investigated. The research will aim to evaluate the possibility and practicality of incorporating the researched man-made crystals and their design process and overarching crystal growing methodology into a contemporary jewelry practice. Furthermore, the terminology used to reference man-made crystals will be fully reviewed in order to identify the need for the reframing and renaming of enhanced and designed crystal materials when used in a contemporary jewelry context.

Acknowledgement

This paper was written as part of a PhD study investigating the design implications, possibilities, and limits of utilizing man-made crystals in the development of jewelry at the Centre for Fine Print Research in the University of the West of England. For their encouragement and guidance in the conducting of my research, I would like to thank my Director of Studies, Dr. Sarah Bodman, supervisor Dr. Laura Morgan, and mentor Adrian Geisow. A special thanks also to Dr. Daniel Rytz, whose guidance through many hours of discussion has sharpened my focus.

REFERENCES

Abrose, Julian. 2020. “Ecotricity Founder to Grow Diamonds ‘Made Entirely from the Sky’.” *Guardian*, October 30, 2020. http://www.theguardian.com/environment/2020/oct/30/ecotricity-founder-to-grow-diamonds-made-entirely-from-the-sky.

Arem, Joel E. 1973. *Man Made Crystals*. Washington, DC: Smithsonian Institution Press.

Bain & Company. 2019. “Diamonds In The Rough: Global Diamond Industry Experiences Challenges Across Value Chain Leading Up To Holiday Season.” *PR Newswire,* December 11, 2019. https://www.prnewswire.com/news-releases/diamonds-in-the-rough-global-diamond-industry-experiences-challenges-across-value-chain-leading-up-to-holiday-season-300972912.html.

Bergstein, Rachelle. 2016. *Brilliance and Fire: A Biography of Diamonds*. New York: Harper.

Boons, Sofie. 2021. “Crystals as Co-Creators: An Investigation of Growing Crystals as a Methodology for Jewelry Designers.” *FormAkademisk - Forskningstidsskrift for Design Og Designdidaktikk* 14 (2). https://doi.org/10.7577/formakademisk.4190.

Danziger, Pamela N. 2019. “While Mined Diamond Sales Decline, The Future Of Lab Grown Diamonds Is Much More Than Jewelry.” *Forbes*, December 15, 2019. https://www.forbes.com/sites/pamdanziger/2019/12/15/mined-diamond-sales-decline-as-the-future-is-in-laboratory-grown-diamonds/.

Dieulafait, Louis, G. F. Herbert, William F. Foshag, Richard M. Pearl, Robert Webster, and A. H. Church. 2011. *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*. Alcester: Read Books Ltd.

Elwell, D. 1979. *Man-Made Gemstones*. Chichester: Ellis Horwood Ltd.

Federal Trade Commission. 2018. *Federal Register*. Vol. 83. https://www.govinfo.gov/content/pkg/FR-2018-08-16/pdf/2018-17454.pdf.

Herbert, G. F. 1912. *Gemstones*. London: Methuen and Co LTD.

Kac, Eduardo. 2020. “Bio Art.” *AI & SOCIETY*, June. http://link.springer.com/10.1007/s00146-020-00958-4.

Karana, Elvin, and Serena Camere. 2017. “Growing Materials for Product Design.” In *Alive Active Adaptive: International Conference on Experiential Knowledge and Emerging Materials* EKSIG, 101–115. Delft: Delft University of Technology.

Koivumen, Hamnele. 2005. “Bio Design Products: Co-Design with Nature.” In *Joining Forces,* 4. Helsinki: University of Art and Design Helsinki. http://www.uiah.fi/joiningforces/papers/Koivunen.pdf.

Lerma, Beatrice, and Doriana Dal Palù. 2019. “Natural Materials. A Family on the Move, but Where Is the Last Stop?” *Design Journal* 22 (supp1): 1543–1554.

Leslie, Esther. 2005. *Synthetic Worlds: Nature, Art and the Chemical Industry*. London: Reaktion.

Lonite. n.d. “Lonite: Swiss Cremation Diamonds.” March 3, 2021. https://www.lonite.com/cremation-ashes-into-diamonds/.

Manzini, Ezio. 1989. *The Material of Invention*. Cambridge, MA: MIT Press.

Maturana, H. R., and F. J. Varela. 1980. *Autopoiesis and Cognition the Realization of the Living*. Dordrecht: D. Reidel Publishing Company.

Myers, William. 2012. *Bio Design: Nature, Science, Creativity*. London: Thames & Hudson.

Natural Diamond Council. n.d. “Natural Diamond Council.” *Only Natural Diamonds* (blog). Accessed June 10, 2020. https://www.naturaldiamonds.com/council/.

O’Donoghue, Michael. 2007. *Artificial Gemstones*. London: NAG Press.

O’Donoghue, Michael. 2008. *Synthetic, Imitation and Treated Gemstones*. London: NAG Press.

Ogden, Jack. 1992. *Ancient Jewelry*. Berkeley, CA: University of California Press.

Ogden, Jack. 2018. *Diamonds: An Early History of the King of Gems*. New Haven, CT: Yale University Press.
Ormondroyd, Graham A., and Angela F. Morris. 2019. *Designing with Natural Materials*, 1st ed. Milton: CRC Press. https://doi.org/10.1201/9780429457029.
Pearl, Richard M. 2011. "Popular Gemology." In *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*, 26–49. Milton Keynes: Read Books Ltd.
Pedersen, Maggie Campbell. 2004. *Gem and Ornamental Materials of Organic Origin*. Oxford: Elsevier Butterworth-Heinemann.
Pyne, Lydia. 2019. *Genuine Fakes How Phony Things Teach Us About Real Stuff*. London: Bloomsbury Sigma.
Scheel, Hans J. 2003. *Crystal Growth Technology*. West Sussex: John Wiley & Sons Ltd.
Skydiamond. n.d. "Skydiamond." March 3, 2021. https://skydiamond.com/.
Swarovski. n.d. "Vibrance Family: Swarovski Gemstones and Zirconia." February 3, 2021. https://www.swarovski-gemstones.com/launch/Vibrance_Family.en.html.
The National Association of Jewellers. 2020. "The DPA Relaunches as 'Natural Diamond Council'." June 1, 2020. https://www.naj.co.uk/news/the-dpa-relaunches-as-natural-diamond-council.
White, E. A. D. 1961. "Quarterly Reviews: Synthetic Gemstones." *Chemical Society* 1.
Zoellner, Tom. 2007. *The Heartless Stone: A Journey through the World of Diamonds, Deceit, and Desire*. New York: Picador.

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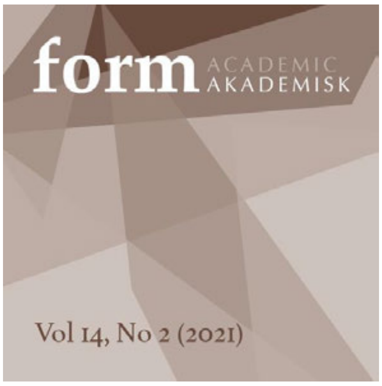

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Crystals as Co-creators

An investigation of growing crystals as a methodology for jewellery designers

ABSTRACT
Grown crystals are used for a range of novel innovations supporting a wide array of industries. Within the jewellery industry however, grown crystals are only used in a limited capacity and mainly as a surrogate for mined gemstones. This paper investigates the methodology of Crystal Growing Design, through conducting experiments testing four hypotheses developed around the practice. Through utilising a DIY approach the author investigates the opportunities and challenges presented by incorporating the methodology into her jewellery design practice. Sugar, alum and salt are experimented with to provide a theoretical experimentation of the methodology to justify the further incorporation and adaptation of more enhanced growing processes as used for the growing of gemstone quality crystals.

Keywords:
Crystal Growing Design, methodology, jewellery.

INTRODUCTION
Jewellers around the world have used crystals for the creation of jewellery for centuries (Arem, 1977; Philips, 2012). Within the field, expert identification and optimisation techniques have developed and a worldwide gemstone trade was established. Today however, some significant innovations in the materials and processes naturally associated with jewellery have been achieved in other sectors. Bespoke man-made crystals are revolutionising technology and engineering; diamonds grown microscopically on sheet to optimise conductivity (American Institute of Physics, 2017) are present in high performing microchips and the laser industry has seen major improvements due to the introduction of synthetic sapphire components developed to specifications (Stone-Sundberg, 2013), to name just a few. In the jewellery industry, where crystals are used most visually and in significant numbers however, there has been limited innovation in the creative use and adaptation of man-made crystals, aside from investing in the creation of man-made crystals to imitate mined crystals. Limited attention is spent on the exploration of the possibilities man-made crystals and related processes provide in a creative jewellery design context.

Meanwhile outside the jewellery industry, the democratisation of science has led to an increasing number of designers interested in DIY approaches to growing materials (Karana & Camere, 2017). Even though the materials used in biodesign/art (Kac, 2020; Myers, 2012) are not crystals, the processes to grow crystals have clear commonalities with those related to the growth of 'alive' materials in biodesign/art. Scholars in the field (Kac, 2020; Karana & Camere, 2017; Myers, 2012; Rognoli et al., 2015; Van Dijk, 2016) have commented on the opportunities the methodology of growing materials holds for designers, ranging from achieving novel aesthetics, their grow-ability and their sustainability credentials. With the number of product designers involved with growing materials expanding, and the emerging practice of DIY growing evolving (Karana & Camere, 2017; Rognoli et al., 2015; Van Dijk, 2016) this paper documents and reflects on the jewellery designs produced with DIY grown crystals. This in order to identify whether the methodology of growing crystals holds further possibilities for enhanced creativity when designing jewellery as well as exploring other benefits.

GROWING MATERIALS AS DESIGN METHODOLOGY

> In a crystal we have clear evidence of the existence of a formative life principle, and though we cannot understand the life of a crystal, it is nonetheless a living being. (Nikola Tesla, 1900)

Contemporary jewellery design situates itself between design and art (den Besten, 2011). Since examples of the use of grown materials are more prevalent in the design discipline, the contextual review has been extended to this neighbouring discipline. Writings from the field of mostly design, and less prevalent art, are therefore reviewed in order to establish commonalities in the practice that can be considered crossdisciplinary.

Biodesign/art apply biotechnological methods in order to manufacture artefacts with living organisms (Koivumen, 2005). Even though the materials used in biodesign/art (Kac, 2020; Myers, 2012) are not crystals, the processes to grow crystals have clear commonalities with those related to the growth of *alive* materials in biodesign/art. Also referred to as *The New Artisans* (Collet, 2013) these makers consider nature as co-creator and utilise natural growth for fabrication (Karana & Camere, 2017), taking advantage of the self-controlled production process (Rognoli et al., 2015) and the diverse form of expressions that are achievable (Antonelli, 2012). In the article 'Materials for Product Design' Serena Camere and Elvin Karana (2017) reflect on the distinct characteristics and advantages of *Growing Design*. They indicate designers employ living organisms to achieve specific design purposes and materials for the use in products.

Their outcomes bring higher sustainability, not only because what they are made of is often compostable and biodegradable, but the way they are produced is increasingly efficient in contrast with the production of artefacts from materials that have often taken ages to form. Additionally, the *grow-ability* of the material provides new opportunities for designs as well as increases efficiency, for example through the growing of the material directly in a pre-determined shape using moulds. The article also highlights the importance and opportunities linked to time and scale as a characteristic of *Growing Design*. Often requiring weeks instead of days, and working on a microscopic level, the design process is impacted and designers have to adapt to working methods generally applied by scientists. Which as a benefit enables them to increase control over the qualities of the material and the fabrication process. The variables designers can manipulate range from the material ingredients and growing conditions to the processing. Finally the article reflects on the symbiotic relationship between the designer and nature as co-creator, as stimulation to reflect on our relation to nature. 'Growing Designers forge the conditions for the invention of new matter, which would not exist otherwise.' (Karana & Camere, 2017). Designers set up processes in which nature as co-creator, with some degree of unpredictability, completes some key elements of the process.

GROWING CRYSTALS FOR JEWELLERY DESIGN

Crystals, gemstones and gems

The word crystal has Greek roots and used to mean clear ice, and still to date is called upon for a range of confusing uses from signifying cut glass and a clear ball to predict the future, to a gem in a piece of jewellery (Holden & Morrison, 1982). To physicists and chemists however, a crystal is a solid material with atoms arranged in an orderly way.

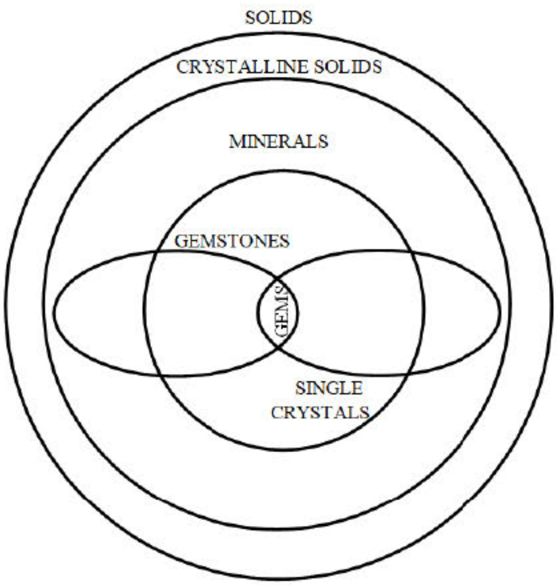


FIGURE 1. The classification of solids, crystalline solids, minerals, gemstones, single crystals and gems.

Not all gemstones are crystals (Arem, 1977) and even though a range of the minerals considered gemstones can be classed as single crystals (gems), there are exceptions: for example opal, which is a non-crystalline material; and agate, which is a microcrystalline material. Furthermore, not all single crystals are considered gemstones, since the minerals generally considered suitable for jewellery designs are usually expected to be adequately resistant to the conditions in which jewellery is worn. Therefore most crystals used for jewellery are durable in addition to displaying appealing optical properties. A table (Table 1) with the properties of four common single crystal gemstones (gems) used for jewellery are documented below.

TABLE 1. Properties of common gems.

Crystal	SPECIFIC GRAVITY	HARDNESS	REFRACTIVE INDEX	LUSTRE	COLOUR
Diamond (Carbon)	3.4-3.5	10	2.42	Adamantine	All colours
Sapphire (Aluminium Oxide)	4-4.1	9	1.76-1.77	Adamantine to vitreous	Most colours
Emerald (Aluminium Berryllium Silicate)	2.7-2.8	7.5-8	1.565-1.602	Vitreous	Green, yellow-green to blue
Quartz (Silicon Dioxide)	2.65	7	1.54-1.55	Vitreous	All colours

Crystal growth

The quest to reproduce materials found in nature can be traced back to the Egyptians (Pearl, 2011) and most gemstones have been reproduced in the lab (Webster, 2011) through a range of techniques, many of which are still in use today (Arem, 1973, 1977; Carter, 2015; Holden & Morrison, 1982; Scheel, 2003). Focussing here on the growth of single crystals, these techniques enable the perpetuation of the pattern or order of atoms either through vapour growth, melt growth, flux growth or solution growth (Arem, 1977) and display many parallels in methodology with the growth of *alive* materials in biodesign/art. Furthermore, since crystal growth is theoretically simple to do (Holden & Morrison, 1982), some of these processes lend themselves well to a *DIY material practice* (Karana & Camere, 2017; Rognoli et al., 2015). The process chosen for the experiments conducted as part of this paper is solution growth, one of the most familiar crystal growth environments (Arem, 1977).

Chosen for its major advantages, including high mobility of dissolved elements, convenience and relative controllability, it provided the ideal process for initial testing as part of the research. In the solution growth process a seed crystal is used to attract unattached atoms present in the solution. Growth takes place when the solution contains more loose atoms than the solution can handle at a specific temperature (Arem, 1977), also called saturation (Holden & Morrison, 1982). Because the growth of gemstone grade crystals in solution (for example emerald, amethyst, quartz and citrine) generally requires more elaborate and high cost equipment, in order to achieve higher temperature and pressure, the first experiments set to test the methodology of Crystal Growing Design for jewellery were conducted with crystals not considered gemstone quality. Alum, sugar and salt can all be disolved in water and the growth of these crystals can be achieved at normal room temperature and pressure. The low-cost equipment needed, and subsequent process to grow the chosen crystals, is relatively straightforward to set up within the jewellery studio, easing the shifting between traditional jewellery and crystal growing processes.

Crystal selection and their use for jewellery design to date

Alum, sugar and salt (Table 2), are not considered gemstone quality and evidently have only been used by a handful designers to date.

TABLE 2. Properties of alum, sugar and table salt.

Crystal	SPECIFIC GRAVITY	HARDNESS	REFRACTIVE INDEX	LUSTRE	COLOUR
Alum (Aluminium Sulfate)	1.47	2-2.25	1.47-1.48	Vitreous	Clear to amber or light green
Sugar (Aluminium Oxide)	1.1	2-2.25	1.76-1.77	Vitreous	Clear to light yellow
Table Salt (Sodium Cloride)	2.17	2-2.25	1.54	Vitreous	Clear to white

Among those designers incorporating salt is Naama Bergman (Anderson & Carboo, 2016; Bergman, n.d.) whose pieces are made out of crystallised salt on iron structures. The brooches are a celebration of the geometric patterns both created by the structures and the salt crystals and celebrate the material's nature. Similarly, the collection titled 'Eclats the Roche' (Figure 2 and 3), in which silver necklaces and earrings were crystallised with sugar, the fragile nature of the crystals also formed an inherent part of the concept for the pieces, which once the sugar has broken off or disolved, change appearance and shape. As a final example, the choice of salt in the work of Jiyoon Hyun (Creativity Oggetti, n.d.; Hyun, n.d.) in contrast, aims to elevate the status of salt in our current society and here the crystals' fragile nature has been bypassed by protecting them with a layer of varnish. The associated material experience (Karana et al., 2014) is a key factor for the choice of salt and sugar by the respective designers. The material experience of the materials used for the experiments in this paper will not be further explored, instead the paper will investigate the methodology of growing crystals for the development of creative designs incorporating grown crystals as pre-cursers to justify the further incorporation and adaptation of more enhanced growing processes as used for the growing of gemstone quality crystals.

FIGURE 2. Eclats De Roche 1, by Sofie Boons, Maga Hermans, Lien Herreijgers, 2009, photography by Max De Cock.

FIGURE 3. Eclats De Roche 2 by Sofie Boons, Maga Hermans, Lien Herreijgers, 2009, photography by Max De Cock.

Review of four Crystal Growing Design experiments for jewellery

To evaluate the growing of crystals as a methodology for jewellery designers, four sets of experiments were developed in response to four hypotheses. The multiple experiment approach was chosen in order to evaluate and compare different approaches in growing crystals within the jewellery studio environment. Below each hypothesis is explained and images of the set up, various stages of the design (to document the growth) and the final outcomes are discussed. The results of the experiments selected for this paper represent only a small fraction of the total number of experiments conducted over a six-month period. The incorporated results were chosen to illustrate the theoretical examination of the methodology.

Environment and equipment

All experiments were conducted in the jewellery studio (Figure 4) at room temperature and room pressure over a period of 6 months.

FIGURE 4. Jewellery studio. All following photographs in this article are by the author.

All crystals were grown in glass bowls, located on a shelf (Figure 5 and 6). The equipment used was: steel and brass wire, glass bowls, plastic measuring cups, portable electric hob, a pan, plastic stirrers and a scale. For some experiments silicon moulds were produced. No additional specialist equipment was purchased. Plant based transparent resin (to enable the inspection of the growth) or green wax (to enable casting) models were created using a small UV 3D printer. Silver and brass models were produced through casting wax models or direct forming techniques.

FIGURE 5 AND 6. Saturated solutions in glass containers (Figure 5) and crystal growing set up (Figure 6).

Seed crystals and saturated solutions

All experiments required the preparation and monitoring of supersaturated and saturated solutions and production, placement and suspension of seed crystals. The solutions were a selection of de-ionised water or tap water and alum, sugar or salt. Both de-ionised water and tap water were used to compare the resulting crystals, which resulted in a difference of colour for sugar (de-ionised water grown crystals were less yellow in tone), but seemed to have little impact in the appearance of alum and salt crystals. The working procedure and the recipe for alum is documented in the book 'Crystals and Crystal Growing' by Alan Holden and Phylis Morrison (1982). The recipe for sugar and salt was 1:2 water/sugar or salt ratio, and was based on previous experimentation. The *growing by evaporation method* and *sealed jar* method were both trialled for a selection of the experiments. From the tests, both methods worked more or less as described (Holden & Morrison, 1982), and neither were found to have distinct advantages. In all experiments seed crystals were used as a basis for developing the designs. These were then suspended in saturated solutions until a desired size was achieved, after which they were removed and washed with tap water.

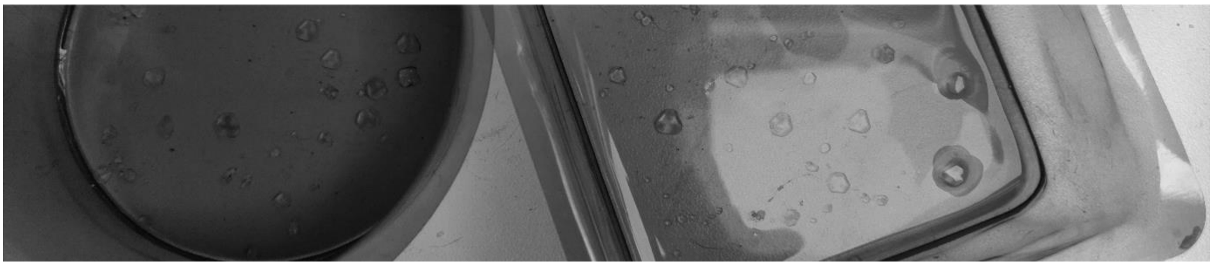


FIGURE 7. Alum seed crystal growth.

Hypothesis 1: growing crystals in situ

The first hypothesis identified to be tested is the growing of crystals in situ in a design. Generally gemstones are incorporated in designs by *setting*. The art and craft of setting gemstones in jewellery has mostly revolved around the creation of a setting, or creating a suitable space in the metal where the stone is held into place in the design. There are many varieties and approaches to setting gemstones (Cheadle, 2018; Hunt, 2013; McIntyre, 2020; Young, 2012). Growing a stone in situ in the design would enable the designer opportunities to reimagine how stones could be incorporated and fixed into their designs. To test this hypothesis a range of experiments were conducted in which a range of produced rings were fitted with a seed and suspended from a steel wire in the saturated solution (Figure 8, 9 and 10). In these experiments the hypothetical growth of crystals was kept in mind whilst designing pieces.

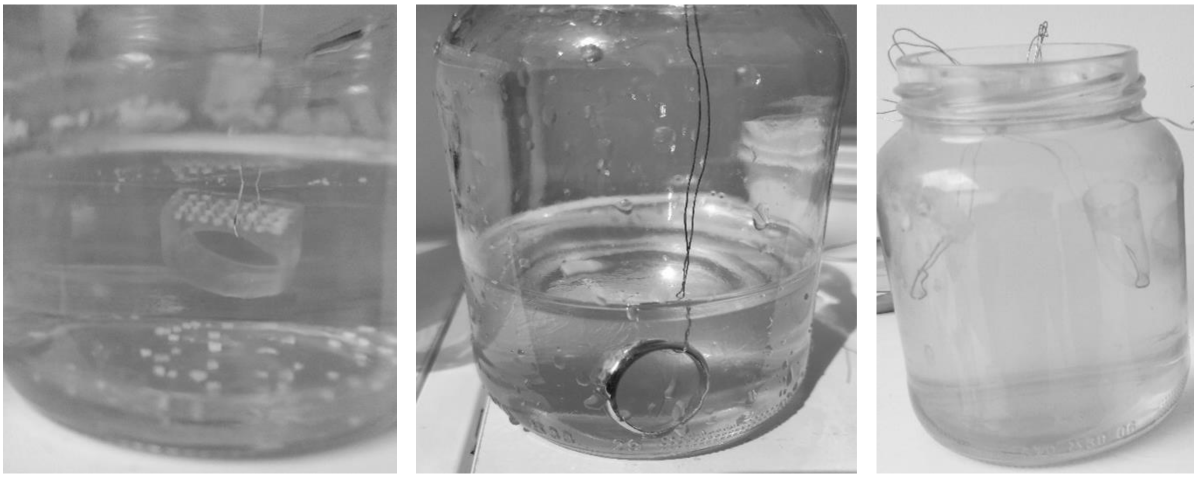
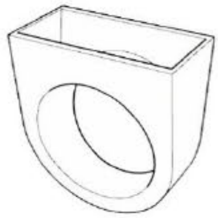


FIGURE 8, 9 AND 10. Salt crystal growing experiment with resin model (Figure 8). Alum crystal growing experiment with silver ring (Figure 9). Sugar saturated solution with resin models suspended from brass wire (Figure 10).

In a first range of tests it was the intention to grow a single crystal in a predetermined open space. The designs of the pieces were simple in terms of shape in order to enable the close monitoring of the crystal growth. Evident in these experiments is the individual shapes each crystal displays, and the unpredictable direction the growth of the crystal has. Sugar atoms grow in a monoclinic structure resulting in a hexagonal prism shape, whereas alum atoms grow in a cubic structure resulting in octahedras with flattened corners. Salt on the other hand grows in the cubic structure resulting in cubelike crystals. The single crystal sugar ring (Table 3), which was grown over a period of 3 weeks, started growing over the edge of the ring. It did however not grow in the other directions.

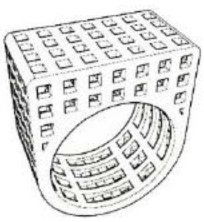
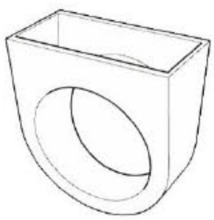
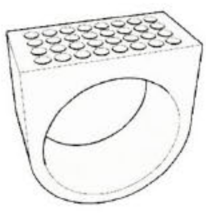
TABLE 3. Single crystal experiments.

Crystal	3D DESIGN	RESIN 3D PRINT	MODEL + SEED	OUTCOME
Alum				
Sugar				

Interestingly, when a solution became unsaturated the crystals suspended inside them would decrease in size. This process, albeit challenging to control without further tools to monitor the solution, could be useful to correct crystals that have grown too large.

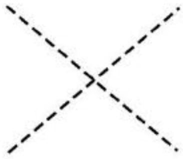
In further experiments the base model allowed for multiple seed crystals to be grown simultaneously, in order to incorporate a range of crystals in an organised or unorganised pattern and study the formation of *polycrystalline crystals*.

TABLE 4. Polycrystal formation experiments.

Crystal	3D DESIGN	RESIN 3D PRINT	MODEL + SEED	OUTCOME
Alum				
Sugar				
Salt				

The resin 3D printed models posed no issues for the glueing and attaching of crystals. To test whether the same would be true for metal, some experiments were conducted with silver models (Table 5). There was no distinct difference between the growth of crystals on silver or resin. Further research could test whether this applies to all precious metals and their various alloys, albeit most logically this research takes place with gemstone quality solution growth crystals instead.

TABLE 5. Crystal growth on metal experiments.

Crystal	3D DESIGN	RESIN 3D PRINT	MODEL + SEED	OUTCOME
Alum				
Sugar				

Hypothesis 2: growing single crystals with inclusions

For the second hypothesis the fact crystals can contain impurities, by for example growing around obstacles, was discovered as an opportunity whilst testing the growing of a single sugar crystal, suspended in its saturated solution through a brass wire. Since the crystal faces exposed continued to connect with sugar molecules in the saturated liquid the wire eventually became encapsulated by the crystal (Figure 11, 13 and 14). Within gemmology, inclusions are generally considered 'faults', however, the design opportunity present with growing crystals incorporating *designed inclusions*, seems very promising.

FIGURE 11. Single sugar crystal suspended from brass wire in supersaturated sugar solution.

Therefore, for the second single crystal growth experiment, the brass wire was shaped into the number 2020 before it was wrapped around an alum seed crystal and suspended into a saturated solution. The resulting crystal incorporated the shaped brass wire as an inclusion. Even though there was some distortion of the number, the result was promising. Further experiments currently under development will be investigating the opportunities which designed inclusions can provide jewellery designers in more detail.

FIGURE 12, 13 and 14. Single crystal alum with silver inclusion grown in resin model – before image on the left and after growth images on the right (Figure 12). Various views of a grown single sugar crystal with brass wire inclusion (Figure 13). Various views of a grown single alum crystal with brass wire inclusion (Figure 14).

Hypothesis 3: grow-ability: controlling the shape of the crystals whilst growing

The third hypothesis at the basis of further experiments was the *grow-ability* of the crystals, which is comparable to the *grow-ability* (Karana & Camere, 2017) of materials generally associated with bio design/art. Since crystals grow until something gets in their way, stopping nourishment from reaching the now blocked face of the crystal (Holden & Morrison, 1982), it seemed possible to *shape* the crystal by restricting growth in certain locations. To do so, a range of tests were conducted, placing seed crystals in silicon moulds before suspending them in the saturated solution. When left undisturbed, many tests resulted in polycrystalline masses, which, albeit shaped as the mould, were not formed of substantially sized single crystals, and therefore remained fragile.

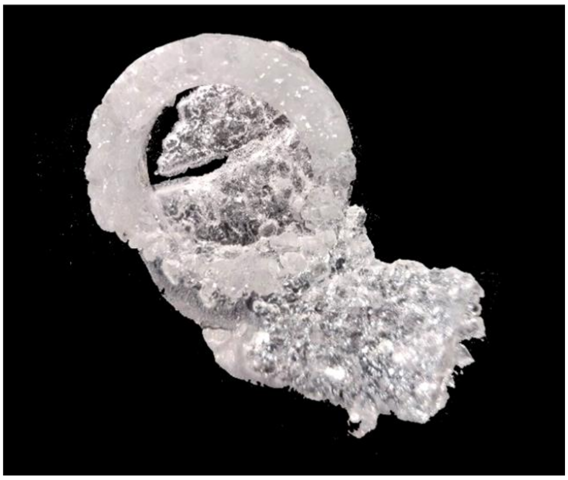



FIGURE 15 and 16. Alum crystals grown in silicon ring mould over 10 days (Figure 15). Sugar crystals grown in silicon ring mould over 6 days (Figure 16).

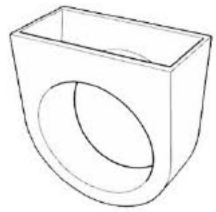
Quite quickly it appeared necessary for the moulds to be checked daily for excess crystal seed deposits, which needed to be removed, and for growing equally spaced larger single crystals to avoid deposits in the first place. When certain single crystals nearly reached one another, one was removed, in order to allow the others to continue growing. To date it has been possible to use this method to achieve single crystals that have been grown in a predetermined shape (Figure 17), however, further research will require the trial of various shapes and sizes of moulds (also in order to prevent the growth of the crystal in height) in order to draw detailed conclusions between the various variables and the outcomes. The opportunity for the controlling of the shape of crystals is promising for the development of new stone shapes, which would perhaps currently prove too wasteful in relation to their naturally occurring shape.


FIGURE 17 and 18. Sugar crystals grown in ring mould over 8 days (Figure 17). Alum seed crystals distributed across a ring mould, suspended in saturated solution days (Figure 18).

Hypothesis 4: growing crystals as models for casting in metal

The shape of crystals as they grow will always be structured in an orderly way, yet allows for many variations in size and orientation. The shapes produced, even when applying the exact same conditions, will always be unique. This is the basis for the fourth hypothesis, in which experiments were conducted using crystals' shapes (some grown on wax models) to cast in metal.

TABLE 6. Crystal growth on wax models experiments and outcome of casting in brass.

Crystal	3D DESIGN	WAX + SEED(S)	WAX + GROWN CRYSTAL	BRASS CASTING
Alum				
Sugar				

Even though the pieces provided interesting designs, their departure from the preservation of the stone in the design was deemed less relevant to the aims of this research.

FIGURE 19 and 20. Alum crystals (Figure 19). Silver earrings produced from cast crystals (Figure 20).

Growing crystals as a methodology for jewellery designers

Understanding the growth of crystals

In order to successfully plan, set up and conduct experiments for the growing of crystals, an understanding is required of the physics and chemistry involved with crystal growth. Since crystal growth is a key scientific endeavour, a large amount of literature from scientific authors is available documenting various highly complex procedures and findings related to crystal growth across the spectrum. It was however more challenging to locate literature communicating the process in laymens' terms. The book 'Crystals and Crystal Growing' by Alan Holden and Phylis Morrison (1982) proved to be the most accessible, yet detailed introduction to crystal growth with the specific purpose of growing *DIY crystals*. The prior knowledge requirement could be a barrier for jewellers to implement it as a design methodology into their practice. This understanding of the process would also be required in order to design more complex crystal innovations even if ultimately the growth would be organised by a crystal growing company providing it as a service. The jewellery designer, designing bespoke crystals or crystal growth designs, will ultimately need to understand the process in order for it to become an additional tool in their design repertoire.

Crystal Growth Process

As a jewellery designer/maker techniques and processes are generally learnt by experiencing and practicing (Untracht, 1982). The more traditional techniques (forming, joining, finishing, etc) require constant hand-eye coordination, which inform progress. This process, in which models are investigated by touch and both visual and haptic information inform the further development of the piece, provide the jeweller - who is used to working on a small scale - more or less full control. When reflecting upon the general use of gemstones in jewellery this is no different. The stone is often purchased from a dealer, either in response to a design or prior to the design is produced and it is generally a known element prior to the production of the piece. In the methodology of growing crystals, the shape of the crystals is significantly less predictable, and hands-on tactile feedback of the stone as well as measuring it can only be done once the stone has been removed, washed and dried. To avoid contamination and disturbing the solution (which could result in failed growth) the removal of the stone for handling and measuring has to be minimised. The growth of the crystal is therefore mainly monitored by visually checking the shape in solution, which as an approach highly differs from the approach generally applied by jewellers working at the bench. In Figure 21 a visual diagram is pictured of the crystal growth process as applied for the experiments in this paper.

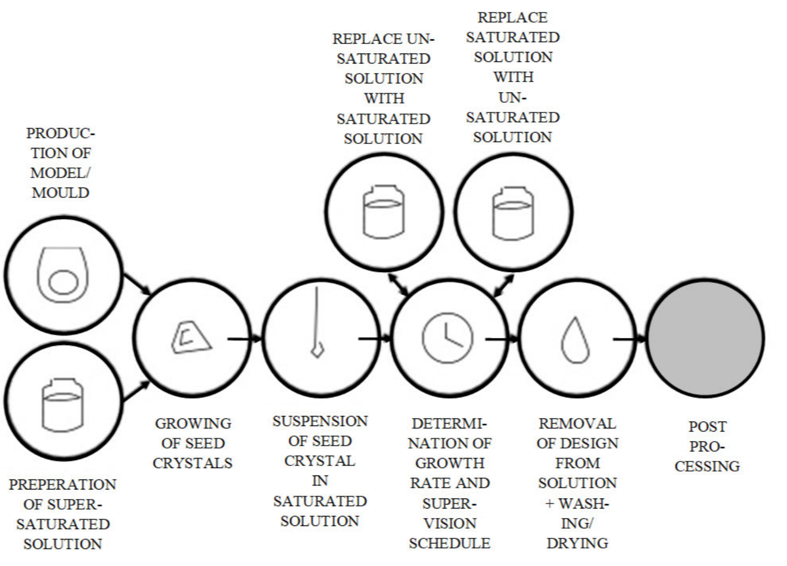


FIGURE 21. Crystal growth process schematised.

Similarly, to *Growing Design* (Karana et al., 2018; Karana & Camere, 2017; Rognoli et al., 2015), the growing of crystals additionally also requires the monitoring of growing conditions, which ultimately will affect the outcome. The fluctuations in temperature, pressure, moisture, and the various options in which to contain and store the solution, all have an impact on the growing crystal. As a jeweller, temperature is controlled only for metallurgical purposes (casting, soldering, annealing, etc.). Most of the materials jewellers generally work with do not *respond* to changes in room temperature, room pressure, and even reasonable fluctuations in moisture levels. Even though some control of these conditions was achieved to conduct the experiments referenced in this paper, more control and measurement tools would be advisable for further research to be meaningful. Figure 22 provides a first attempt towards a material taxonomy, identifying the various variables and categorisations of affecting conditions.

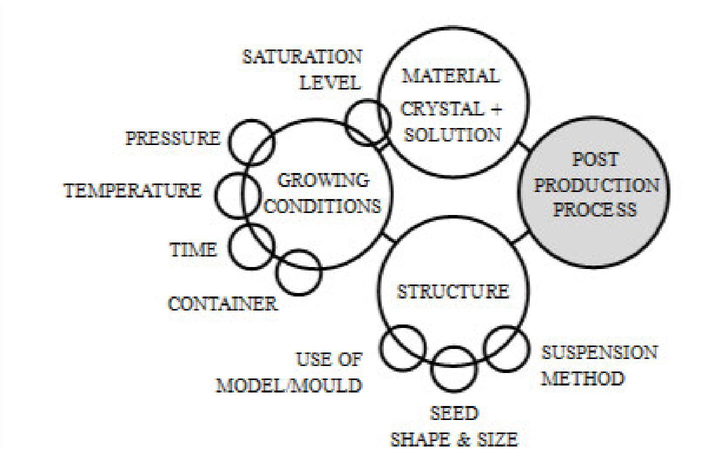


FIGURE 22. First draft of crystal growing material taxonomy to support experimentation.

The opportunity to shape, alter and adjust the grown crystals in the post production process has not been explored in the experiments conducted for this paper. The cyrstals chosen would likely not survive traditional lapidary post production processes (cutting, facetting and polishing). This is however an exciting prospect for crystals grown of gemstone grade quality, providing some additional control to the designer and reintroducing a process allowing tactile feedback.

FIGURE 23. Silver ring with in situ grown sugar crystal.

Opportunities and Challenges

The growing of crystals as a methodology for jewellery design holds great potential, but also poses a number of challenges. With additional control of the growing conditions, designers could influence the process significantly which could lead to opportunities for the creation of innovative crystals that could not be found in nature. However, to gain additional control over the growing conditions, additional equipment and resources would have to be brought into the studio environment, which could be costly. The alternative, growing at a location that resembles a lab, would further distance the growing process from the making process. Furthermore, the *grow-ability* of the material, influenced by the use of models/moulds, the characteristics and attachment of the seed and the suspension method, also provide designers opportunities to re-think the way crystals can be incorporated in designs. The integration of the methodology in the studio environment allowed for model designing and making to take place whilst monitoring solutions and growth simultaneously. When certain problems were observed, model redesign and development enabled the set up of additional experiments faster. Distancing this process from the studio environment would therefore disadvantage this flow. The incorporation of more complex equipment to grow gemstone grade quality stones into the jewellery studio would require further investigation in terms of practicality. For alternatives to be considered: e.g. a collaborative approach where the designer works with a company providing the growth of crystals as a service, or when a designer uses an alternative location for the growth of crystals, mitigations in order to increase the seemless interaction between studio practice and crystal growth processes would have to be considered.

Even though the growing of crystals can be a lengthy process for the designer, who generally does not need to spend this time when purchasing a stone from a dealer, the process is in fact significantly more sustainable when compared to the supply chain of most stones extracted from the earth. Further experiments with more specialist equipment in order to grow gemstone grade stones might result in less energy efficient growth processes, but the impact of the growth could be calculated and analysed in detail. It is expected that it would still be significantly more sustainable to grow stones locally, eliminating the need for extraction and transportation.


FIGURE 24 and 25. Resin ring with in situ grown alum crystal, top view (Figure 24) and side view (Figure 25).

The opportunity to co-create with nature (Karana & Camere, 2017) invites an element of chance which could in turn lead to unique outcomes. This uncertainty, on the other hand, can also be a challenge for designers who are generally used to having full control. The immediate impact of environmental changes and resulting changes to saturation levels of the solutions, the lack of control on the direction of growth, as well as the delay in achieving results, separating the production of the pieces and final (tactile) evaluation process (Karana & Camere, 2017), all posed challenges to the usual making practice. A significant period of time dedicated to the tinkering (Barati et al., 2015; Karana et al., 2015, 2018) with the material to consider the process impact on quality and its constraints, led to a greater understanding and acceptance of the uncertainty. All designers who in future would wish to implement the growing of crystals in their practice would be recommended to dedicate time to explorative and evaluative tinkering.

Ultimately the growing of crystals displays a range of advantages and challenges similar to those of *Growing Design* (Karana & Camere, 2017), and in a future where sustainability and unique designs are highly valued charactristics, the application of the methodology of growing crystals for jewellery designers warrants continued research.

FIGURE 26. Silver ring with in situ grown alum crystal from various views - before image on the left and after growth images on the right

CONCLUSION

This paper explored the growing of crystals as methodology for jewellery designers through conducting a range of experiments in response to four hypotheses. The goal was to provide an account of the hands-on experience of DIY growing crystals in the jewellery studio, and an insight into this material-driven process. Furthermore, a critical analysis was conducted of the methodology exploring the overlap with biodesign/art as well as its suitability for jewellery designers.

It was illustrated that the methodology holds a range of opportunities, whilst at the same time posing a number of challenges for the designer. A good understanding of the chemistry and physics of growing crystals and additional equipment to control the growing conditions are barriers to be overcome. Furthermore, a shift in approach was needed in order to apply the methodology: an openness to uncertainty, patience and a reliance on visual rather than tactile inputs differs from the usual bench based method of production. Nevertheless, the conducted experiments and their outputs clearly demonstrated the opportunities for innovation, enhanced understanding and potentially localised sustainability practice, which all warrant the continuation of the research into the methodology of Crystal Growing Design.

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REFERENCES

Anderson, K. R., & Carboo, S. S. (2016, March 16). 10 Best Newcomers at Munich Jewelry Week 2016. *Art Jewelry Forum*. https://artjewelryforum.org/10-best-newcomers-at-munich-jewelry-week-2016

Antonelli, P. (2012). Vital Design. In W. Meyers, *Bio Design: Nature, Science, Creativity* (pp. 6–7). Thames & Hudson.

Arem, J. E. (1973). *Man Made Crystals*. Smithsonian Institution Press.

Arem, J. E. (1977). *Encyclopaedia of Gemstones* (Second Edition). Van Nostrand Reinhold Company.

Barati, B., Karana, E., & Hekkert, P. (2015). A case of designing with an underdeveloped computational composite for materials experience. *Proceedings of the International Conference of the DRS Special Interest Group on Experiential Knowledge (EKSIG)*, 118–132.

Bergman, B. (n.d.). *Naama Bergman*. Naama Bergman. https://www.naamabergman.com/

Carter, W. (2015). *Crystals and Crystal Growth*. Nova Science Publishers.

Cheadle, S. (2018). *Mounting and Setting Stones*. Herbert Press.

Collet, C. (2013). *Alive | About*. This Is Alive. http://thisisalive.com/about/

Creativity Oggetti. (n.d.). *Jiyoon Hyun*. Creativity Oggetti. https://www.creativityoggetti.it/en/artist/item/1491-jiyoon-hyun.html

Den Besten, L. (2011). *On Jewellery: A Compendium of International Contemporary Jewellery Art*. Arnoldsche Art Publishers.

Holden, A., & Morrison, P. (1982). *Crystals and crystal growing* (1st ed.). MIT Press.

Hunt, M. (2013). *Stone setting for Contemporary Jewellery Makers: Techniques, inspiration & professional*. Search Press.

Hyun, J. (n.d.). *SaLux*. Jiyoon. https://www.comomatilda.com/copia-de-object

Kac, E. (2020). Bio art. *AI & SOCIETY*. https://doi.org/10.1007/s00146-020-00958-4

Karana, E., Barati, B., Rognoli, V., & Zeeuw Van Der Laan, A. (2015). Material Driven Design (MDD): A Method to Design for Material Experiences. *International Journal of Design*, *9*(2), 35–54. http://www.ijdesign.org/index.php/IJDesign/article/view/1965/693

Karana, E., Blauwhoff, D., Hultink, E.-J., & Camere, S. (2018). When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials. *International Journal of Design*, *12*(2), 119- 136. http://www.ijdesign.org/index.php/IJDesign/article/view/2918

Karana, E., & Camere, S. (2017). *Growing materials for product design*. In *the Proceedings of International Conference of the Design Research Society Special Interest Group on Experiential Knowledge (EKSIG)* (pp. 101–115).

Karana, E., Pedgley, O., & Rognoli, V. (2014). *Materials experience: Fundamentals of materials and design*. Butterworth-Heinemann.

Koivunen, H. (2005). Bio Design Products: Co-design with Nature. In *Joining forces conference ERA, University of Art and Design, September 22-24*. http://www.uiah.fi/joiningforces/papers/Koivunen.pdf

McIntyre, S. (2020). *Stone Setting*. The Crowood Press.

Myers, W. (2012). *Bio design: Nature, science, creativity*. Thames & Hudson.

Pearl, R. M. (2011). Popular Gemmology. In *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*. Read Books Ltd.

Philips, C. (2012). *Jewelry: From Antiquity to the Present*. Thames & Hudson.

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015). DIY materials. *Materials & Design*, *86*, 692–702. https://doi.org/10.1016/j.matdes.2015.07.020

Scheel, H. J. (2003). *Crystal Growth Technology*. John Wiley & Sons. https://doi.org/10.1002/0470871687

Tesla, N. (1900). The Problem of Increasing Human Energy. The Century Magazine, (June). http://www.tfcbooks.com/tesla/1900-06-00.htm

Untracht, O. (1982). *Jewelry concepts and technology*. Robert Hale.

Van Dijk, E. S. (2016). *Bio Art, DIY Biology, and Academics* [Published Master thesis, Leiden University]. Leiden University Student Repository. https://studenttheses.universiteitleiden.nl/handle/1887/37421

Webster, R. (2011). Practical Gemmology: A Study of the Identification of Gemstones, Pearls and Ornamental Minerals. In *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*. Read Books.

Young, A. (2012). *The Guide to Gemstone Settings: Styles and Techniques*. Bloomsbury Visual Arts.

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Crystal Growing Design method: An investigation into the growing of crystals for jewellery designs

Keywords

Crystal Growing Design method
jewellery
growing materials
contemporary jewellery
bespoke design

Abstract

Grown crystals are used for a range of novel innovations supporting a wide array of industries such as technology, medicine and electronics. Within the jewellery industry however, grown crystals are only used in a limited capacity and those of gemstone quality mainly as a surrogate for mined gemstones. They have remained largely underused, despite their potential sustainability credentials and the creative possibilities the incorporation of the process of crystal growth holds for jewellery designers. The bespoke growth of gemstone quality crystals could lead to highly unique jewellery designs which would result in higher consumer attachment. This in addition to the potentially more sustainable production of these stones would lead to overall more sustainable products. To address the barriers that are holding jewellery designers back from exploring the growth of crystals in their practice, and to address the knowledge gap *that underpins this barrier, this article presents a practice-based exploration into the method of Crystal Growing Design for jewellery. Alongside reviewing a selection of the limited number of jewellery designers who have explored organic crystal growth, the article discusses the results of the practice-based explorations done. Three hypotheses derived from the characteristics and advantages of Growing Design were tested in three case studies and aimed to explore the design opportunities the method provides designers when (1) growing* in situ *either in designs or (2) around shapes or (3) when utilizing the* grow-ability *of the process as a feature. Because the growth of gemstone quality crystals requires more elaborate and high-cost equipment, sugar, alum and salt were experimented with as a prelude to further experimentation with the technique using gemstone grade crystals. Through utilizing an explorative Do-It-Yourself (DIY) approach, the author documents and discusses the opportunities and challenges presented by the incorporation of a crystal growth method into the jewellery design practice. The research article will additionally reflect on the DIY growth of these non-gemstone quality crystals as a meaningful learning process for jewellery designers wishing to gain a deeper understanding of crystal growth. The DIY growth of crystals can be considered a valuable tinkering process to investigate design ideas. Which is particularly relevant since the method of growing crystals holds creative potential when designing jewellery in collaboration with crystal growers, or through incorporating gemstone crystal growth processes, which are the topic of the author's overarching Ph.D. research.*

Introduction

Jewellers around the world have used mined crystals for the creation of jewellery for centuries (Arem 1977: 1). Within the field, expert gemmological gemstone identification and optimization techniques have developed and a worldwide gemstone trade has been established. Today however, some significant innovations in the materials and processes naturally associated with jewellery have been achieved in other sectors. Bespoke man-made crystals are revolutionizing technology and engineering; diamonds grown microscopically on sheet to optimize conductivity are present in high-performing microchips (Liu et al. 2017) and the laser industry has seen major improvements due to the introduction of synthetic sapphire components developed to specifications (Stone-Sundberg 2013), to name just a few. In the jewellery industry, where crystals are used most visually and in significant numbers however, there has been limited innovation in the creative use and adaptation of man-made crystals, aside from investing in the creation of man-made gemstone quality crystals to imitate mined crystals. Limited attention is spent on the exploration of the possibilities man-made gemstone crystals and their related processes provide in a creative jewellery design context. This despite the fact the growth of crystals can result in aesthetic and creative designs, as demonstrated and documented in this article through the case studies and through the review of a small selection of jewellery designers who have incorporated the growing of non-gemstone quality crystals in their practice. In order for more jewellery designers to become interested in the designing of bespoke crystals or crystal growth designs, this article will additionally aim to underline the need to understand the crystal growth process in order for it to become an additional tool in a jewellery designers' repertoire.

Growing materials as a design method

Even though crystals were historically considered to have magical powers, they are in most scientific contexts conversely not considered to be alive materials. Outside the jewellery industry, the democratization of science has led to an increasing number of designers interested in Do-It-Yourself (DIY) approaches to growing materials (Karana and Camere 2017: 101). Bio design/art applies biotechnological methods in order to manufacture artefacts with living organisms (Koivunen 2005: 1). Even though the materials used in bio design/art are not crystals, the processes to grow crystals have clear commonalities with those related to the growth of *alive* materials in bio design/art. Also referred to as *The New Artisans* (Collet 2013), these makers consider nature as co-creator and utilize natural growth for fabrication (Karana and Camere 2017: 101), taking advantage of the self-controlled production process (Rognoli et al. 2015: 698) and the diverse forms of expressions that are achievable (Antonelli 2012: 7). Scholars in the field (Kac 2021; Karana and Camere 2017; Myers 2012; Rognoli et al. 2015; Van Dijk 2016; Collet 2020) have commented and documented the opportunities the methodology of growing materials holds for designers, ranging from achieving novel aesthetics, their *grow-ability*, to their sustainability credentials. The artist Kac coined the term 'bio art' in 1997 and has created and described the processes deployed as well as their aesthetic and social ramifications (Kac 2021: 1367). Venturing beyond art, with the number of product designers involved with growing materials expanding, the emerging practice of DIY growing is also evolving (Karana and Camere 2017: 102; Rognoli et al. 2015: 701; Van Dijk 2016: 3). In the book *Bio Design* (Myers 2012), a range of design projects and artefacts are reviewed for their incorporation of living materials, and how they serve the sector in various ways across design disciplines. DIY Biology is described by Van Dijk (2016: 24) as a global movement that aims to spread and popularize the use of biotechnology beyond academic and industrial contexts and those operating within. This paradigm shift promises to open up new possibilities for bio fabricating future intelligent materials as well as for engaging with new sustainable processes as described by Collet (2020: 1331), who examines the approaches to designing with living systems and proposes a framework for design to engage with a prospective future bio-materiality.

In the article *Growing Materials for Product Design*, authors and experts in bio design Karana and Camere (2017) reflect on the distinct characteristics and advantages of *Growing Design*. They indicate designers employ living organisms to achieve specific design purposes and materials for the use in products. Their outcomes bring higher sustainability, not only because what they are made of is often biodegradable, but the way they are produced is increasingly efficient in contrast with using materials that have often taken ages to form. Additionally, the *grow-ability* of the material provides new opportunities for designs, for example through the growing of the material directly in a pre-determined shape. The article also highlights the importance and opportunities linked to time and scale as a characteristic of *Growing Design*. Often requiring weeks instead of days, and working on a microscopic level, designers have to adapt to working methods generally applied by scientists. Which as a benefit enables them to increase control over the qualities of the material and the fabrication process. Reflecting on the symbiotic relationship between the designer and nature as co-creator they state: ‘Growing Designers forge the conditions for the invention of new matter, which would not exist otherwise’ (Karana and Camere 2017: 111). Designers set up processes in which nature as co-creator, with some degree of unpredictability, completes some key elements of the process.

Another key author on the subject, is Collet, who established a framework for the designing with the living which has informed the Design and Living Systems Lab at Central Saint Martins at the University of the Arts London. The framework aims to portray a hierarchy: nature as model, where designers explore biomimicry principles; nature as co-worker, where designers combine biomimicry approaches with husbandry techniques resulting in a *designer cultivator*; and nature as a ‘hackable’ system, where designers use the advances of synthetic biology to create bespoke genetic engineered simple living organisms resulting in a *designer biologist* (Collet 2020: 1334). Anchoring the framework within the changing cultural perception of nature, she highlights a divergence of position: nature as model acknowledges the supremacy of natural models; nature as co-worker endorses a partnership with nature; nature as a ‘hackable’ system aligns with values of dominance over nature which is inherent to contemporary thinking, positioning nature as an exploitable commodity. The growth of DIY crystals aligns comfortably with nature as co-worker, however, those growing bespoke crystals in the lab, altering their chemical composition, could be situated under nature as a ‘hackable’ system.

In this article, I present the research and related reflections I have made on the jewellery designs produced with DIY grown crystals. This in order to demonstrate that the DIY growth of crystals can be a powerful learning process for jewellery designers wishing to gain a deeper understanding of crystal growth and that it is expected to be a valuable tinkering process to investigate design ideas involving the process of gemstone quality crystal growth in the development of jewellery. Particularly since the method of growing crystals holds creative opportunities when designing jewellery in collaboration with crystal growers, or gemstone crystal growth processes.

Growing crystals for jewellery design

Crystals, gemstones and gems

The word 'crystal' has Greek roots and used to mean clear ice and still to date is called upon for a range of different uses from signifying cut glass containing lead and a clear ball to predict the future, to a gem in a piece of jewellery (Holden and Morrison 1982: 17). To physicists and chemists however, a crystal is a solid material with atoms arranged in an orderly way, in line with its lattice structure.

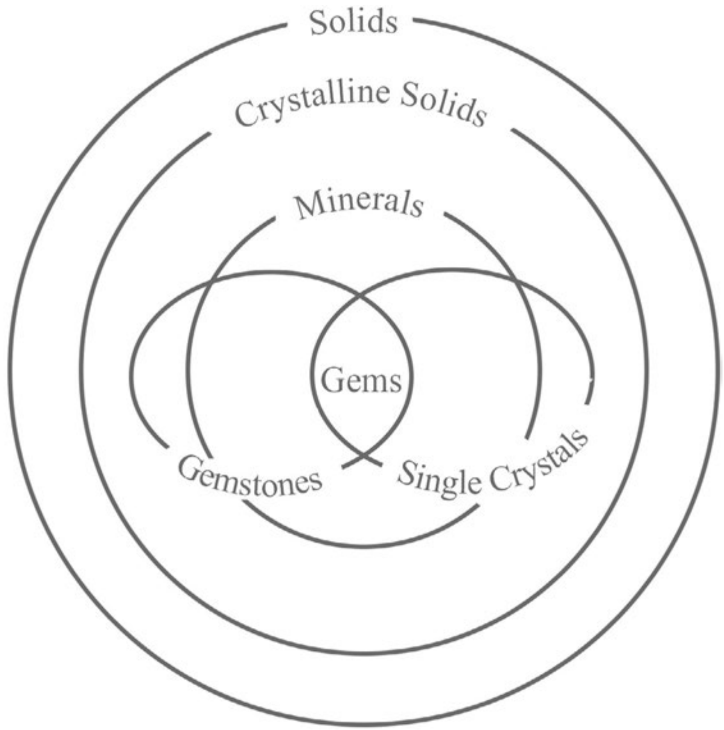


Figure 1: Sofie Boons (2022). The classification of solids, crystalline solids, minerals, gemstones, single crystals and gems. © Sofie Boons.

Table 1: Properties of common gemstones assembled by the author from several public sources.

Crystal	Specific gravity	Hardness	Refractive index	Lustre	Colour
Diamond (carbon)	3.4–3.5	10	2.42	Adamantine	All colours
Sapphire (aluminium oxide)	4–4.1	9	1.76–1.77	Adamantine to vitreous	Most colours
Emerald (aluminium beryllium silicate)	2.7–2.8	7.5–8	1.565–1.602	Vitreous	Green, yellow-green to blue
Quartz (silicon dioxide)	2.65	7	1.54–1.55	Vitreous	All colours

Not all gemstones are crystals (Arem 1977: 2) and even though a range of the minerals considered gemstones can be classed as single crystals (gems), there are exceptions: for example opal, which is a non-crystalline material, and agate, which is a microcrystalline material. Furthermore, not all single crystals are considered gemstones, since the minerals generally considered suitable for jewellery designs are usually expected to be adequately resistant to the conditions in which jewellery is worn. Therefore, most crystals used for jewellery are durable in addition to displaying appealing optical properties. A table (Table 1) with the properties of four common single crystal gemstones (gems) are documented.

Crystal growth

The quest to reproduce materials found in nature can be traced back to the Egyptians (Pearl 2011: 26) and most gemstones have now been reproduced in the lab (Webster 2011: 43) through a range of techniques, most of which are still in use today (Arem 1973, 1977; Carter 2015; Scheel 2003). Focusing here on the growth of single crystals, these techniques enable the perpetuation of the order of atoms either through vapour growth, melt growth, solution growth (Arem 1977: 212) and less commonly solid-state growth, and some display parallels in methodology with the growth of *alive* materials in bio design/art. Furthermore, since crystal growth can be theoretically simple to do (Holden and Morrison 1982), some of these processes lend themselves well to a *DIY material practice* (Karana and Camere 2017; Rognoli et al. 2015).

The process ultimately chosen for the experiments conducted as part of this article is *solution growth*, one of the most familiar crystal growth environments (Arem 1977: 215). Chosen for its major advantages, including high mobility of dissolved elements, convenience and relative controllability, it provided the ideal process for initial testing. In the solution growth process, a seed crystal is used to attract unattached atoms present in the solution. Growth takes place when the solution contains more loose atoms than the solution can handle at a specific temperature (Arem 1977: 215), also called saturation (Holden and Morrison 1982: 76). Because the growth of gemstone grade crystals in solution (e.g. emerald, amethyst, quartz and citrine) generally requires more elaborate and high-cost equipment in order to achieve higher temperature and pressure, the first experiments set to test the method of Crystal Growing Design for jewellery were conducted with crystals not considered gemstone quality. Alum, sugar and salt can all be dissolved in water and the growth of these crystals can be achieved at normal room temperature and pressure. The low-cost equipment needed, and subsequent process to grow the chosen crystals, is relatively straightforward to set up within the jewellery studio, easing the shifting between traditional jewellery and crystal growing processes.

Crystal selection and their use for jewellery design to date

Alum, sugar and salt (Table 2) are not considered gemstone quality and evidently have only been used by a limited number of jewellery designers to date.

Among those designers incorporating the crystal growth process of sugar in jewellery accessories is Helmond (Fairs 2007) who produced necklaces by delicately controlling the growth of sugar. A designer who has incorporated the growth of salt crystals in their jewellery designs on the other hand is Bergman (Anderson and Carboo 2016; Bergman n.d.) whose pieces are made by crystallizing iron structures. The resulting brooches are a celebration of the geometric patterns both created by the structures and the salt crystals. Similarly, the collection titled 'Eclats De Roche' (Boons 2010), for which the author collaborated with Herreijgers and Hermans, uses a silver base for crystallization and contains crystallized silver chain. This resulted in pieces where the fragile nature of the crystals also formed an inherent part of the concept for the designs, which once the sugar has broken off or dissolved, changed their appearance and shape. A concept jeweller Smith (Smith 2010) also explored in her jewellery pieces around the same time, and in her collaboration with Clarke in 2014 also applied to silver tableware (Decker 2016). As a final example, the choice of salt in the work of Hyun (Creativity Oggetti n.d.; Hyun n.d.) in contrast aims to elevate the status of salt in our society and here the crystals' fragile nature has been bypassed by protecting them with a layer of varnish.

Table 2: Properties of alum, sugar and salt.

Crystal	Specific gravity	Hardness	Refractive index	Lustre
Alum (aluminium sulphate)	1.47	2–2.25	1.47–1.48	Vitreous
Sugar (aluminium oxide)	1.1	2–2.25	1.76–1.77	Vitreous
Salt (sodium chloride)	2.17	2–2.25	1.54	Vitreous

All pieces discussed demonstrate that the incorporation of the growth of crystals into the jewellery design process can result into aesthetic and creative jewellery designs. The use of these relatively fragile materials (salt and sugar respectively) is in itself innovative, when incorporated into jewellery designs, and the associated material experience (Karana et al. 2014) is in most examples also a key factor for them being chosen by the respective designers. The material experience of the crystals used for the experiments in this article will however not be further explored, because the material experience of gemstone grade crystals would not be comparable. Instead the article will investigate the method of growing crystals for the development of creative designs incorporating grown crystals as pre-cursers to justify the further incorporation and adaptation of more enhanced growing processes as used for the growing of gemstone quality crystals, potentially in collaboration with industrial growers.

Despite the evidence of some use of organic crystal growth by jewellery designers, there remains very limited practice-based research documentation of these processes in the field and context. To fill this gap, the article will report on the process and outcomes of the conducted case study experiments. This is of importance particularly since the DIY growth of crystals can be an important learning process for any jewellery designer wishing to gain a deeper understanding of the process of crystal growth and is additionally expected to serve as a valuable tinkering process to investigate design ideas involving the process of gemstone quality crystal growth in the development of jewellery.

Review of three Crystal Growing Design case study experiments for jewellery

To evaluate the growing of crystals as a method for jewellery designers, and craft educators, three sets of experiments were developed in response to three hypotheses. The three hypotheses aimed to test the distinct characteristics and advantages of *Growing Design* as referenced and aimed to explore the design opportunities crystal growth provides when (1) growing *in situ* either in designs or (2) around shapes or (3) when utilizing the *grow-ability* of the process as a feature. The multiple case study approach (Yin 2018: 98) was chosen in order to evaluate and compare different approaches in growing crystals within the jewellery studio environment. Below each hypothesis is explained and images of the set-up, various stages of the design (to document the growth) and the final outcomes are discussed. The results of the experiments selected for this article represent only a small fraction of the total number of experiments conducted over a six-month period. The incorporated results were chosen to illustrate the main arguments of this article.

Environment and equipment

All experiments were conducted in the jewellery studio at normal room temperature and room pressure over a period of six months. All crystals were grown in glass bowls, located on a shelf. The equipment used was: steel and brass wire, glass bowls, plastic measuring cups, portable electric hob, a pan, plastic stirrers and a scale. For some experiments, silicon moulds were produced. No additional specialist equipment was purchased. Plant-based transparent resin (to enable the inspection of the growth) models were created using a small UV 3D printer. Silver models were produced through casting wax models or direct forming techniques.

Seed crystals and saturated solutions

All experiments required the preparation and monitoring of supersaturated and saturated solutions and production, placement and suspension of seed crystals. The solutions were a selection of de-ionized water or tap water and alum, sugar or salt. Both de-ionized water and tap water were used to compare the resulting crystals, which resulted in a difference of colour for sugar (de-ionized water grown crystals were less yellow in tone) but seemed to have little impact in the appearance of alum and salt crystals. The working procedure and the recipe for alum is documented in the book *Crystals and Crystal Growing* by Holden and Morrison (1982). The recipe for sugar and salt was 1:2 water/sugar or salt ratio and was based on previous experimentation. The *growing by evaporation method* and *sealed jar* method were both trialled for a selection of the experiments. From the tests, both methods worked more or less as described (Holden and Morrison 1982: 93), and neither were found to have distinct advantages. In all experiments, seed crystals were used as a basis for developing the designs. These were then suspended in saturated solutions until a desired size was achieved, after which they were removed and washed with tap water.

Hypothesis 1: Can the growing of a single crystal or multiple crystals in situ *in designs be introduced as part of the design process?*

The first hypothesis identified to be tested is the growing of crystals *in situ* in a designed space. Generally, gemstones are incorporated in designs by *setting*. The art and craft of setting gemstones in jewellery has mostly revolved around the creation of a setting, or creating a suitable space in the metal where the stone is held into place in the design. Growing a stone *in situ* in the design would enable the designer opportunities to reimagine how stones could be incorporated and fixed into their designs. To test this hypothesis, a range of experiments were conducted in which a range of produced rings were fitted with a seed and suspended from a steel wire in the saturated solution. In these experiments, the hypothetical growth of crystals was kept in mind whilst designing pieces.

In the first range of tests, it was the intention to grow a single crystal in a pre-determined open space. The designs of the pieces were simple in terms of shape to enable the close monitoring of the crystal growth. Evident in these experiments is the individual shapes each crystal displays, and the unpredictable direction the growth of the crystal has. Sugar atoms grow in a monoclinic structure resulting in a hexagonal prism shape, whereas alum atoms grow in a cubic structure resulting in octahedra with flattened corners. Salt on the other hand grows in the cubic structure resulting in cube like crystals. The single crystal sugar ring (Table 3), which was grown over a period of three weeks, started growing over the edge of the ring. It did however not grow in the other directions.

When a solution became unsaturated the crystals suspended inside them would decrease in size. This process, albeit challenging to control without further tools to monitor the solution, could be useful to correct crystals that have grown too large.

In further experiments (Table 4), the base model allowed for multiple seed crystals to be grown simultaneously, in order to incorporate a range of crystals in an organized or unorganized pattern and study the formation of *polycrystalline crystals*.

The resin 3D printed models posed no issues for the gluing and attaching of crystals. To test whether the same would be true for metal, the most common material used for the production of jewellery, some experiments were conducted with silver models (Table 5). There was no distinct difference between the growth of crystals on silver or resin. Further research could test whether this applies to all precious metals and their various alloys, albeit most logically this research takes place with gemstone quality solution growth crystals instead.

Hypothesis 2: Can the process of growing single crystals in situ *in designs be adapted to result in the growth of crystals with inclusions?*

Table 3: Single crystal experiments.

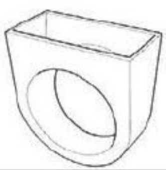
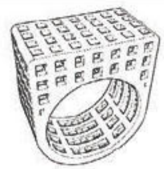
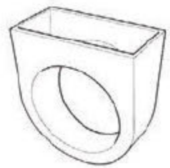
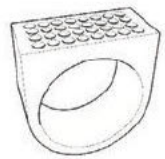
Crystal	3D Design	Resin 3D Print	Model + Seed	Outcome
Alum				
Sugar				

Table 4: Polycrystal formation experiments.

Crystal	3D Design	Resin 3D Print	Model + Seed(s)	Outcome
Alum				
Sugar				
Salt				

For the second hypothesis, the fact that crystals can contain impurities, by for example growing around obstacles, was discovered as an opportunity whilst testing the growing of a single sugar crystal, suspended in its saturated solution through a brass wire (Figure 2). Since the crystal faces exposed continued to connect with sugar molecules in the saturated liquid, the wire eventually became encapsulated by the crystal. Within gemmology, inclusions are generally considered 'faults', however, the design opportunity present with growing crystals incorporating *designed inclusions* seems very promising.

Therefore, for the second single crystal growth experiment (Figure 3), the brass wire was shaped into the number 2020 before it was wrapped around an alum seed crystal and suspended into a saturated solution. The resulting crystal incorporated the shaped brass wire as an inclusion. Even though there was some distortion of the number, the result was promising.

Table 5: Crystal growth on metal experiments.

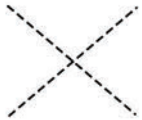
Crystal	3D Design	Silver Model	Model + Seed	Outcome
Alum				
Sugar				

Figure 2: Sofie Boons (2020). Single sugar crystal suspended from brass wire in supersaturated sugar solution. © Sofie Boons.

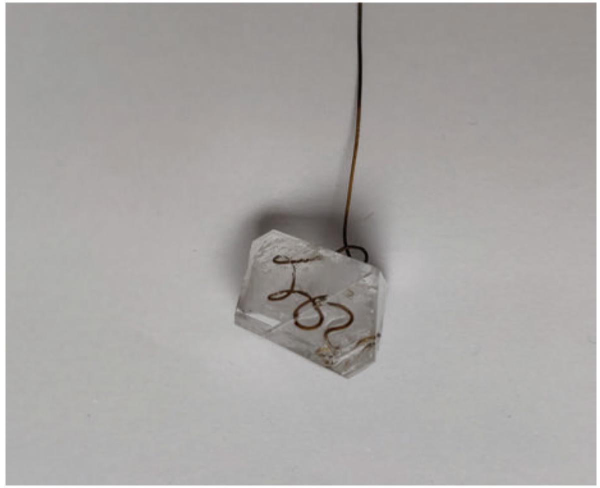


Figure 3: Sofie Boons (2020). Grown single alum crystal with shaped brass wire inclusion. © Sofie Boons.

Another experiment conducted involved the growing of a single crystal in a resin ring design, with an inclusion (a silver wire shaped as a small ring) positioned so the crystal would grow to embed it. The result once more indicated that there are challenges with the control of the growth of the crystal in relation to the inclusion. The outcome however still provided a range of distortions of the inclusion, which would be of interest if the cut of the stone could be altered. Further experiments currently under development will be investigating the opportunities which designed inclusions can provide jewellery designers in more detail. The feasibility of designing inclusions in gemstone grade stones could however prove more challenging due to the nature of the processes used.

Hypothesis 3: Can the grow-ability *of crystals and the resulting controlling of its shape whilst growing be exploited as part of the design process?*

The third hypothesis as a basis of further experiments was the *grow-ability* of the crystals, which is comparable to the *grow-ability* (Karana and Camere 2017) of materials generally associated with bio design/art. Since crystals grow until something gets in their way, stopping nourishment from reaching the now blocked face of the crystal (Holden and Morrison 1982), it seemed possible to *shape* the crystal by restricting growth in certain locations. To do so, a range of tests were conducted, placing seed crystals in silicon moulds before suspending them in the saturated solution. When left undisturbed, a number of tests resulted in polycrystalline masses, which, albeit shaped as the mould, were not formed of substantially sized single crystals, and therefore remained fragile.

Quite quickly it appeared necessary for the moulds to be checked daily for excess crystal seed deposits, which needed to be removed, and for growing equally spaced larger single crystals to avoid deposits in the first place. When certain single crystals nearly reached one another, one was removed, in order to allow the others to continue growing. To date, it has been possible to use this method to achieve single crystals that have been grown in a pre-determined shape (Figure 4), however, further research will require the trial of various shapes and sizes of moulds (also in order to prevent the growth of the crystal in height) in order to draw detailed conclusions between the various variables and the outcomes. The opportunity for the controlling of the shape of crystals is promising for the development of new stone shapes, which would perhaps currently prove too wasteful in relation to their naturally occurring shape.

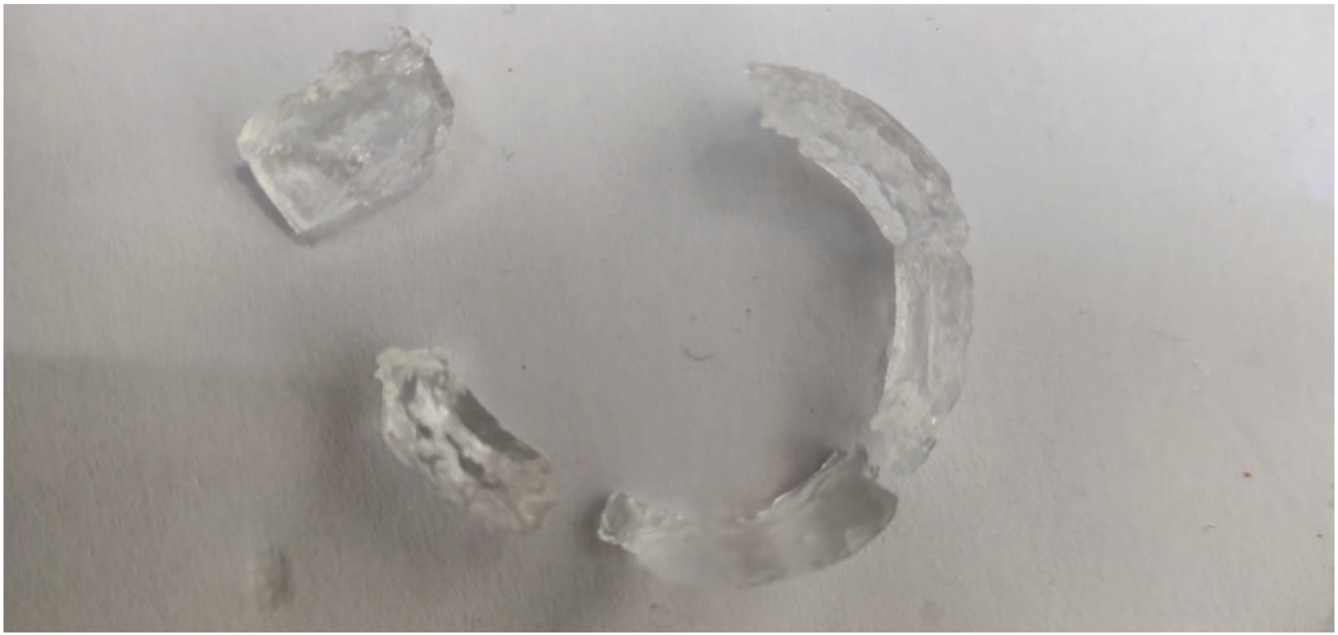


Figure 4: Sofie Boons (2020). Sugar crystals grown in ring mould over eight days. © Sofie Boons.

Growing crystals as a method for jewellery designers: Understanding the growth of crystals

The DIY growth of crystals is an important learning process for any jewellery designer wishing to gain a deeper understanding of the process of crystal growth and is expected to serve as a valuable tinkering process to investigate design ideas involving the process of gemstone quality crystal growth in the development of jewellery. In order to successfully plan, set up and conduct experiments for the growing of crystals, an understanding is required of the physics and chemistry involved with crystal growth. Since crystal growth is a key scientific endeavour, a large amount of literature from scientific authors is available documenting various highly complex procedures and findings related to crystal growth. It was however more challenging to locate literature communicating the process in laymen's terms. The book *Crystals and Crystal Growing* by Alan Holden and Phyllis Morrison (1982) proved to be the most accessible, yet detailed introduction to crystal growth with the specific purpose of growing *DIY crystals*. The prior knowledge requirement could be a barrier for jewellers to implement it as a design method into their practice. This understanding of the process would also be required in order to design more complex crystal innovations even if ultimately the growth would be organized by a crystal growing company providing it as a service. The jewellery designer, designing bespoke crystals or crystal growth designs, will ultimately need to understand the process in order for it to become an additional tool in their design repertoire.

Crystal growth process reflections

As a jewellery designer/maker, techniques and processes are generally learnt by experiencing and practising (Untracht 1982). The more traditional techniques (forming, finishing, etc) require constant hand-eye coordination. This process, in which models are investigated by touch and both visual and haptic information inform the further development of the piece, provide the jeweller more or less full control. When reflecting upon the general use of gemstones in jewellery this is no different. The stone is often purchased from a dealer and it is generally a known element prior to the production of the piece. In growing crystals, the shape of the crystals is significantly less predictable, and hands-on tactile feedback of the stone as well as measuring it can only be done once the stone has been removed, washed and dried. To avoid contamination and disturbing the solution (which can result in failed growth), the removal of the stone has to be minimized. The growth of the crystal is therefore mainly monitored by visually checking the shape in solution, which as an approach highly differs. In Figure 5, a visual diagram is pictured of the crystal growth process as applied for the experiments.

Similarly to *Growing Design* (Karana et al. 2018; Karana and Camere 2017; Rognoli et al. 2015), the growing of crystals also requires the monitoring of growing conditions, which ultimately will

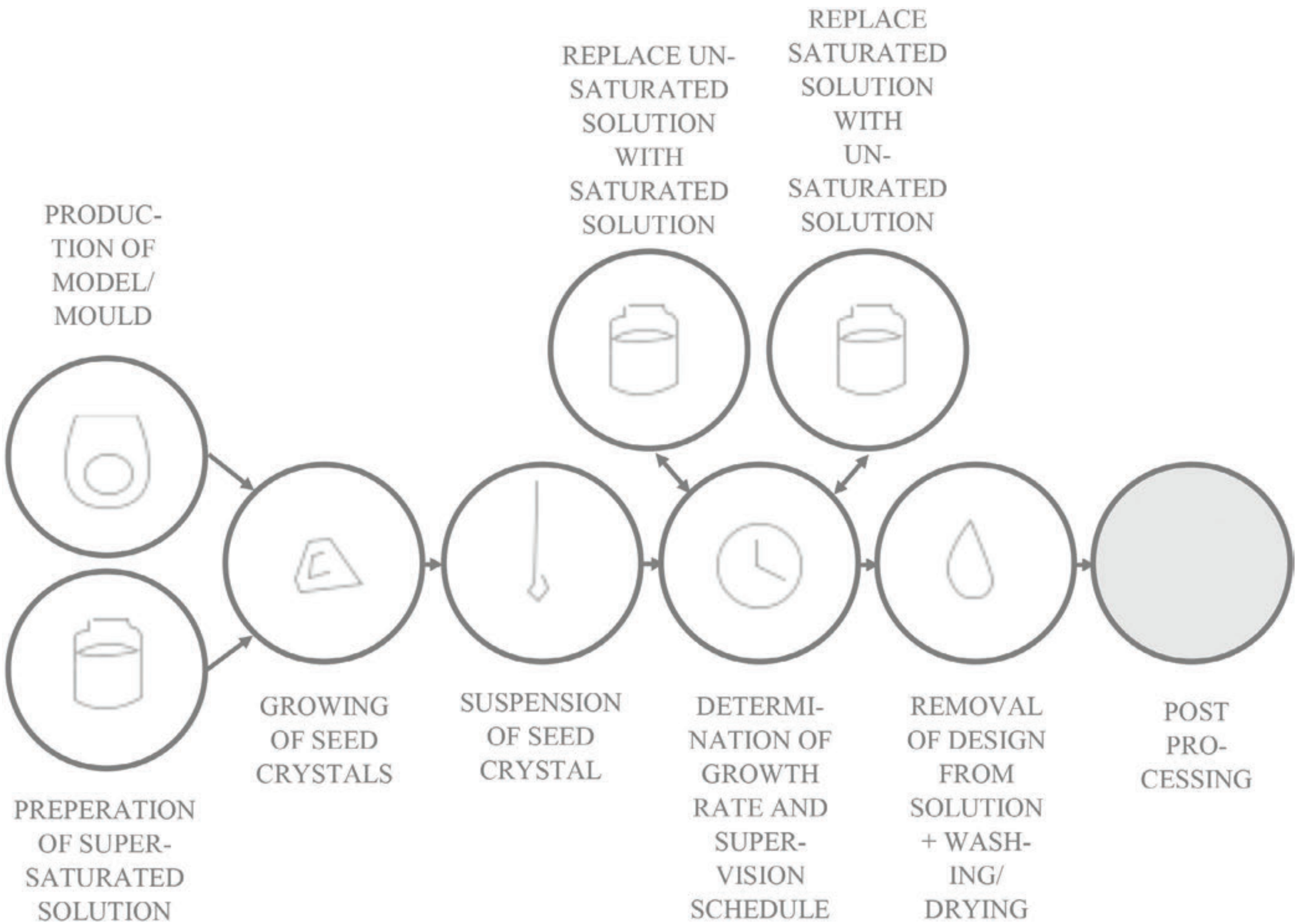


Figure 5: Sofie Boons (2020). Crystal growth process schematized. © Sofie Boons.

affect the outcome. The fluctuations in temperature, pressure, moisture and the various options in which to contain and store the solution, all have an impact on the growing crystal. As a jeweller, temperature is controlled only for metallurgical purposes (casting, soldering, etc.). Most of the materials jewellers generally work with do not respond to changes in room temperature, room pressure and even reasonable fluctuations in moisture levels. Even though some control of these conditions was achieved, more control and measurement tools would be advisable for further research to be meaningful. Figure 6 provides a first attempt towards a material taxonomy, identifying the various variables and categorizations of affecting conditions.

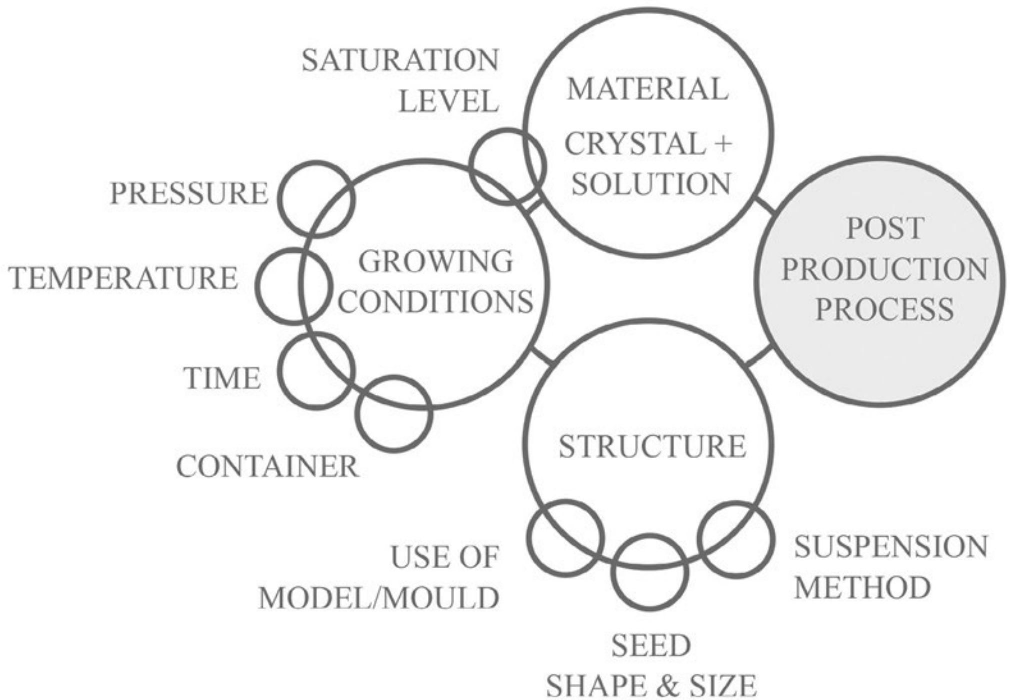


Figure 6: Sofie Boons (2020). First draft of crystal growing material taxonomy to support experimentation. © Sofie Boons.

The opportunity to shape, alter and adjust the grown crystals in the post production process has not been explored in the experiments. The crystals chosen would likely not survive traditional lapidary post production processes (faceting, polishing, etc). This is however an exciting prospect for crystals grown of gemstone grade quality, providing some additional control to the designer and reintroducing a process allowing tactile feedback.

Opportunities and challenges

With limited resources available for designers to explain the process in layman's terms, this article aimed to reflect on a jewellery designer's starting point on the growth of crystals. The experiments were relatively easy to set up and conduct, and the outcomes enabled close inspection of the technique in relation to the production of designs which resulted in an enhanced understanding of the theory. For these reasons, the DIY Crystal Growth Design experiments conducted would lend

Figure 7: Sofie Boons (2020). Silver ring with in situ *grown alum crystal. © Sofie Boons.*

themselves well to being introduced in jewellery design educational settings which could prove to be a valuable contribution towards addressing the knowledge and skills gap jewellers face.

When reflecting upon the growing of crystals as a method for jewellery design, it can be stated it holds great potential but does also pose a number of challenges beyond the initial barrier to understanding and implementing the process. With additional control of the growing conditions, designers could influence the process significantly which could lead to the creation of innovative crystals that could not be found in nature. However, to gain additional control over the growing conditions, additional equipment and resources would have to be brought into the studio environment, which could be costly. The alternative, growing at a location that resembles a lab, would further distance the growing process from the making process. Furthermore, the *grow-ability* of the material, influenced by the use of models/moulds, the characteristics and attachment of the seed and the suspension method, also provides designers opportunities to re-think the way crystals can be incorporated in designs. The integration of the method in the studio environment allowed for model designing and making to take place whilst monitoring solutions and growth simultaneously. When certain problems were observed, model redesign and development enabled the set-up of additional experiments faster. Distancing this process from the studio environment would therefore disadvantage this flow. The incorporation of more complex equipment to grow gemstone grade quality stones into the jewellery studio would require further investigation in terms of practicality. For alternatives to be considered: e.g. a collaborative approach where the designer works with a company (such as RSA in France) providing the growth of crystals as a service, or when a designer uses an alternative location for the growth of crystals, mitigations in order to increase the seamless interaction between studio practice and crystal growth processes would have to be considered.

Even though the growing of crystals can be a lengthy process for the designer, who generally does not need to spend this time when purchasing a stone from a dealer, the process is in fact significantly more sustainable when compared to the supply chain of most stones extracted from the earth. Further experiments with more specialist equipment in order to grow gemstone grade stones might result in less energy efficient growth processes, but the impact of the growth could be calculated and analysed in detail. It is expected that it would still be significantly more sustainable to grow stones locally, eliminating the need for extraction and transportation. Additionally, the bespoke nature of the outcomes would benefit the uniqueness of the resulting designs and likely influence consumer attachment, therefore affecting their longevity.

The opportunity to co-create with nature (Karana and Camere 2017) shifting from manufacture to *biofacture* and become a designer cultivator (Collet 2021) invites an element of chance which could in turn lead to unique outcomes. This uncertainty, on the other hand, can also be a challenge for designers who are generally used to having full control. The immediate impact of environmental changes and resulting changes to saturation levels of the solutions, the lack of control on the direction of growth, as well as the delay in achieving results, separating the production of the pieces and final (tactile) evaluation process (Karana and Camere 2017), all posed challenges to the usual making practice. A significant period of time dedicated to the tinkering (Barati et al. 2015; Karana et al. 2015, 2018) with the material to consider the process impact on quality and its constraints, led to a greater understanding and acceptance of the uncertainty. All designers who in future would wish to implement the growing of crystals in their practice would be recommended to dedicate time to explorative and evaluative tinkering using organic crystal growth (using a material like sugar, alum and/or salt).

Future research: Flux growth of gemstone grade crystals

Flux growth, which is considered a solution growth technique, likely bears most resemblance to the DIY solution growth experiments conducted for this article. Further research in the incorporation of flux growth and the collaboration with experienced crystal growers will aim to compare the method of the growth of gemstone grade crystals in flux with the method documented for this article.

Conclusion

This article explored and documented the growing of crystals as a method for jewellery designers through conducting a range of case study experiments in response to three hypotheses. The goal was to provide an account of the hands-on experience of DIY growing crystals in the jewellery studio, and an insight into this material-driven process in order to demonstrate that the DIY growth of crystals is expected to be a valuable tinkering process to investigate design ideas involving the process of gemstone quality crystal growth in the development of jewellery. Since a good understanding of the chemistry and physics of growing crystals and additional equipment to control the growing conditions remain barriers to be overcome, it can be a powerful learning process for any jewellery designer wishing to gain a deeper understanding of crystal growth and its processes. The introduction of DIY crystal growth experiments in educational settings could be a first step towards addressing this knowledge gap more broadly. Following a short critical analysis of the method's overlap with bio design/art, it was illustrated that the method holds a range of opportunities, whilst at the same time posing a number of challenges for the jewellery designer. It will therefore require jewellers to undergo a shift in their approach when incorporating the processes as demonstrated, which is needed in order to apply the method: an openness to uncertainty, patience and a reliance on visual rather than tactile inputs, all differ from the usual bench-based methods of production. The additional potential benefits of localized sustainability practice and more sustainable products both through process and longevity of outcomes through enhanced consumer attachment, warrants the continuation of the research into the method of Crystal Growing Design. Particularly since the method of growing crystals holds further possibilities for enhanced creativity when designing jewellery in collaboration with crystal growers, or gemstone crystal growth processes, which are the topic of the author's overarching Ph.D. research.

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References

Anderson, K. R. and Carboo, S. S. (2016), '10 best newcomers at Munich Jewelry Week 2016', Art Jewellery Forum, March, https://artjewelryforum.org/10-best-newcomers-at-munich-jewelry-week-2016. Accessed 5 October 2020.

Antonelli, P. (2012), 'Vital design', in W. Myers (ed.), *BioDesign: Nature, Science, Creativity*, High Holborn: Thames & Hudson, pp. 6–7.

Arem, J. E. (1973), *Man Made Crystals*, Washington, DC: Smithsonian Institution Press.

Arem, J. E. (1977), *Encyclopedia of Gemstones*, 2nd ed., New York: Van Nostrand Reinhold Company Inc.

Barati, B., Karana, E., Hekkert, P. P. M. and Jönsthövel, I. (2015), 'A case of designing with an underdeveloped computational composite for materials experience', in *Proceedings of the International Conference of the DRS Special Interest Group on Experiential Knowledge (EKSIG)*, 25–26 November, Kolding: Design School Kolding, pp. 118–32.

Bergman, B. (n.d.), 'Home page', Naama Bergman, https://www.naamabergman.com/. Accessed 5 October 2020.

Boons, S. (2010), 'Eclats De Roche', Sofie Boons, 10 May, http://sofieboons.com/portfolio/eclats-de-roche-2/. Accessed 14 April 2022.

Carter, W. (2015), *Crystals and Crystal Growth*, New York: Nova Science Publishers, Inc.

Collet, C. (2013), 'Alive | About', This Is Alive, March, http://thisisalive.com/about/. Accessed 14 September 2020.

Collet, C. (2020), 'Designing our future bio-materiality', *AI & Society*, 36, pp. 1331–42, https://link-springer-com.ezproxy.uwe.ac.uk/content/pdf/10.1007/s00146-020-01013-y. Accessed 1 May 2022.

Creativity Oggetti (n.d.), 'Jiyoon Hyun', https://www.creativityoggetti.it/en/artist/item/1491-jiyoon-hyun.html. Accessed 5 October 2020.

Decker, A. P. (2016), 'David Clarke: A cup half full', Objektion, 24 April, https://objektion.wordpress.com/2016/04/24/david-clarke-a-cup-half-full/. Accessed 14 April 2022.

Fairs, M. (2007), 'Unsustainable by Greetje van Helmond', Dezeen, 27 June, https://www.dezeen.com/2007/06/27/unsustainable-by-greetje-van-helmond-2/. Accessed 14 April 2022.

Holden, A. and Morrison, P. (1982), *Crystals and Crystal Growing*, Cambridge, MA: MIT Press.

Hyun, J. (n.d.), 'SaLux', comoMATILDA, https://www.comomatilda.com/copia-de-object. Accessed 5 October 2020.

Kac, E. (2021), 'Bio art', *AI & Society*, 36, December, pp. 1367–76, http://link.springer.com/10.1007/s00146-020-00958-4. Accessed 26 August 2020.

Kappenberger, R., Aswartham, S., Scaravaggi, F., Blum, C. G. F., Sturza, M. I., Wolter, A. U. B., Wurmehl, S. and Büchner, B. (2018), 'Solid state single crystal growth of three-dimensional faceted LaFeAsO crystals', *Journal of Crystal Growth*, 483, February, pp. 9–15.

Karana, E., Barati, B., Rognoli, V. and Zeeuw Van Der Laan, A. (2015), 'Material driven design (MDD): A method to design for material experiences', *International Journal of Design*, 9:2, pp. 35–54.

Karana, E., Blauwhoff, D., Hultink, E.-J. and Camere, S. (2018), 'When the material grows: A case study on designing (with) *Mycelium*-based materials', *International Journal of Design*, 12:2, p. 18.

Karana, E. and Camere, S. (2017), *Growing Materials for Product Design*, Delft: Delft University of Technology, pp. 101–15.

Karana, E., Pedgley, O. and Rognoli, V. (2014), *Materials Experience: Fundamentals of Materials and Design*, Amsterdam: Butterworth-Heinemann.

Koivunen, H. (2005), *Bio Design Products: Co-Design with Nature*, Helsinki: University of Art and Design Helsinki, p. 4.

Liu, J. W., Oosato, H., Liao, M. Y. and Koide, Y. (2017), 'Enhancement-mode hydrogenated diamond metal-oxide-semiconductor field-effect transistors with Y_2O_3 oxide insulator grown by electron beam evaporator', *Applied Physics Letters*, 110:20, p. 203502.

Milisavljevic, I. and Wu, Y. (2020), 'Current status of solid-state single crystal growth', *BMC Materials*, 2:1, p. 2.

Myers, W. (2012), *Bio Design: Nature, Science, Creativity*, London: Thames & Hudson.

NGK Insulators Ltd (1982), 'Method for producing a single crystal of ferrite', 20 April, https://patents.justia.com/patent/4339301. Accessed 23 August 2021.

O'Donoghue, M. (2007), *Artificial Gemstones*, London: NAG Press.

Pearl, R. M. (2011), 'Popular gemology', in *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*, Milton Keynes: Read Books Ltd, p. 26.
Rognoli, V., Bianchini, M., Maffei, S. and Karana, E. (2015), 'DIY materials', *Materials & Design*, 86, December, pp. 692–702.
Scheel, H. J. (2003), *Crystal Growth Technology*, West Sussex: John Wiley & Sons Ltd.
Sefat, A. S. (2008), *Flux Method for Preparing Crystals*, http://www.icmr.ucsb.edu/programs/documents/Sefat1.pdf. Accessed 23 August 2021.
Smith, N. (2010), 'Natalie Smith: Crystal world: 2010', Natalie Smith, http://natalielsmith.blogspot.com/p/crystal-world-2010.html. Accessed 14 April 2022.
Stone-Sundberg, J. (2013), 'Sapphire series part 3: Modern synthetic sapphire applications', GIA, 21 August, http://www.gia.eduhttps://www.gia.edu/gia-news-research-sapphire-series-modern-applications. Accessed 15 June 2020.
Tesla, N. (1900), 'Problem of increasing human energy: With special reference to the harnessing of the sun's energy', *The Century Magazine*, 60:2, pp. 175–211, https://teslauniverse.com/nikola-tesla/articles/problem-increasing-human-energy. Accessed 1 May 2022.
Untracht, O. (1982), *Jewelry Concepts and Technology*, London: Robert Hale.
Van Dijk, E. S. (2016), *Bio Art, DIY Biology, and Academics*, Leiden: Leiden University, https://studenttheses.universiteitleiden.nl/handle/1887/37421. Accessed 11 December 2020.
Way, M. (2017), 'What I cannot create, I do not understand', *Journal of Cell Science*, 130:18, pp. 2941–42.
Webster, R. (2011), 'Practical gemmology: A study of the identification of gemstones, pearls and ornamental minerals', in *Artificial Gemstones: A Collection of Historical Articles on the Production of Synthetic Gemstones*, Milton Keynes: Read Books Ltd, p. 43.
Yin, R. K. (2018), *Case Study Research and Applications: Design and Methods*, 6th ed., Los Angeles, CA: Sage Publications.

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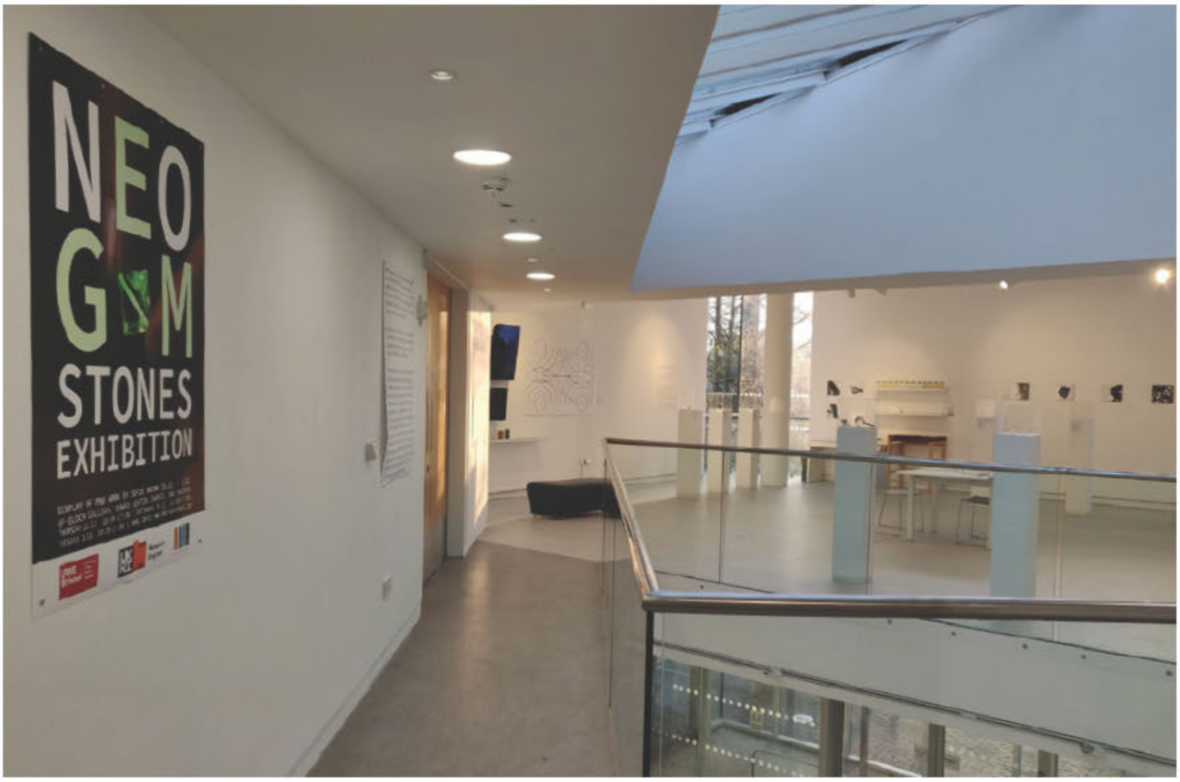

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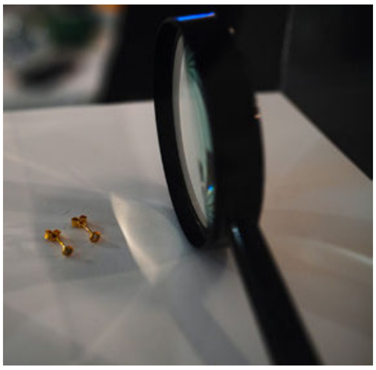
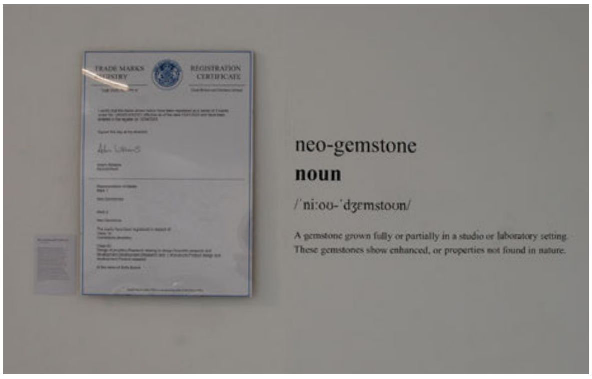
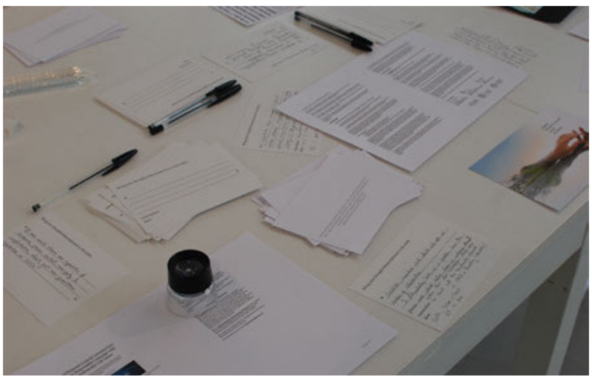
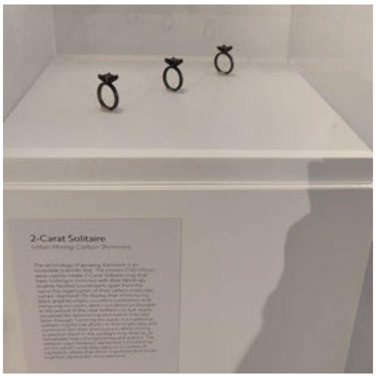
STONES
EXHIBITION



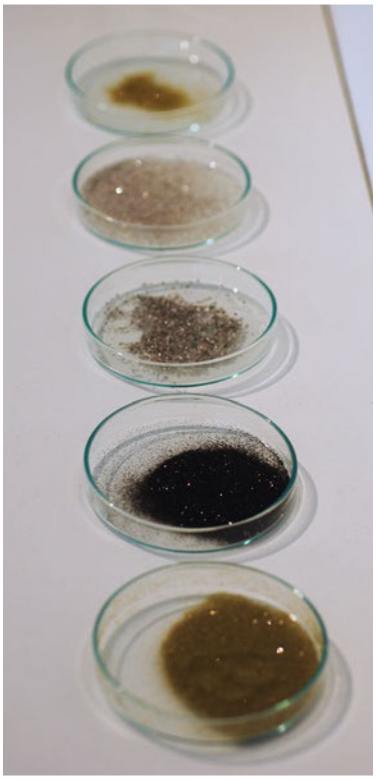

1. Context
neo-gemstone
noun


TRADE MARKS REGISTRY
REGISTRATION CERTIFICATE
neo-gemstone
noun
/ˈniːoʊ-ˈdʒɛmstoʊn/
A gemstone grown fully or partially in a studio or laboratory setting.
These gemstones show enhanced, or properties not found in nature.

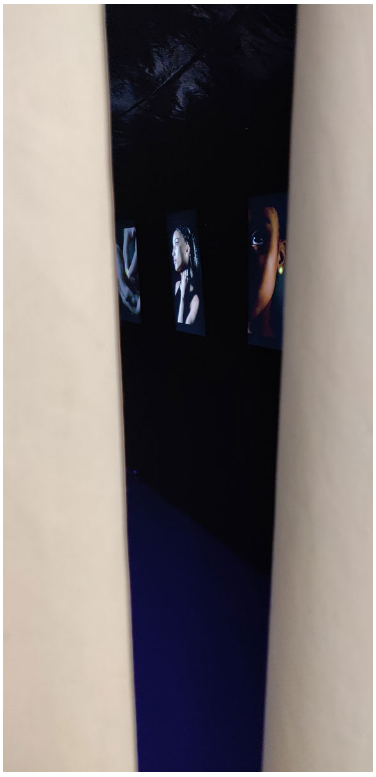


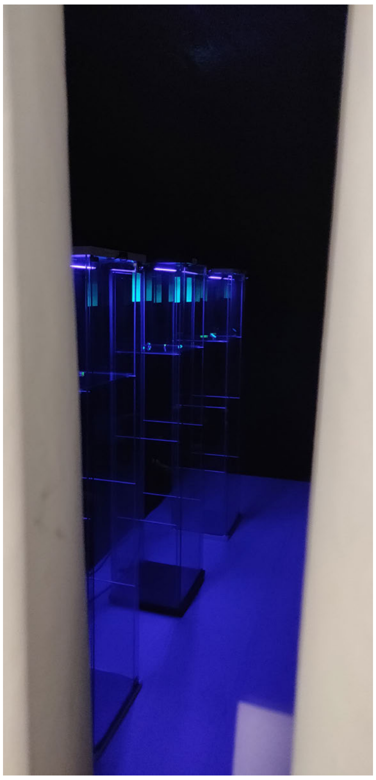

2-Carat Solitaire

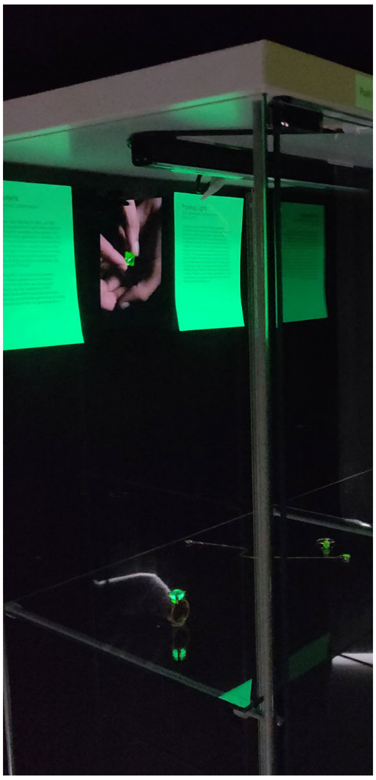

2. Urban Mining
The first case study as part of the research project aimed to investigate and test existing lab-grown gemstone materials, used in non-jewellery contexts, for the production of jewellery
The identification and use of industrial waste, sourced through urban mining activities, proved most interesting to explore. The practice of urban mining
and limitations were
evaluated first independently and then through a workshop with jewellery students.
While urban mining as a methodology is not new, its application to crystal materials is limited yet could provide both sustainability and creativity benefits.

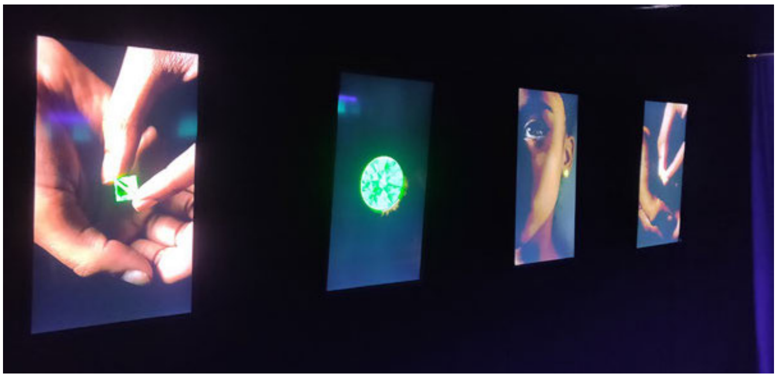


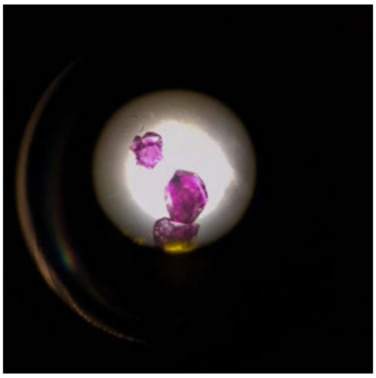

3. Sci/Art Collab












NEO


Outgrown