BIO-BASED DESERT SAND MATERIAL IN ARTWORK

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ABSTRACT

This research involves developing of biodegradable materials to replace traditional non-recyclable and unsustainable art materials. The project centres on the experimental development of desert sand (DS), complementing its application as a material in the arts. Sodium alginate is an important component of the material development for this project. As a bio-binder, it improves sand cohesion and constrains the sand particles to form a mouldable material. This material's properties were enhanced during the practice-based research process, and it was named the SA-DS material. The research outcome involves the intersection of three different disciplines: bio-based materials, horticulture, and soil mechanics. The material achieves an extension of its value so that it is suitable for casting in any shape and nourishes new green life in the form of compost at the end of its lifetime, achieving zero waste.

The project also explores SA-DS's sensory properties and develops two situational prototypes: botanical ornaments (planters) and indoor decorations (lightweight lampshades). Both applications highlight the individualised properties of SA-DS. The results demonstrate the applicability of SA-DS as a sustainable material in practical applications and provide data and directions for further development. The creative utilisation of desert sand resources intends to bring the issue of natural resources and the environment into the limelight, encouraging participation in sustainable practices across disciplinary boundaries.

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FIGURE LIST

Black sand of Bethell's beach, Auckland, New Zealand

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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INTRODUCTION

There is a paradoxical situation that exists between plentiful yet under utilised desert sand (DS) and the over exploitation of other “usable” types of sand. Sand has an immeasurable value driven by contemporary society's economy and culture, and it is widely used in our daily lives, for example, mobile phones, cosmetics, glass, ceramics, and concrete all contain sand as an ingredient (Roger, 2022). Generally, it is usable sand that meets processing and production standards. “Usable” sand ranges from 0.2mm-2mm in diameter (Jack, 2023), whereas desert sand is very fine sand with a diameter of less than 0.3mm and is not suitable for most applications. This is due to the fine and rounded shape of its grains that makes it weak in aggregation, therefore challenging for developing any application. While there has been a depletion of usable sand resources (Hernandez et al, 2021) due to over-extraction, the application of desert sand is still a subject that has not received much attention. This project initiates a research and development of a sculptural medium made of desert sand, combined with bio-resin as a more sustainable material that demonstrates its application potential.

Since bio-based composites are sustainable materials made from natural materials, they are seen as an ideal alternative to petroleum-derived polymer composites (Rudin & Choi, 2013). They have great scope for applications where excellent mechanical properties are not required (Mohanty, et al., 2002). They can be recycled or disposed of at the end of their lifetime without adversely affecting the environment. This thesis focuses on exploring how a bio-based composite formed by combining desert sand and sodium alginate extracted from natural brown algae has the potential to act as a mouldable material. The research involves the establishment of a set of production, process, and aesthetic standards through organising the material experiences, and the implementation of eco-cycling through the flexible utilisation of material properties.

The original motivation for this research stems from my personal experience as I worked in the curatorial department of an art museum in 2022. In my day-to-day interactions with exhibition constructors and the public education department, I saw that some 70% of the materials used for exhibition set up and educational activities could not be saved for the next exhibition or event. After a short period of usage, they were disposed of directly as industrial waste and disposable waste. For example, even though casting and ceramics are generally popular craft activities, the amount of waste generated after the event is also significant, and clay even becomes a non-biodegradable material once it is converted into ceramics. After gaining a deeper understanding of these unsustainable behaviours in curatorial and creative practice, I set out to express the necessity of sustainable practices in the form of a personal project.

The definition of “sustainability” often entails the pursuit of functional diversity in the design field. The Cradle-to-Cradle model of sustainability and the philosophical framework of New Materialism are incorporated as strategic and theoretical frameworks to inform and drive my research findings into shaped artefacts. The final artwork of the project demonstrates my desire to raise the profile of neglected desert resources and also my vision related to waste reduction.

CHAPTER 1. LITERATURE REVIEW

A scanning electron microscope of SA-DS (black sand) sample

1 LITERATURE REVIEW

This chapter discusses an issue of the insufficient reserves of usable sand, as well as the abundance of unutilised sand resources in deserts. These issues underpin the focus of this research project, which reflects on an opportunity for an improvement in the field of art and design.

New materialism is an essential theoretical framework that values the coexistence of people and the environment. The project follows its commitment to sustainability, as it does not use existing scarce resources and ensures its continuity into the eco-cycle. At the same time, it has also carried out some practical actions to bring environmentalism into the physical world to implement it. To support the creative practice component of this research, this chapter also presents a background investigation and review of existing research on sodium alginate to confirm the role it plays as a bio-binder. Finally, the work of creative practitioners and artists that inspired the artistic expressions of this project, are considered so that the materials and themes of the practice are discussed and examined from an artistic perspective.

1.1 WHY SAND

The existing paradox between usable sand and desert sand reflects the intimate relationship between human well-being and nature. Current knowledge of sands is useful in constructing a detailed background for my project.

1.1.1 The Paradox of Sands Resources

From a human perspective, sand has been considered as an inconspicuous natural substance that covers deserts and coastlines worldwide; it was readily available as a cheap and accessible resource. However, in some places a sand crisis has already started, with a shortage of sand reserves spreading across the globe (Peduzzi, 2021).

It is noted that the depleted reserves do not refer to all sand in general, but to usable sand that can be processed and produced for construction or manufacturing, with diameters ranging from 0.2mm to 2mm (Jack, 2023). On the other hand, desert sand with diameters ranging from 0.075mm to 0.3mm (Zhishuan Lv et al., 2023) has overflowed and is ignored. One reason is that it does not meet safe housing standards (Beiser, 2019). Some reports have revealed countries with abundant sand reserves dredge billions of tons of sand annually from rivers, beaches, and quarries to supply it to other countries as a commodity (Meynen, 2017). The value of sand has been pushed by contemporary socio-economic and cultural developments, and it has an immeasurable value as a commodity. For example, toothpaste, mobile phones, cosmetics, glass and ceramic products that we use daily all contain sand components (Beiser, 2019).

However, usable sand is being excavated faster than it can be renewed on itself (Kothari & Arnall, 2020). Besides, sea level rise and climate change-induced increases in storm intensity cause more wind, waves and flooding, leading to shoreline erosion and sand reduction (Guterres, 2020). It also radicalises some people to profit through illegal trade and extraction driven by the current value of sand, and even violence and deaths have even occurred in the competition for sand resources (Beiser, 2019; *Sand War,* 2012).

There are several suitable alternatives to natural sand in practice nowadays, such as recycled concrete, artificial gravel, and glass sand (Langweil & Lambin, 2022). Nevertheless, the alternatives are still limited and are far less than the enormous annual utilisation of sand, gravel, and crushed stone worldwide (Langweil & Lambin, 2022). Overall, developing alternatives to sand-based products and eco-friendly materials is an urgent priority for sustainable development today. Desert sand is the main research object of this project. While thinking about how to utilise sand, creative design ideas around eco-friendliness was gradually stimulated, which bridges to the next section about another research component.

1.2 SUSTAINABILITY

Figure 1. A three chasing arrows of the international recycling logo. It is sometimes accompanied by the text "reduce, reuse and recycle. The original symbol created by Gary Anderson.

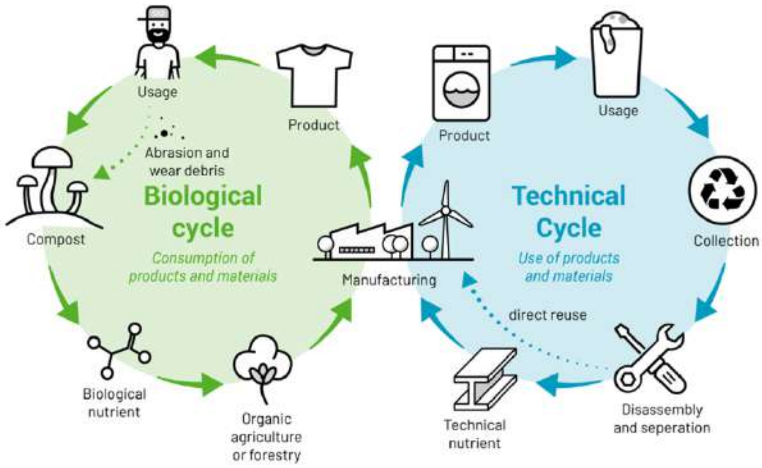

Figure 2. A diagram of Cradle-to-Cradle concept by M. Braungart and W. McDonough. The diagram's copyright © Felix Joerg Mueller.

Reuse, recycle and reduction or the 3Rs (Anderson 1970) have been proposed as a sustainable approach to alleviating pollution, and resource scarcity (Fig.1). This approach is based on the principle of incorporating green investments while actively phasing out unsustainable options (SEI & CEEW, 2022). There are many materials that run counter to sustainability in their current utilisation and operation (Vadén et al., 2020). For example, some chemical reagents are used while recycling and producing products again. And this kind of recycling is not good for the environment.

In the 1970s, Walter R. Stahel refined "sustainability" into the Cradle-to-Cradle (C2C) system, which was further developed by Michael Braungart and his team (Fig.2). The C2C model appears as a solution to the "eliminating waste" interpretation. The formula "waste equals food" was introduced to explain that "everything is a resource for something else"; all "waste" is food for the next phase or system, eventually returning to nature by decomposition (Braungart & Mcdonough, 2009).

The illustration (Figure 2.) shows the emphasis that C2C places on eco-efficiency, where natural forces are used correctly and enter a healthy cycle of interdependent supply between humans and the planet. Additionally, this can be predicted once the 3Rs enter and creatively converge with

C2C to enable the upcycling of resources and materials. Therefore, the 3Rs and C2C approaches provided me a waste-free design perspective in this project. The scope of the application developed in this project is limited to short-term situations or small artifacts, where consuming fewer chemicals is the critical factor.

1.3 A SUSTAINABLE SOLUTION BASED ON BIO-BASED COMPOSITE

Bio-based composites are integral to the development of this project practice, sodium alginate (SA) is an essential component in this project for binding with desert sand to make a sustainable material. This section discusses the definition of bio-based composites and the advantages and disadvantages of SA as a material. Combining experiences from various disciplines, the section also highlights the role of SA in improving mechanical properties and achieving ecological self-cycling through biodegradability. The results of the existing research provided a knowledge foundation for the practical hands-on experimental work, thus predicting the material feasibility described in the 3.0 *Creative Practice* chapter.

1.3.1 Bio-based Composites

With the rise of green and eco-friendly topics, material research has gradually focused on ecological sustainability and compatibility (Španić, 2012). Bio-based Composites (BBCs), an eco-friendly alternative to petroleum-derived polymers, are advantageous as they have a lower environmental impact at the end of their lifecycle (Rudin & Choi, 2013).

Most BBCs are derived from sustainable biomass, such as a combination of bio-fibres and polymer matrices (Jefferson & Dhakal, 2022). Their raw materials come from regenerative agriculture and forestry, such as cotton, hemp, coconut husk and resins, starch and cellulose (Mantia & Morreale, 2011). Depending on the biomass' properties, various applications and adaptations exist for different industries. For example, cutlery and food containers formed from sugar cane and bamboo fibres can replace plastics (Liu et al., 2020).

In the past few years of research, bio-based composites have shown great commercial potential and development prospects in some application fields that do not require mechanical properties (Dwivedi et al., 2015; HM & TA, 2017; Mantia & Morreale, 2011). Conventional petroleum-derived polymers have limitations in terms of recycling and reuse, and existing disposal options, either incineration or landfill, pose a threat to the Earth's environment. BBCs demonstrate strengths in these areas, providing outstanding advantages in terms eco-efficiency, resourcefulness, waste generation and energy consumption during production, the risk of inhalation of hazardous substances by production line workers, and lifecycle greenhouse gas emissions (Jefferson & Dhakal, 2022; Mantia & Morreale, 2011). And its thermal insulation and acoustic properties are not inferior to inorganic mineral-based materials (Hassan et al., 2020; Španić et al., 2012). These advantages provided a complement to my project in seeking the most optimal research components and interpreting the criteria of bio-based composites produced from natural and sustainable sources.

1.3.2 Sodium Alginate (SA)

This subsection focuses on a review of sodium alginate (SA), a polysaccharide from seaweed, understanding the properties of this natural composites is helpful to access inspiration for the production process of products with the associated application properties (Španić et al., 2012).

Brown algae, a rich marine resource, is considered a low-investment yet high-return eco-industry due to its fast growth rate and simple harvesting process (Vasco Costa Delgado et al., 2022). Algae contains algin that binds sodium ions in aqueous solutions to form SA, it is soluble in cold and hot water, non-toxic, odourless and it is easily combined with other substances (Beata Łabowska et al., 2019). Its mechanical properties can be modified by adding fibres or bio-based materials, to improve flexibility or reduce brittleness (Gurgel et al., 2011).

Although SA is a safe and stable natural material, its products still have limitations in terms of ductility, processability and dimensional stability. Its hydrophilic properties are an obstacle to production and utilisation, the consequence of hygroscopicity or water absorption is a structural change in the molecular formula; if SA is mixed as a filler (binder) with other matrix materials, its initial water occupation affects porosity and density - an increase in water absorption leads to a decrease in the hydrogen bonds of this SA-treated material, thereby lowering the overall mechanical properties (Španić et al., 2012). Although, calcium chloride can enable SA to form an insoluble gel in certain specific conditions, this problem becomes more pronounced over time, especially with shrinkage and swelling in composites with a high filler content (Senturk Parreidt et al., 2018).

1.3.3 Biodegradability

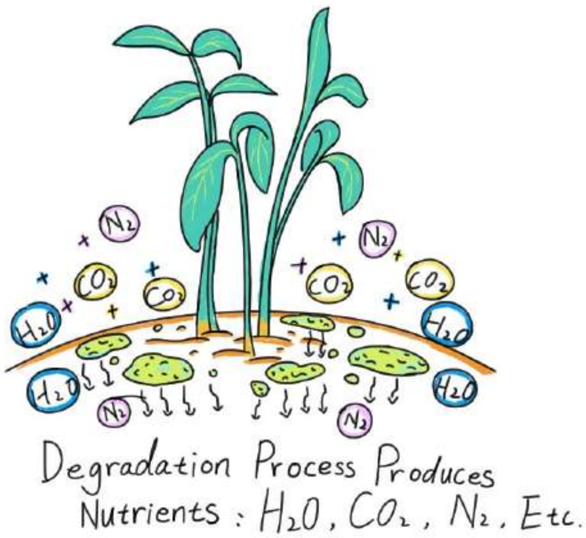

Figure 3. An illustration of degradation releasing substances needed by plants.

Biodegradation usually refers to almost any substrate degradation caused by biological activity unrelated to conventional petroleum-derived polymers (Haque & S, 2023). Biodegradable natural composites contain polysaccharides (starch, gelatin, alginate, and so on), proteins (albumin, silk, elastin, and so on), lignin, lipids, and so forth (Mantia & Morreale, 2011). In comparatively humid environments, microbial activity and enzymatic reactions contribute to the degradation and conversion of soil-harmless substances that meet the plant's needs (Mohanty et al., 2002).

Gao et al. (2022) explored the biodegradability of sodium alginate (SA) and investigated the changes in soil microbial communities during the degradation. Their experiments with the soil burial method found that SA's biodegradation was 90% within 28 days (Gao et al., 2022). The soil microbial results showed that biodegradation kept soil pH within the normal tolerance range for plant growth and increased soil organic carbon, total nitrogen, adequate nitrogen, and water retention capacity (Fig.3). It revealed that sodium alginate is ecologically acceptable for soil and plants, and it facilitated the optimisation of bacterial community structure and function, such as the activity of biological soil crust.

The degradation process is like composting, converting nutrients as soil conditioners; carbon dioxide (CO^2) and water are produced as gas and vapour respectively (Peigné and Girardin, 2004). The composting approach minimises waste without a further environmental threat. I obtained a secondary source of data on the biodegradability of SA and I also advanced the project's reflections on the potential value of the material at the end of its life cycle, matching the Cradle-to-Cradle model.

1.3.4 Mechanical Properties of SA-treated Sand

Natural-organic derivatives and bio-based composites have been discussed as alternatives to cement-based systems by Plank and Viera et al., (Dove, 2014). They have enormous potential as eco-friendly binders, fillers and soil conditioners. A review of two studies centered around sand modification follows.

Hadi Fatehi and his civil engineering team researched the improvement of sand properties and found that sodium alginate (SA) improved the mechanical properties of sand. Testing with the California Bearing Ratio (CBR), they found that compressive strength of SA-treated sand was significantly enhanced if the SA content was increased. For example, while the untreated sand was only 21 Kilopascal (kPa) according to the Uniaxial Compressive Strength (UCS) estimation, whereas the values increased to 800 kPa after the addition of 2% sodium alginate. Scanning Electron Microscope (SEM) images also revealed the gaps between the sand particles were reduced appreciably by applying SA and the contact surface between the particles was increased, leading to an improvement in the mechanical properties of the sand (Fatehi, Bahmani, & Noorzad, 2019).

Yi and Zhao focused on the cultivation of sand and claimed that water soluble composite- treated sand has the same eco-mechanical properties as soil (soil mechanics), i.e., it has the capacity for plant growth (Yi & Zhao, 2016). The improved mechanical properties allow the sand to be changed repeatedly and steadily between “wet soil” and “dry soil” (Fig.4). Planting seeds and seedlings in the desert was their method of verifying the modification of “sand to soil”. After seasonal cycles, including scientific cultivation and maintenance methods, the experimental field grew healthy and vigorous plants successfully, and crusted microbial communities appeared on the surface.

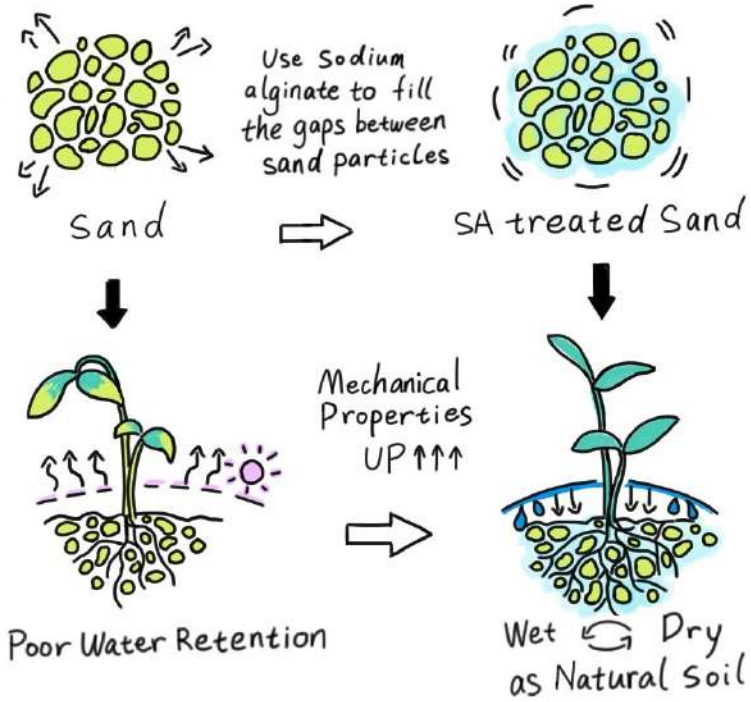

Figure 4. An illustration showing that sodium alginate helps to improve the mechanical properties of sand and is suitable for plant growth.

The above studies and experiments illustrate the role and contribution of bio-based composites as binders. From an interdisciplinary perspective, this project initiated creative research that crosses the intersection of horticulture and soil mechanics. It aims to explore the application potential of the material made by the combination of SA and desert sand for creative applications.

1.4 ART PROMOTES ENVIRONMENTALIST MOVEMENTS

Art can be a robust tool for transforming the mind, raising awareness for the conservation, and for understanding and appreciating of the earth's ecology. This research project adopted a new materialism framework to explore the ecological world without impacting the health or balance of nature. The organic nature of the materials is an indispensable component throughout the research process. Art provides a form of display to visualise the project concept.

1.4.1 The Role of Art

Art reflects the concerns and interests of a time or a period. For instance, as the unsatisfactory state of natural resources gradually came into people’s consciousness, environmental art was established by artists involved in the environmentalist movement (Friedman, 1994).

Environmental art has a history dating back to the 1960s (Gablik, 1984). It refers to any art that responds to nature and environmental issues through artistic means and utilising natural substances (Bower, 2014). One of the pioneers, Robert Smithson, believed artists can engage in the restoration of industrial landscapes (Holt, n.d.). The field of environmental art is broad, it involves a range of artistic practices, including land art, bio art and eco-art. Although these concepts share similarities, their areas of exploration and elements are different. Eco-art arose in the 1990s with an emphasis on the relationship between nature and human (Sanders, 1992). My project references its focus on sustainability and ecological considerations.

The artworks are often thought-provoking and imply the artist's concern for the environment. Appropriating natural materials to create art that lives and breaks with the seasons contributes to raising environmental awareness among the public. Agnes Denes, an environmental art pioneer, described a new role for the artist in the Anthropocene, to create art that goes beyond decoration, commodities or political tools, this art questions the status quo and the direction of life and it also takes keys from other systems and unifies them into a unique, coherent vision (Denes, 1993, p397).

Therefore, this project's outcomes were presented in an artistic form. Built on certain aesthetics, the outcomes became interactive and visual, serving to stimulate the audience to reflect and discuss the background of the project.

1.4.2 NEW MATERIALISM

New materialism, as a philosophical framework, emerged at the start of the millennium (Yi

Sencindiver, 2017). It emphasises the interrelationship between all things and substances in nature. It helps us understand how art and the environment are intertwined and shape each other in a complex “material-discursive” process (Golanska, 2018). This theoretical framework assumes that materials, objects, and substances are agencies (actions) and that all organisms have equal intrinsic value. Therefore, New Materialism can provide a theoretical art-based material practice to transcend the humanist bias of traditional art, favouring the exploration of the interaction between materials on hand and the environment. For example, *Revival Field* (Fig. 5), by artist Mel Chin, connected a heavily contaminated piece of land to “green remediation“ (Pivetz & Kovalick, 2001)” through planting (Chin, 1990). This work was regarded a modern alchemical/metallurgical project (Beardsley, n.d.), because the hyperaccumulator plants Chin utilised extract heavy metals from the soil (Chin, 1990). Once the artwork was completed, it was also the birth of technology with ecological and economic value since the harvested plants could be burnt and extracted into a pure metal product for sale (Loring, 2020).

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Figure 5. A photograph of *Revival Field.* The image demonstrates the circular configuration of the planting of hyperaccumulators that was done on site. Copyright © Mel Chin.

This promotes not only the restoration of destroyed landscapes via artistic means, as well as the integration of the artwork with the ecological world as part of the system and substances around us, rather than merely an exhibit or external landscape (Friedman, 1994). This approach motivated me to reflect on the interaction of materials with the environment, thereby translating the metaphors drawn from nature into the final practice outcomes.

1.5 ARTIST REFERENCES

The following two artists and one designer have unique ways of responding to the current ecological drama. Agnes Denes used plant crops and cultivation to demonstrate environmental issues; Meg Webster juxtaposed plants and technologies in a work that emphasises the creation of spatial atmosphere and visual effects; Magnus Larsson has a bold vision of the future of dune architecture, with the application of bio-based materials to desert sand as mentioned. These artists provided inspiration and creative ideas that informed the development of my project.

1.5.1 Agnes Danes - A Wheatfield in Manhattan

Denes' work *Wheatfield, a Confrontation 1982 was* a two-acre wheatfield consisting of dense wheat grown by artificial planting (Denes, 1982). This work was purposely located on a landfill site opposite the World Trade Twin Towers. This abandoned land produced a bumper harvest through a process of agricultural operations (Hoban, 2019). Afterwards, the harvested wheat was sent around the world for exhibitions to publicise environmental and social issues (Denes, 1982).

This work artistically performed the sustainable exploitation of land as well as revealing the causes of the ecological crisis (Hessel, 2022). While my project is still located in a gallery space rather than outdoors in a natural environment, it still involves the interweaving of my personal experience and personal concern for the environment into my personal practice, like the work of Denes, appropriating agricultural knowledge to form a distinctive artistic language.

1.5.2 Meg Webster - Solar Grow Room

Meg Webster's work shows further reflection about the intersection of nature and technology. She invites the audience to interact with the work by directly engaging the senses - smell, touch and hearing in the experience (Geggenheim, n.d.).

Solar Grow Room is an interior exhibit, it focuses on the dramatic decline of bees due to habitat loss and overuse of pesticides (Webster, 2017), like a small garden greenhouse (Fig.6). The work consists of four raised planters in which the plants are pollinator (insect)-friendly mosses, herbs, lettuce, beans and various flowers from local farms and greenhouses (Johnson, 2016).

Webster used some materials to enhance the ambient sense of the work, such as pink LED lights, and silver film. These amplified the beauty of the plants (Webster, 2016). I was inspired to think about how to use the appropriate visual elements to enhance an artwork using light and shadow in this artwork.

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Figure 6. A photograph of *Solar Grow Room*, copyright © Meg Webster. Photography by Steven Probert.

1.5.3 Magnus Larsson - Dune Blue Architectural Blueprint

The project “*Dune*”, initiated by Swedish architect Magnus Larsson, provided insights and complements in stopping the onslaught of desertification and building a “green barrier” against sand (HOLCIM Foundation, 2008). Larsson proposed a 6000 kilometres sand wall across the Sahara Desert from east to west that would provide housing for refugees and assist the GGWSSI in building a micro-landscape support structure (Larsson, 2011).

Professor Jason DeJong of the University of California and his microbial development team provided technical support for Larsson’s dune anti-desertification architecture concept. The technology is based on microbiologically induced calcite precipitation (MICP) employing the microbe bacillus pasteurii as bio-cement to modify mechanical properties of sand – the sand can achieve optimum strength in a week, with high durability like conventional bricks (Deniz & Keskin-

Gundogdu, 2018). Larrson expanded his *Dune* on this method, the modified dune became functional structures and spaces in architectural design as floor datum, wall membrane, spatial divider arches and so on (Fig. 7) (Larsson, 2011).

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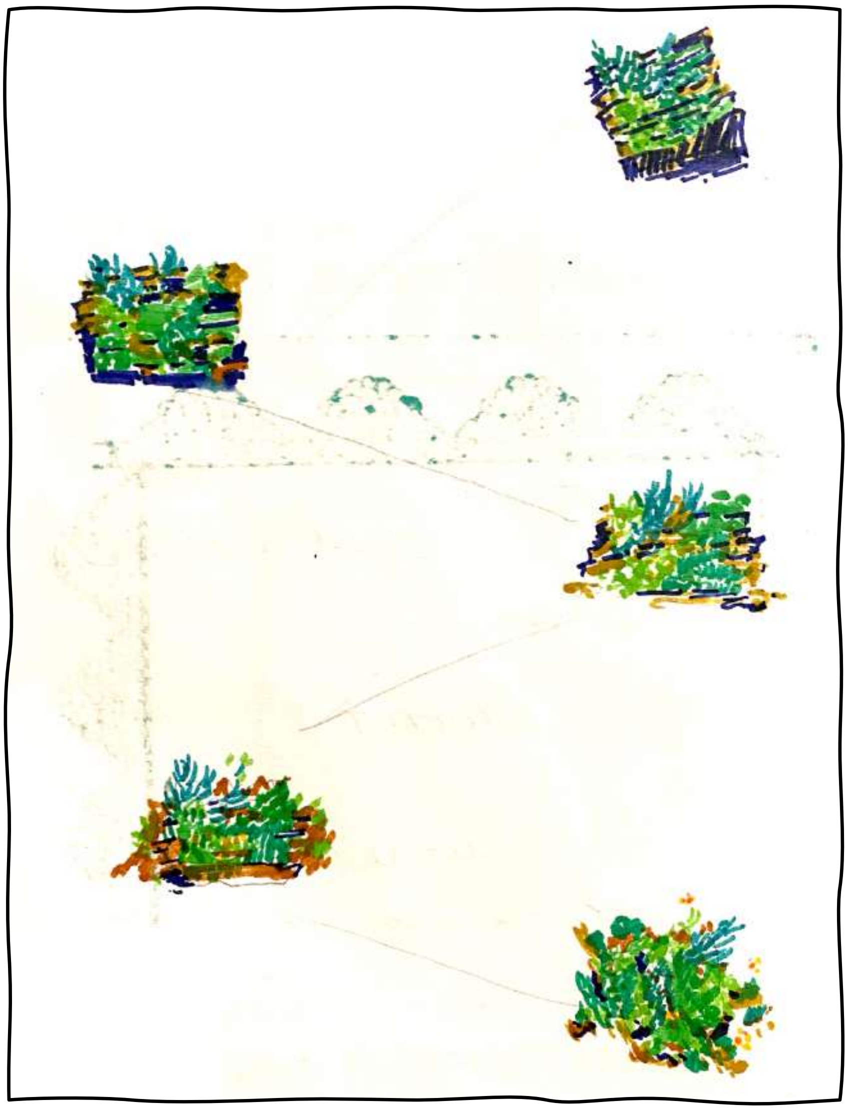
Figure 7. A diagram of *Dune*'s internal structure. Copyright © Magnus Larsson

The dune is an architectural blueprint for the future, the localised curing of the desert sand presents a new sustainable solution for human well-being. Even though many details still need to be explored before B. pasteurii is planted on a large scale in practical desert conditions, it has the advantage of maximising the utilisation and exploitation of the abundant local sand resources by directly manipulating the dune landscape. The building is a direct appropriation of the existing wind-created dunes form, without intentional ornamentation, it provided my project with a new way of developing the structure and appearance of prototypes. While Larsson's project aligns with my project in terms of sand selection and bio-based materials properties, my application of sand is currently limited to small artworks and short-term exhibition needs. Therefore, the results of the study and prototyping are not similar or conflicting.

CHAPTER 2. METHODOLOGY AND METHOD



A drawing of plants interacting with and degrading SA-treated sand

2 METHODOLOGY AND METHOD

2.1 METHODOLOGICAL FRAMEWORK

The project conducts research design on specific bio-based materials (BBMs) from four methodological perspectives.

With "sustainability" as the entry point, the project has two main goals: one is to formulate and validate prototypes and new methods that match the needs, including corroborating the knowledge in Chapter 1 to enhance the robustness of the research; and two is to develop theories, techniques and tools based on these prototypes and new methods for refining design strategies towards better integration into the application of the artwork (Calderon, 2010).

2.1.1 New Materialism (NM)

New Materialism is this project's theoretical framework, it emphasises material agency and responsiveness. It serves as a guideline in the design creation process and encourages creative practice as a tool or method to reflect on new issues and ideas that arise during the design research process, combining knowledge and technology (Nimkulrat, 2009). Throughout the project research I practice and write as a reflective practitioner.

2.1.2 Practice-Based Research (PBR)

PBR is an explorative approach that generates new knowledge through the cooperation of practice and research (Candy & Edmonds, 2018). Therefore, an original investigation through practice can help to understand the appearance in terms of the characterisation of the interaction of the two materials. There are no specific studies and data on mixing and curing sodium alginate with desert sand/beach sand for creative applications. As discussed in the literature, the role of SA as a bio-binder is validated in this practical process. The results of the hands-on experiments complement my personal understanding and are transformed into primary resources. It provides the basis for optimising the making the recipe of SA-DS, exploring the mechanical properties and setting the scope of the application.

The research process can assess the nature of the project, such as dimensions and timelines. Artefacts are an integral component of PBR and underpins the outcome of a research practice, which leads to evaluation, insight, and reflection (Candy & Edmonds, 2018). Artefacts can also be seen as tools that help practitioners to connect closely with their existing practice. This derives from the project's aim to develop an emerging artistic material to create a work with artistic expression. The creation of artistic experiments facilitates the development of the visual appeal of the material, thus gaining an opportunity for parallel communication with the audience. Presenting the research's findings will have an effect on the effectiveness of information dissemination.

2.1.3 Material-Led Design Research (MLDR)

MLDR prioritises the exploration of materiality and expressivity of materials in the design process. In this research strategy, a material-centered mindset is introduced into the early steps of the design process, and an experience-oriented perspective like PBR is demonstrated through hands-on experiments and prototyping. Differently, MLDR emphasises developing the sensory attribute aspects of SA-DS, thus establishing aesthetic criteria to maximise the expression of the material's properties. To produce artefacts or artworks that are very close to the material's nature and perfectly matched to the application, it is necessary to experience both positive and negative practices, and based on the resulting experience a researcher can conceive the situational application of SA-DS (Manzini, 1989; Karana et al 2008; Karana et al., 2015).

The application of MLDR in this project is based on the direct intervention. As such I manifested the intervention as prototypes and iterated the design through questions, planning, testing, and reflection to discover new potential and innovative applications of SA-treated sand (Wilson et al., 2022). Bio-based materials' distinctive qualities influence the outcome and final artefacts. The design model from Karana et al. (2015) has been adapted for this project and is detailed further in section 2.2 that outline in the steps of the research design.

2.1.4 Biodegradability

This study adheres to sustainability principles and investigates the biodegradability rate of experimental samples in a controlled environment. The degradability testing evaluates whether artefacts made from bio-based materials are plant-friendly and potentially compostable at the end of their life. This approach was inspired by a review of *Biodegradabilit*y (in section 1.3.3).

Bio-based materials are often associated with environmental protection. Sustainability is about "remaking the way we make things (Braungart & Mcdonough, 2009)" to the greatest extent possible", including where they are used and how they are recycled (Rosenboom et al., 2022). Composting an influential strategy to reintroduce organic substances to the soil. It has become from the waste has become an emerging recycling method and contributes to ecological sustainability.

Once the positive effects of the SA-DS developed in this project on plants are identified, its derivation as a plant growth substrate can be utilised in subsequent artistic experiments and final designs. NM drives a very intuitive symbiotic connection between SA-DS and plants, inspiring the artistic expression of this project. Symbiosis is a promising research topic for the further development of the SA-DS, and how to appropriately utilise greenery in the works produced by the SA-DS is a topic that is explored in the next chapter of *Creative Practice*.

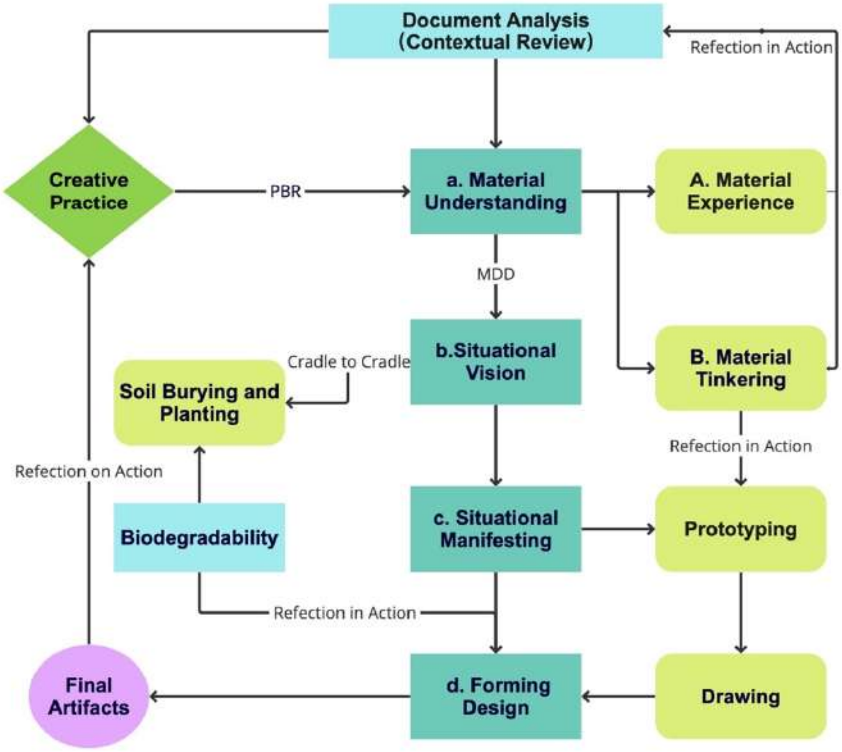


Figure 8. A diagram of methods flowchart.

2.2 Steps in Research Design

To enable the final transformation of abstract concepts into physical artwork, the research steps revolve around an experience-oriented design process. Through the development of the aspects of “understanding”, “vision”, “manifestation”, and “design”, a range of design steps are formulated and allowed to be iterated and transformed (Fig. 8).

Because different experiences, expectations, and perceptions of social and cultural values directly affect the ability to judge things, thus constructing different experiences (Giaccardi & Karana, 2015). Therefore, while combining the design model of Karana et al. (2015), I added personal design tendencies in detail to intervene in the direction of material development (see Chapter 3 for details).

a. Material Understanding

While working with an unfamiliar material, gaining a preliminary understanding of it is important. If the material has already been developed, its physical, mechanical, and technical properties and crafting techniques can be found in material databases or previous literature. The Materiom, Fab Lab Barcelona and Material District online material databases were accessed during the preliminary research phase of this project. For example, what is sodium alginate? However, if the material has not yet been fully developed, we must employ some technical and empirical means to approach the material (Karana et al., 2015). For example, little is known about the applications of SA-DS in art. Creating sensory-level interactions can inspire new insights into materials. The juxtaposition of the material with similar or interchangeable materials can reveal the unique qualities of the material. In this step, the research questions are answered by making small samples:

- In terms of SA-treated sand's inherent qualities, limitations, and opportunities, what are they?
- How will the sand be characterised if mixed with other bio-based composites?

b. Situational Vision

This step involves the expression of design intentions, i.e., giving situational meaning to sand after judging its individual characteristics (Giaccardi & Karana, 2015). I summarise and combine them into a whole based on the work done in step a. This step leads to a potential niche for applied visions or broader topics related to society and the planet; in the Karana et al. design model (2015), this step is called *Creating Materials Experience Vision*.

Due to my interest in greenery, art and plants, situational vision interweaves creative skills with horticulture. I applied the "waste = food" formula of the C2C model to consider the recycling of SA-DS in this project and its gardening-related value, thus serving the purpose of diverse applications. In this study, SA-DS was defined as a craft material alternative to traditional unsustainable materials by reflecting on (1) the positive role of the material in a broader context, (2) the interaction with a particular environment, and (3) the recycling management of the material.

c. Situational Manifesting

The design criteria and aesthetics are established through hands-on experimentation to manifest the material vision of the step b, including smell, hardness, toughness, colour, and texture. The results of step c. directly affect the formal quality of step d.

Colour: The original colour of the sand is used and preserved for environmental protection. Sand from different regions has different colours, mostly neutral tones, is interpreted as "modest (Karana et al., 2015)" materials. These naturally occurring sands are often less than perfect and compact, but this is their unique attribute. Different combinations of sands can form patterns without extra pigments.

Smell: Bio-based materials have an unpleasant odour and due to their properties have a slightly rancid and sour odour that depends on the organism. In practice, dehydrated samples also retain this odour. It has been observed that this is related to temperature and humidity. The next chapter shows the effects of natural and oven drying on the smell. This test can evaluate SA-DS's life cycle and external placement conditions.

Texture: In the design field, texture is an alternative aesthetic language besides colour; we can explore the feel and appearance of a surface or substance and discuss the quality of design work (Wiberg & Robles, 2010). Compared to other structural materials, SA-treated sand is not sufficiently strong to achieve fine textures, but this does not affect the continued development of SA-DS. The emergence of minimalism signifies a fascination with anti-fabricated design. The prototypes as shown in my drawings include hand carving and mould casting.

Hardness and Toughness: The primary admixture in SA-DS is SA, it acts as a bio-binder in the composite. Its proportion and the concentration directly affect its cohesion, hardness and toughness. Although the project does not require high-strength mechanical properties, it is still necessary to ensure a stable structural and formal qualities.

d. Forming Design

The concept of the artwork (or functional artefact) is formed by converging the above three steps. Personal intuition and design vision contribute to formal rationalisation. Creating emotional interactions with surrounding items and existing products can quickly spark creativity.

Although SA-DS still requires professional exploration, from development to marketing, this step summarises the research design above and is demonstrated through the artworks. The forming design tends to convey a value that reinforces the appreciation of "sustainability" and provides a topic for further exploration in the future.

2.3 Methods

Under the methodological framework outlined in 2.1, there are multiple methods to drive the practice through the various steps of the study (Fig.8).

2.3.1 Materials Experimentation

Materials experiment refers to experiencing the material in practice, discovering problems and opportunities, and finally deciding on the design. The experiments were divided into two phases: A. Material Experience and B. Material Tinkering.

A. Material Experience

Direct experience with the material through the senses can have a preliminary understanding of the material, for example, the sensations conveyed once a hand touches the material's surface, and a nose approaches it. In addition, in the field of art, this practical interaction can inspire forming design and drawing, gaining aesthetic experience (Karana et al., 2015). This project experiment planned the different experiences of SA and sands to prompt me to develop materials consciously.

B. Material Tinkering

“Tinkering” is a term that refers to manipulating and deciphering materials in a creative way to innovate and interact with unfamiliar material (Parisi et al.,2017). This method is closely connected to crafting, and its techniques and knowledge are instructive in improving design quality. Do-it-yourself and hands-on is not a retrospective of traditional craftsmanship but a crucial step in understanding and developing material (Parisi et al.,2017).

The experiment involves setting up a mixing test of sand and SA solution to confirm the optimal proportion. The test result supplements the SA-treated sand data in a way that answers the research questions outlined in section 2.2 a.

2.3.2 Drawing

Drawing is used to measure cognitive development (Goodenough, 1926), and complement the written word as a research tool capable of projecting expression not easily verbalised. Drawing is often associated with artwork. We develop an intuitive perception of the material in the draft and capture selected features of shape and line in drafts, shaping aesthetic awareness (Heimer, 2022). The drawing method relies on visual arts (Mitchell et al., 2011), which helps me create artwork with personal beauty and meaning.

2.3.3 Prototyping

This process is a necessary design process before the final artwork is installed (Buchenau & Suri, 2000). For example, after we confirmed the situational vision of the design intention mentioned in section 2.2. b., we should provide convincing design practice and prototyping. This project employs the prototype's functionality as an experimental component, aiming to validate the usability of the design draft, aesthetic criteria, and other specific assumptions through the experimental setting (Wensveen & Matthews, 2014). This method allows a constructive investigation of the four factors in section 2.2 c since material quality changes with time,.

2.3.4 Soil Burying and Planting

Biodegradation is the biochemical transformation of composite materials by microorganisms (see section 1.3.3). The "soil burying" method involves burying materials in the soil that are broken down into constituent molecules through natural processes (Prakash et al., 2014). I set up this experiment up to examine SA's biodegradation rate to confirm SA-DS's recycling management. The experiment involves regularly observing the state changes of dehydrated samples in the soil within 50 days.

The planting experiment was inspired by Yi and his team on desert cultivation (see section 1.3.4). The literature shows that the BBMs mixed with the sand changed the original mechanical properties and increased cohesion. Cultivation is a practical means of verifying this principle without sophisticated scientific instruments. This experiment was set up in a specific captive environment. The purpose of the experiment is to verify the non-toxicity and environmental friendliness of SA-treated sand by observing the germination rate and growth trend of the seeds. It also sets forth a practical foundation for subsequent studies to confirm the broad application of SA-DS.

2.3.5 Documentation

The documentation focuses on recording or researching the process for further reference and reflection (Nimkulrat, 2007). Photographs, hand drawings, research notes, observation diaries and other forms provide a logical way to label, store, and rearrange samples and prototypes produced during BPR and MLDR processes. It includes challenges, successes, and insights from experimentation and prototyping iterations.

Figure 9. A photograph of partially archived samples.

2.3.6 Reflection-in-action & Reflection-on-action

To demonstrate the rigour and logic of the overall research design, the researcher often reflects on the steps and thinks through all the details. Dewey (1933) explained the term “reflection” as carefully considering assumptions and milestones on various supporting or dispositional grounds. The terms “reflection-in-action” and “reflection-on-action” are original concepts proposed by Donald Schön (1983). The former occurs in practice (in-action) by “thinking while doing”. The resulting decision or practice continually intervenes in the following action or result. The latter occurs after the action. As a holistic review reflecting on the completed research or practice it facilitates obtaining the limitations and stimulates research directions that have not yet been addressed.

While placing oneself in the role of a reflective practitioner, it is possible that *“the stance appropriate to reflection is incompatible with the stance appropriate to action”* (Schön, 1983, p. 278). Therefore, I included reflection-in-action in Steps b. and c. (in section 2.2) to ensure that reflection is consistent with action.

CHAPTER 3. CREATIVE PRACTICE

The visual effect of the final work in a dark environment

3 Creative Practice

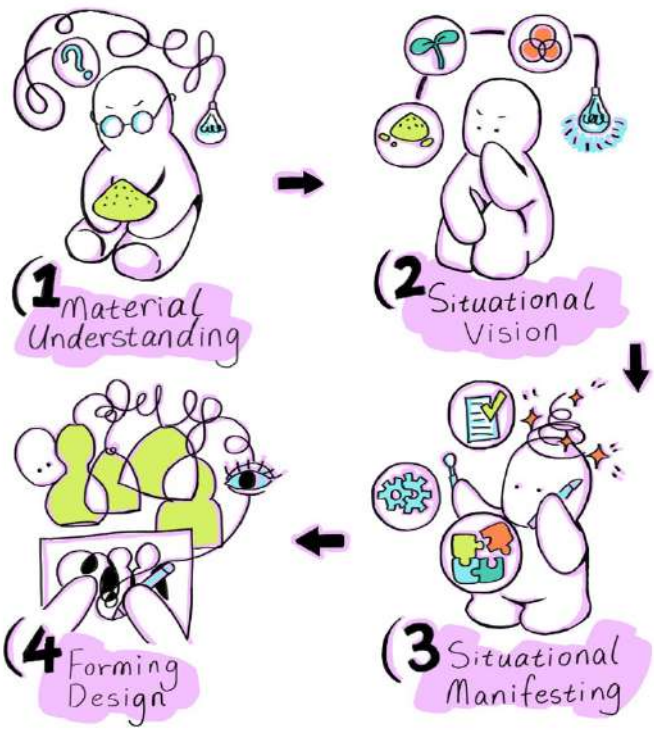


Figure 10. An illustration of the four phases of *Creative Practice*.

3.1 Overview

This chapter describes a practice-based research process focusing on developing the bio-based admixture produced by mixing SA with sand and its potential application in creative art projects. The methodologies and methods mentioned above have served to organise the practice and experimentation described in this chapter. After detailing this process of production, discussion and reflection, this chapter concludes with a set of artefacts and highlights the material's usability, feasibility, and versatility as a sustainable material.

The practice was executed following the steps identified in section 2.2 of the *Research Design*:

-Phase 1. Material Understanding

-Phase 2. Situational Vision

-Phase 3. Situational Manifesting

-Phase 4. Forming Design

A timeline of sand utilisation: The project's original intent was to apply plentiful desert sand (DS), so a year-long study spanning from mid 2022 to mid 2023 was developed around DS. Some hands-on experiments and a preliminary exploration phase were carried out from July to December 2022 was conducted in China, where DS can be obtained easily; the data and work generated in phases 1 and 3 were built on the DS. Then, from January 2023 until August, I moved to New Zealand to study on campus, but natural desert sand was not accessible in the region. To continue development and research, the experimental material was changed from desert sand to native New Zealand beach sand. With the change of sand species, the practice added a new component to the work in phases 1 and 3.

Although international shipping was considered as a way of continuing to access the original DS, customs quarantine was recognised as a risk because of the seeds or bacteria that may be hidden in the sand - exotic species cannot successfully enter New Zealand. Also, there is the issue of greenhouse gas emissions associated with transport. As an environmentally conscious project, minimising the project's carbon footprint is also a responsibility. Besides excluding shipping, electricity consumption has also been restricted during the practice, e.g., no external equipment such as ovens, dehydrators, or others have been used to accelerate the practice's progress.

3.1.1 Ethical Consideration

The practice was informed by ethical considerations and did not involve human research. In order to reduce the utilisation of ecologically unfriendly and toxic chemical additives, the practice involved raw materials that are natural substances, coming from or extracted from nature.

The sand utilised in this research was either procured commercially in China or collected from local New Zealand beaches. The sand obtained from the beach as material is sensitive because the coastal sand belt is decreasing (Graffin et al., 2022). An example of human and environmental factors is the fact that Maiami Beach in the US has to be regularly replenished with white sand in order to keep its beauty pictured on postcard souvenir photographs (Barroux & Depardon, 2022). Therefore, the samples collected in New Zealand were small, involving up to two buckets of sand from any one site. It is recognised that any sand utilisation beyond the scope of this project, and the small size of the experimental outcomes, would require the identification of commercial sand sources to meet environmental laws. However, the focus of this project is desert sand which is commercially available in China.

Besides, considering the potential contamination of natural soils from the operations at work, the planting experiment in 3.3.3 was designed in a captive environment to mitigate anthropogenic factors.

3.1.2 Material Acquisition

Main Materials:

- Desert sand (DS): from Mongolia's Kubuqi Desert (MKD) of China.
- Constructed sand (CS): no source information known, obtained at construction sites during research in Nanjing, China.
- New Zealand beach sand collected from: (1) Bethell's Beach, Auckland, New Zealand; (2) Kaiteriteri Beach, Tasman, New Zealand; (3) Mission Bay, Auckland, New Zealand; (4) Waiheke Island, New Zealand.
- Sodium alginate powder: made by Lianyungang Tiantian Seaweed Ltd., China.

Secondary Materials:

- Light plaster of paris (powder): made by Gedeo Pebeo
- Glycerol: made by (1) Shangqiu Shengbang Biotechnology Ltd., China; (2) Home essentials, PSM Healthcare Ltd, New Zealand.

Compared Materials:

- Carboxymethyl cellulose (powder): made by Shanghai Zhongguang Food Chemicals Ltd.
- Pine resin (solid, melting point 70-80°C, acid value 166°T): made by Shenzhen Jitian Chemical Ltd, China.
- Agar (powder): made by Chenming County Laocheng Dafu Agar Factory, China.
- Gelatin (granule): unknown production company, sourced from Alibaba online shopping platform.

The following section describes the role and techniques used with the above materials in this project.

3.2 Phase 1: Material Understanding

This phase of the project involved hands-on experiments to explore and better understand the characteristics of desert sand and New Zealand west coast black sand when combined with o bio-based materials. To obtain relatively reliable results, five comparable materials were individually mixed with the sand, among which SA met the conditions and properties required to develop sand for this project.

3.2.1 Material Experience

Before the formal practice began, a preliminary understanding of the sand collected from the Kubuqi Desert was necessary. Following Giaccardi and Karana's approach (2015), material experiences with unfamiliar materials from different levels were prioritised. The feedback provided below came from the researcher's reflection and personal experience records.

Sensorial:
(1) The DS (from MKD) particles are very fine, rounded and homogeneous, close to fine salt particles.
(2) Sand is like a high-density fluid that wraps around the fingers quickly and without any gaps.
(3) The sand itself does not exude any special odour.

Meaning: DS is finely grained and presents a neutral colour conveying a sense of mildness, simplicity, and naturalness, evoking meanings and associations with the DS. For example, sand can be used as a raw material for sculptures, pottery and ornaments, like clay, and their sand colours are almost the same, ranging from yellow, grey and brown.

Performances: A small experiment was conducted by vertically dropping water drops from the air onto a tray of dry sand, where the water and sand rapidly coalesced into clumps, resembling the clumps formed by cat's excreta and litter; sandcastles commonly in the beach, are built up through the beach sand and seawater. Consequently, I confirmed that if particle movement is restricted by water, cohesion can be increased.

Summary

The three levels above enabled an appreciation and first contact experience with an unfamiliar material. These interactions inspired me to have initial ideas about the possible applications of DS, that it has the potential to be used as an art material.

The DS is homogeneous, fine and smooth, eliminating the need for regrinding in factory production lines. From the performance level, it can be concluded that the water solution or other substances are able to fill the sand gaps as a binder. Thus, the composition and raw materials are the main factors controlling the hardness of the sand clump and its viscosity. From this, I proceeded with the process outlined below in 3.2.2 *Material Tinkering,* seeking an optimal binder and initiating a series of comparisons.

3.2.2 Material Tinkering-A

This process was divided into two parts: a hands-on experiment with five bio-based materials used as binder alternatives, to compare and select the optimal one (Tinkering-A). A separate set of experiments was conducted to test and identify the optimal binder for New Zealand beach sand (Tinkering-B).

To compare the differences between the samples, typical construction sand (CS) was used as a control and an extra material, coffee ground, to explore whether the binder appears to have different qualities on other non-sand materials. The binder alternatives were carboxymethyl cellulose (CMC), sodium alginate (SA), agar, gelatin, and pine resin. I have been researching and testing these materials in the Special Project paper of the MCT-809 course at AUT, and it was determined that SA was the most effective binder to be used for subsequent research and development. Therefore, instead of repeating the procedure description in this section, I have placed the experimental details in *Appendix*. The 809 project as Tinkering A, its results are consistent with the research of Plank and Viera et al., in terms of their view of bio-based composites as alternatives to cement-based systems (Dove, 2014), that SA can be successfully used as a bio-cement (bio-binder) in the sand.

The following two figures are a compilation of the Material Tinkering-A, which served as preliminary research materials for this project and an essential component for reflection and documentation.

1.Hardness (H); 2.Smoothness of Surface (SOS); 3.Plasticity (P); 4.Original Colour Preservation (OCP)	**Desert sand (DS)**	**Construction Sand (CS)**	**Coffee Grounds**
Carboxymethyl Cellulose (CMC)	H: ● ○ SOS: ● ● ● P: ● ● ● OCP: ● ● ●	H: ● ○ SOS: ● ● ● P: ● ● ● OCP: ● ● ●	⊗
Sodium Alginate (SA)	H: ● ○ SOS: ● ● ● P: ● ● ● OCP: ● ● ●	H: ● ○ SOS: ● ● ● P: ● ● ● OCP: ● ● ●	Mouldy during air-drying: ●
Agar	H: ● ● SOS: ● ● ● P: ● OCP: ● ● ●	⊗	Mouldy during air-drying: ● ●
Gelatin	H: ● ● ○ SOS: ● ● ○ P: ● ● OCP: ● ● ○	⊗	⊗
Pine Resin White Pine Resin-DS (1:2) Yellow Pine Resin-CS (1.5:1)	H: ● ● ● SOS: ● P: ○ OCP: ● ● ●	H: ● ● ○ SOS: ● ● ● P: ● ● OCP: ○	H: ● ● ○ SOS: ● ● ● P: ● ● OCP: ○

Figure 11: I Table - Characterisation records of sample cubes.

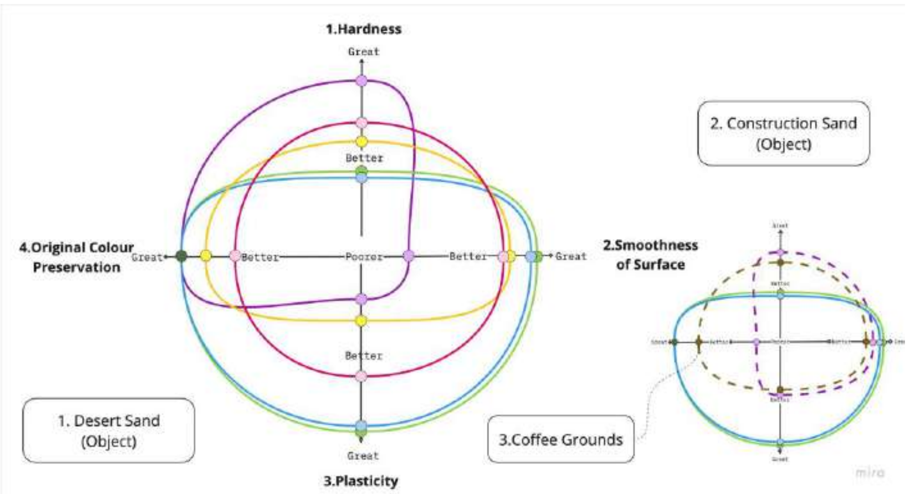


Figure 12: II Graphic Comparison, showing the strengths and weaknesses of methyl cellulose, sodium alginate, agar, gelatine and pine resin. Combined with I Table.

Figure 12 visually presents a comparison of the strengths and weaknesses between the five binders and the three objects (desert sand, construction sand and coffee grounds). Even though the successful samples all displayed some degree of mechanical properties, in terms of hardness, colour, smoothness, and plasticity, it were uneven. These factors directly influence the subsequent modification of the physical properties.

The purpose of Material Tinkering-A was to identify the most appropriate one for the current project, the other binder alternatives are only references (Standardised sand recipe is presented in 3.3).

In Conclusion

Combining Figures 11 and I2, the samples of CMC and SA show the best overall performance. Their sample characterisation is very similar, the colour, smoothness, and plasticity are all higher than the other materials, while only the hardness is relatively weak. Although the lower hardness may not be satisfactory in the durability aspect, it accelerates the rate of biodegradation to achieve a short period of time. The resins, gelatin and agar, on the other hand, their sample characterisation presented in the experiment did not meet the creative development requirments of this project. For example, their dissolution needs to be controlled within a temperature range, which means operational errors or excessive material decomposition can occur (see *Appendix* for details). It is not a convenient choice of binder for manual making or crafting. To minimise improper factors in the material preparation stage, I explored CMC and SA further which have no temperature requirements.

- The Role of Vinegar

Further exploration of CMC and SA revealed the finding that SA has a special property that distinguishes it from CMC. It can form insoluble gel-like substances with lower pH compounds (Morozkina et al., 2022). Utilising this feature can lead to a shorter solidification time of SA-treated sand. In general, SA-treated sand was a fluid colloid without shape until it dries out, whereas spraying acid vinegar on its surface causes an immediate solidification phenomenon, which turns it into a non-fluid state with a jelly-like texture. This near-solidified state allowed easy de-moulding and kept the cast shape intact. It also enabled the air-drying process of the samples to be enhanced there was as more contact with the air.

- Concentration Test

I also conducted to test the concentration. It was found that the 2% SA sample showed a certain degree of shrinkage and deformation if the thickness exceeded 1.5cm (Fig.13). As soon as the concentration reached to 8%, the texture was close to jelly, a non-fluid gel with a high viscosity. However, it reduced plasticity and made SA less compatible with sand. Therefore, the concentration used in this project is at a low value to ensure a wide range of plasticity requirements. Combining the experience from 809's specials project, the optimal a concentration is three (3) percent.

- Comparison with Coffee Grounds

Coffee grounds tinkering was not included in Project 809 and is a newly added comparison object. The figure 11 shows that most of its samples were unsuccessful. Coffee grounds are a plant fibre in the form of fine bran. Although it is a sustainable material with a wide range of current applications, it is unsuitable for mixing with hydrocolloids without an additional dryer or oven to accelerate drying. The reason is that the moisture in the gel gives conditions for mould growth in the unnatural drying process, which leads to a significant reduction in the lifetime of the artefact or other applications. Therefore, it can be deduced that SA as a binder is limited to inorganic or non-fibrous materials. This also reflects that the desert sand developed in this project has an ideal compatibility with SA.

Combined with the above, it is worthwhile to further develop the interaction between SA and sand into artistic applications. The next section of 3.3 has defined the admixtures mixed by them for subsequent expansion and supplementation.

Fig.13. A DS-SA sample (w/w2:1), 1.5 cm thick, slight deformation and shrinkage.

3.2.3 Material Tinkering-B

B: After identifying SA as the optimal binder for DS, I experimented with black sand (BS) obtained from Bethells Beach, New Zealand. The particles are fine and rounded, very close in texture to the DS. This material was explored as an alternative for DS which I was unable to obtain in New Zealand.

- Black Sand (BS) - New Zealand Iron Sand

Five small samples were used to observe the compatibility of BS mixed with SA. Three of the samples were partitioned according to the proportion of the composition of the BS to SA solution (w/w) as 3:1, 2:1, 1:1. The other two samples involved a new combination binder of SA and CMC, BS to it in 2:1 and 1:1 proportion.

The SA and CMC solutions used in the experiments were both 3% hydrocolloids. The newly added combination of CMC and SA was produced in two proportions (w/w) of 50:50 and 40%: 60% (Fig.14)

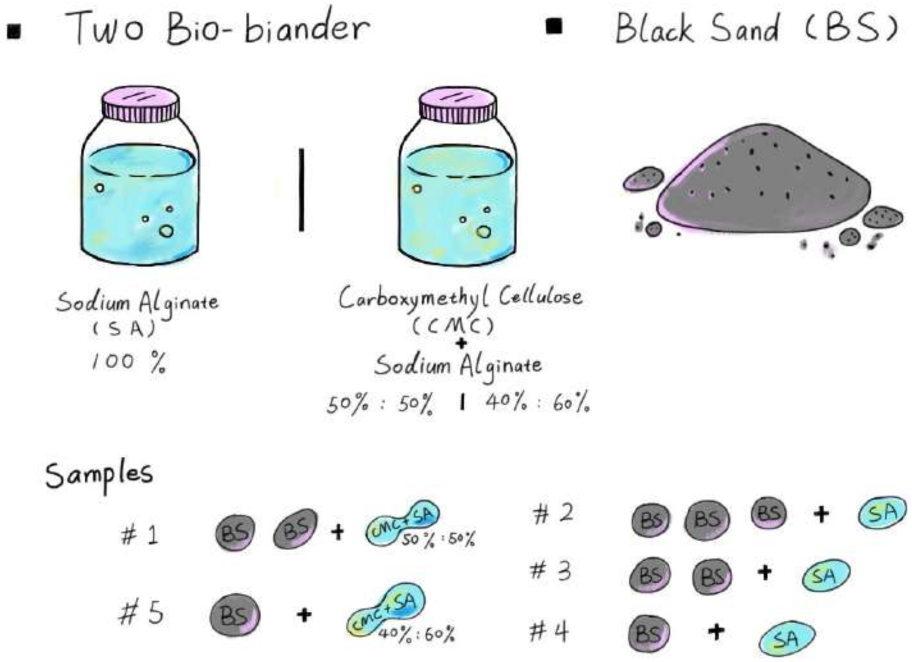


Figure 14. An illustration of the component proportions of the five samples.

These flake samples (Fig.15) were obtained by mixing DS with the binders, dropping them on a marble plate, and waiting overnight. The order in the picture is:

- Sample #1 - BS to CMC-SA (50%:50%) of 2:1.
- Sample #2 - BS to SA of 3:1.
- Sample #3 - BS to SA of 2:1.
- Sample #4 - BS to SA of 1:1.
- Sample #5 - BS to CMC-SA (40%:60%) of 1:1.

The volume of the five samples is similar, about 5 ml. (one scoop of volume). The picture demonstrates that as BS takes up a larger percentage than the SA solution, the lower the probability of shrinkage and deformation. The samples with the larger proportion of BS, #1, #2 and #3, remained flat after drying without any deformation. On the other hand, samples #4 and #5, with a proportion of 1:1, showed shrinkage and curling after the moisture in the binder had evaporated.

Besides, the experiment was also found through the samples：

1. #1 and #3 have a 2:1 proportion of BS to the binder, with no obvious difference in

appearance, but #1 has better fracture toughness than #3; No.3 is relatively brittle.

2．#2 is higher than #3 1% concentration of SA solution, and the hardness of the sample is also relatively better; the edge of #3 is more rounded, and the edge of #2 is angular.

3．#5 had a rough surface with dried white CMC gel. It is a wrong operation caused by mixing with BS before SA, and CMC are uniformly compatible.

4．#1 is a successful sample for CMC-SA compatibility. Although its compatibility is out of the scope of this study, this sample can open a new research direction in the future.

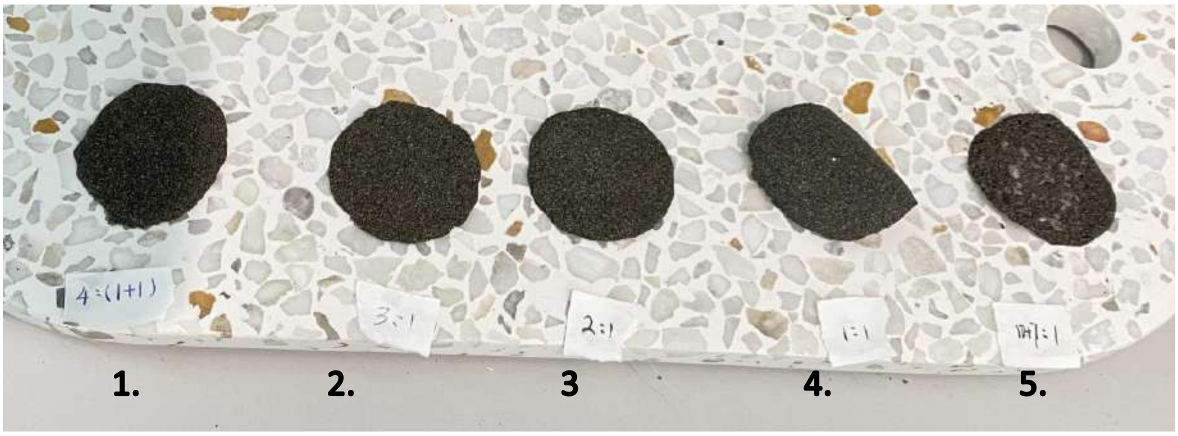


Figure 15. A set of samples for testing the compatibility of black sand with sodium alginate solution.

Summary

I gained an understanding of the properties of SA-treated sand, including physical and mechanical properties (hardness, brittleness, and fracture/ toughness). After comparing the five samples, sample #2 highlighted its overall superiority over the other samples. While sample #3 had a similar performance, according to the experimental results of the figure 13 the 2% solution caused deformation of the sample with a certain thickness. Thus, I decided to keep more detailed documentation of sample #2, which contributed to the editing of the material recipe.

3.3 Phase 2: Situational Vision

After becoming familiar with the materials, an initial judgement was made as to the direction of its future application, i.e., the material's situational application. In order that subsequent practices follow a set of pre-determined guidelines, this section standardises the recipe and process of the admixture produced by combining SA and sand, which not only improves production efficiency it also maintains consistency in the quality of samples and prototypes. This admixture is called SA-DS and is considered for its potential as a sustainable material including its end-of-life disposal options. It led to a developable vision and detailed situational application. Finally, experiments with plants revealed another value, as plant food, showing how biodegradability can turn “waste” into a treasured material.

3.3.1 A Dependable Recipe

The samples obtained from the earlier material tinkering contributed to the refinement and optimisation of the recipe. The key factors to measure whether the recipe can produce a quality sustainable material are controlling the concentration of the solution obtained by dissolving the SA powder in water and allocating the proportion between the SA solution and the sand. For example, the higher the water content or, the lower the sand percentage in the initial proportion, the higher the probability of deformation after dewatering, as in Samples #4 and #5. However, if the SA concentration increases, the solution becomes a less fluid-like jelly, and its plasticity decreases. For this reason, it was decided to refine the recipe using a 3% SA solution and accordingly produce a shaped sample to test its reliability.

The chart below shows the steps and recipe with an example of a small sample:

Required materials:

1.	Desert Sand (DS)	**300g**
2.	Sodium Algniate (SA)	**3g**
3.	Cold Water	**100g**
4.	Glycerol	**2.5ml**
5.	White Vineger	**No Standard**
Other Tools	Measuring cups, glass jars, electronic weighing scales, hand stirrers, spoons, rubber-tipped clay tools and moulds. miro	

- The Role of Secondary Material:

Glycerol increases the plasticity of a material while reducing its brittleness. The material made from SA does not have a solid hardness to support a long lifetime or unstable weather conditions outdoors. Prompted by BS's Sample #1, a new material, glycerol, can increase its toughness and thus compensate for the poor hardness. Glycerol can mobilise the fluidity of the material to enhance the fracture elongation (Tarique et al., 2021; Santana et al., 2018). However, it should be noted that excessive glycerol also affects the density between sand particles. Hence, the amount of glycerol needs to be controlled. In this work, glycerol represented 2.5% of the cold water. Figure 16 shows a 0.1cm paper sheet sample. The role of glycerol in the whole recipe is very well-defined in the very thin sample, which has a certain degree of toughness without fracture and has a leather-like texture.

Figure16. Samples in the paper sheet form.

The role of vinegar in accelerating solidification has been shown in the section Material Tinkering-A. It is applied by spraying or submerging the entire sample. The amount of vinegar used is varied with no precise criteria depending on the size of the sample. Without vinegar, a small sample took 7 days to dry completely. In comparison, the utilisation of vinegar reduced the time to 3 days. Thus, glycerol and vinegar play an active role in developing material properties.

Production Steps (Fig. 17):

1. A sealable glass jar for storing the SA solution is prepared. This needs to be clean and free from impurities attached to the inner surface of the container. As the diluted SA is converted into a hydrocolloid it must be stored in a sealed container to prevent evaporation of water. Without isolated storage, SA solutions are susceptible to deterioration in direct contact with air to produce mould spots.

2. Pour 2.5ml of glycerine into a measuring cup filled with 100g of cold water and stir with a stirrer until the glycerine is completely dissolved in the water.

3. Weigh out 3g of sodium alginate powder using an electronic weighing scale. As SA does not dissolve in water as quickly as glycerol, the powder must be shaken into the glycerol-containing water several times while stirring it to reduce clumping in the water.

4. Observe the swelling of SA in water and stop mixing once the powder forms a gel coat and floats to the top of the water, then pour these mixed liquids into the glass jar for sealing and resting. After approximately 14 hours the powder will be completely expanded in the water to form a 3% SA solution.

5. The 300g of DS also must be dry and free of other impurities, which can affect the smoothness of the dried sample' appearance. The pre-casting preparation is complete once the sand has been mixed well with the SA solution. The admixture of SA and DS in this state is the wet SA-DS material.

6. Apply this wet SA-DS evenly to a pot-shaped mould until completely covered, then use a rubber-tipped tool to smooth the surface; finally, spray with vinegar to make it solid and set.
Leave it to dry indoors in a ventilated area to ensure complete dryness.

7. Repair minor cracks caused by demoulding (using the original admixture) and polish it. Leave after drying off for a day.

8. A planter-shaped sample is completed.

Figure 17. An illustration of the making recipe and process.

Figure 18. A planter-shaped sample

Description

As shown in the figure 18, the sample is a traditional planter, its thickness is about 1cm. The total making time was 5 days. Its contour lines showed that there is no significant deformation or shrinkage. This ensured that the addition of the 3% solution to the recipe did not result in severe deformation and can be recovered with only partial repairs. In addition, the glycerol improved the fracture toughness, which resulted in a crack-free curved surface of the sample. Therefore, this formula is retained for subsequent creative production, this material is referred to as SA-DS.

3.3.2 Defining Material

This section provides personal insights into the application of the SA-DS as a sustainable material. Reflecting on the above research and answering the research questions can help construct the meaning of the material as well as figuring out its value in applications.

I introduced a material-focused mindset to discuss the research question mentioned in section 2.2-b:

(1) What is the positive role of the SA-DS in a broader context?

The current problem of resource consumption can be considered through both subjective and objective perspectives. On the one hand, I realised through my experience of working in art museums that short-term and temporary events often purchase disposable materials to increase execution efficiency. This habit increases the amount of waste discharged and results in dismantling and discarding petroleum-based or wood-based materials before they have been fully utilised to the end of their lifetime. On the other hand, I reflect on the plastic planters used in the marketing of seedlings or landscape plants, which are generally regarded as disposable consumables due to their poor quality and inability to be retained and sustained after purchase by the consumer. These two points prompted me to take bio-based materials as an entry point to think about alternative solutions to these unsustainable behaviours.

However, the emergence of bio-based materials offers a reasonable solution to these obstacles. A planter-shaped sample stimulated inspired a new direction for eco-friendly applications, I suggested that SA-DS has the potential to replace some of the non-biodegradable art materials for short-term or temporary works. Table II demonstrated that SA-treated sand is relatively weak in terms of hardness, which is not sufficient for long-term works, it is an excellent short-cycle material. As stated in feedback from secondary sources in 1.3.4, it has the potential for cultivation, which is aligned with the Cradle-to-Cradle (C2C) principle of “Waste = Food”, allowing this material to fulfil its residual value through composting. Thus, based on this perspective of thinking, the positive role of the SA-DS is not only the sustainability of its resources it is also the flexible application, which changes stereotypes and disposal habits of “waste” materials.

(2) How does SA-DS interact with us through a specific context?

I defined the interaction that SA-DS can elicit through a triple Venn diagram (see Fig. 19). After collecting the keywords from the current research and converging them into a whole, the situational applications were also roughly mapped out, botanical ornament, sculptural objects and interior decorations. Its natural and organic nature opened a creative symbiosis between the material and the plant. In this context, SA-DS can be made into a decorative item to be viewed, also a growing vessel for the plant to connect with nature. This symbiotic relationship can evoke people’s instinctive affection for nature, making the non-durable structure and unemotional colours contained in the SA-DS not associated with inferiority rather underline its individuality and eco-friendliness. Thus, the specific context to interact with the audience is established in this practice through its external casting potential and the unique inner qualities of cultivation.

(3) How to make recycling management organic?

Informed by the framework of New Materialism, the individualised representations of SA-DS should be interpreted through a multidisciplinary intersection. While thinking about the recycling of the material, its degradability reveals an opportunity, composting. It is a versatile process that treats the degradable material as a nutrient for the soil awaiting natural degradation. However, the degradation rate still differs for different raw materials. If we consider the lifetime of a work or a product closed in the loop of the C2C pattern, the elements and components that make it up all contribute to the assessment and implementation (Pfeifer, 2009). Therefore, to realise the SA-DS’s C2C closure, the following section validates its biodegradability and engages greenery in practice.

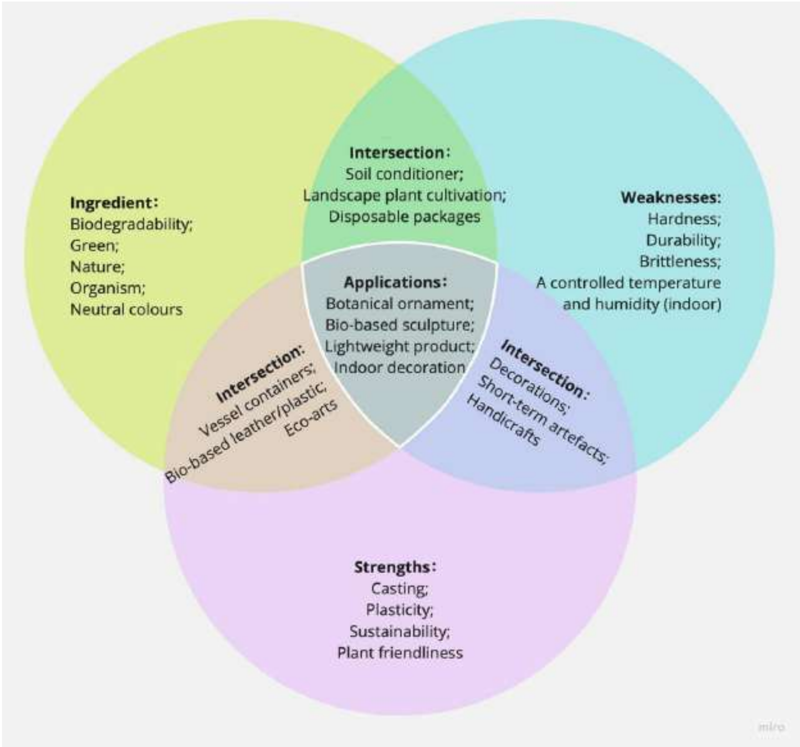


Figure 19. A triple Venn diagram, analysing SA-DS situational applications.

3.3.3 Greenery in Practice

This stage involved a practical study of 3.3.2 *Defining Material* in constructing a symbiosis between plants and SA-treated sand, leading to this section's research. Incorporating a real organic environment into the experiments can verify the eco-friendliness of the SA-DS material. Two small experiments were conducted: A. planting and B. burying to confirm the possibility of intersecting SA-DS with horticulture. The results were in line with the expected vision, which allowed a subsequent prototype and formal design to be clarified.

Experiment A: Planting

Observing the growth of seeds in SA-treated sand can determine whether SA-DS is a threat to living organisms and thus identify its eco-friendliness. This experiment set up two research themes: (1) the adaptability of plants in DS and (2) the feasibility of SA-treated sand as a substrate for plant growth.

- Experiment for Theme (1)

1.Experimental Setting	Cultivating seedlings in pure sand without any bio-based composites
2.Experimental Groups	Desert sand (no. a, e, f, g)
3. Control Groups	Constructed sand (no. b, c, d) and white sand (no. h)
4.Plants	Mixed dry seeds of cosmos, zinnia and galsang (in order to exclude dead seeds, all 8 groups used pre-germinated seedlings)
5.Other Materials	Discarded plastic box (5cm high), used disposable masks
6.Experimental days	34 days
7. Site	A ventilated indoor at a controlled temperature of 24-28°C., China (6 September - 10 October 2022)

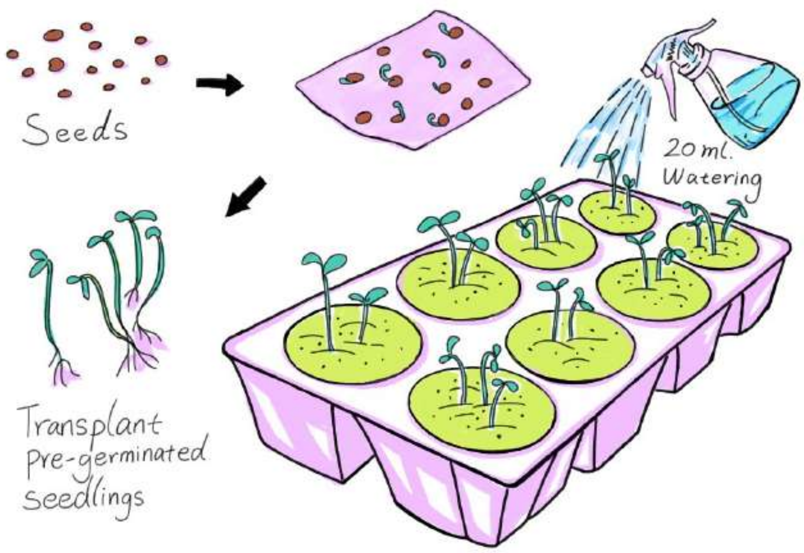


Figure 20. An illustration of transplanting pre-germinated seedlings.

Summary

Based on basic knowledge of horticultural cultivation, the same operations, including light, watering amount and interval, were executed on these 8 groups to observe their adaptability and growth status. Each of the eight groups was transplanted with two to three germinating seeds; the watering amount was fixed at 20ml to 40ml each time, and the water used was distilled water and 0.3% nutrient water.

Figure 20 shows that DS groups a, f, and g persisted longer relative to the other groups in the 34 days of the experiment. The CS groups c and d died completely on the 6th day, while the seedlings in the CS group b survived, which used more nutrient solution. The seedlings were kept alive for a longer period by the 0.3% nutrient water. These revealed DS has better water retention than CS; and the seedlings were able to sustain growth in DS under well-watered and nutrient-supplemented conditions. This planting test created comparable data for the Theme (2) experiment to investigate whether SA-treated sand is more favourable for plant growth.

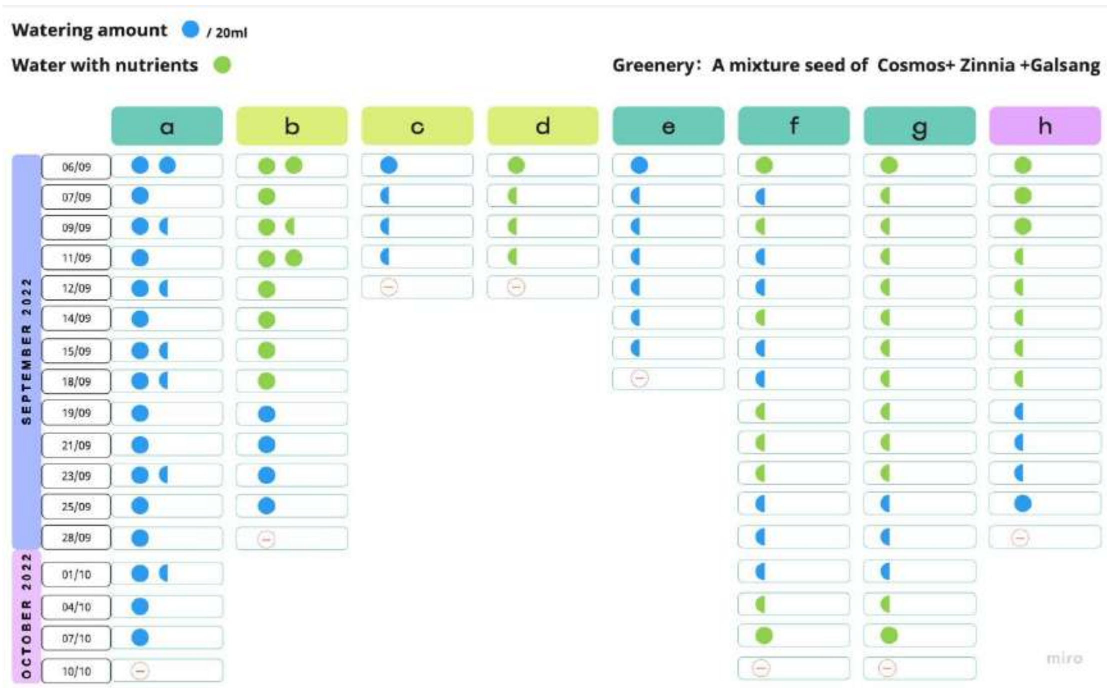


Fig.21. A graph recording watering amounts for 8 groups of seedlings in 34 days.

- Experiment for Theme (2)

Objective 2 Experiment	
1.Experimental Setting	Cultivating various plants in sodium alginate-treated sand
2.Experimental Groups	SA-treated desert sand with seeds (no. i, j); SA-treated desert sand with a vegetative stage plant (no. k)
3. Control Groups	Constructed sand (no. b, c, d) and white sand (no. h)
4.Plants	i: Mixed dry seeds (Cosmos, Zinnia and Galsang); j: Bulb seeds (Freesia); k: Vegetative stage（Lobelia）
5.Other Materials	A flower pot (16.5m high), ceramsite sands, grounded coconut shell
6.Experimental days	23 days
7. Site	A ventilated indoor at a controlled temperature of 20-24°C. China (18 October - 10 November 2022)

The experiments were conducted in a captive environment, where a composite substrate was prepared in the preparation stage to create infiltration conditions closer to the natural cover layers to allow the plants to get better drainage and aeration. This composite substrate has four layers (Fig. 22) containing materials such as an admixture of DS and SA solution (SA-DS, proportion of 2:1), DS, grounded coconut shells and ceramsite sand.

The 2:1 proportion is more suitable for seedling rooting and germination than the 1:3 proportion used for casting, in which more water is retained. The 1:3 proportion is more inclined to be applied to the product, which has better plasticity and a stable structure.

Three groups of subjects were manipulated separately (Fig. 22): (i). approximately 20 mixed seeds were uniformly sown in the admixture layer, (j). bulb-like seeds were planted between the DS layer and the admixture layer which enabled the seeds to be covered entirely, the (k). vegetative stage of Lobelia was transplanted between the DS layer and the grounded coconut shells layer, enabling its entire rootstock to be buried. Since SA-DS layer was prone to drying out, in order not to affect seed germination, the three groups were continuously watered for 10 days.

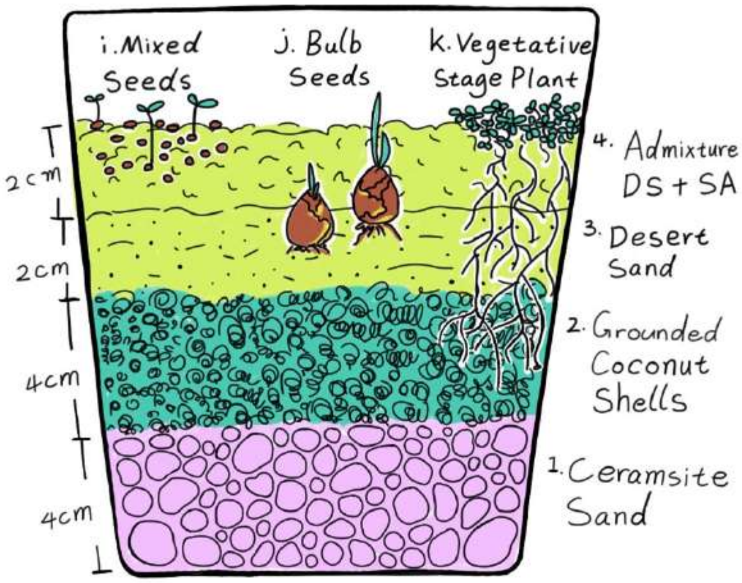


Figure 22. An illustration showing a composite substrate consisting of four layers of different materials.

Summary

Through this experiment, I learned about the adaptability and growth performance of the three plants on SA-treated sand. On the 3rd day after sowing, both (i) and (j) showed signs of seedling development with white endosperm emerging. Compared with the seedlings grown in pure DS, the seedlings in group (i) were significantly more vigorous and taller, ranging from 10 to 23 cm (Fig. 24); Freesia in group (j) had a reasonable growth rate and tended to split into green leaves, reaching a height of 15 cm.

However (k)' Lobelia encountered obstacles, it leaves gradually shrivelled and changed yellow during the 9 days from 22 October to 28 October. Then, its gradually reversed as I changed the amount and interval of watering. Finally, Group (k) had new green leaves on top of the dried leaves.

All three groups did not use additional nutrient solutions to maintain their plants, proving that SA-treated sand is a better substrate for plant growth than pure sand.

Moreover, another finding from the experiment opened my curiosity and interest in organic recycling management. The SA-DS layer gradually softened with days, plant growth no longer formed a hard crust quickly, and its texture was closer to natural soil. This phenomenon matches the biodegradability possessed by SA, which breaks down the original material components in the appropriate environment. These gains diversified the material's meaning, supplementing a primary resource needed for the project's subsequent development, i.e., its application involves not only the potential of casting and also its capacity to act as a container of organic life.

Figure 23. A graph recording watering amounts for 3 groups of greenery in 23 days.

Figure 24. A collage of planting experiments contains three varieties of growth.

Experiment B: Burying

Due to their simple and natural composition, some bio-materials can be naturally decomposed in the soil, which is a way to achieve an eco-efficient cycle. In order to assess the biodegradability that occurred in experiment A, I employed the soil burial method to test SA's biodegradability and observed the changes in its form and size over 50 days.

1.Experimental Setting	Burying sodium alginate samples in natural soil
2.Experimental Groups	Dried SA sample (thin sheets)
3.Material	Natural soil
6.Experimental days	50 days
7. Site	A outdoor captive environment - in pots with plants, at a uncontrolled temperature of 5-23°C., variations according to Auckland weather, New Zealand (7 June to 27 July 2023) miro

Pre-prepared samples of completely dried SA sheets were buried in the soil in the pots (see *Appendix* for preparation) and taken out at regular intervals (5 days, 15 days) to check their changes. To make the experimental samples easy to find after burying I added natural dyes for colouring while making the sheets, which does not disturb the captive soil environment. During this experimental period, the plants in these pots were kept under regular care, basically watered once every three to four days, and placed outdoors in unstable climatic conditions that followed the local natural weather in Auckland, with temperatures fluctuating between 23 and 5°C.

Summary

Comparing the original sample from 50 days ago to the sample 50 days later, there was a significant change in size and shape. As we can see from figure 25, after 5 days of burying, the sample's surface was only slightly wrinkled yet still retained its shape. On 10 days of burying, the samples became relatively less tough. They showed a dramatic shrinkage, with buckled edges and mutilations. To make the degradation changes significant, the burial period was extended from 5 to 15 days. SA sheets gradually disintegrated into small pieces as the days increased. After 50 days, the original shape had disappeared entirely into fragments, and its toughness had disappeared. Successively, the collection became difficult due to their progressive disappearance and diminution. This experiment confirmed that biodegradability helps to develop an organic recycling pathway; 90% of the SA was degraded in these 50 days.

Figure 25. A set of images of gradual degradation and changes in SA sheet samples.

3.4. Phase 3: Situational Manifesting

The SA-DS material has been manifested through the further expansion of its situational application in this phase. To fulfil the practical needs, the types of used sand have been increased from single desert sand to other sands from different regions so that the SA-DS has expanded to include, and not be limited to, desert sand. Manipulating their individual properties and adding extra materials facilitated the establishment of design forms and aesthetics such as colour, texture, smell and hardness and toughness. A series of prototyping exercises set in the specific context allowed me to obtain early feedback to address potential problems and risks quickly.

3.4.1 Material Aesthetic Exercises

The following four specific practices were explored to further explore its sensory properties.

-Colour.
-Texture
-Smell
-Hardness and Toughness

- Colour

Initially, I attempted to change its colour through mineral pigments in the 809 special project. however the mineral pigments that come from naturally coloured stones are poorly compatible with water. Figure 26 is a documentation of my first attempt at colouring in 2022, with a sand to SA solution proportion of 2:1. The blue pigment floated on the sample's surface before drying however, after drying, the blue colour sank to the lower layer from the surface. This demonstrated that the fluidity of the SA solution caused the mineral pigments to migrate between the gaps of the sand particles.

Afterwards, I made a second attempt by increasing the proportion between SA and sand to 3:1, as shown in the recipe in section 3.3.1, and used vinegar to accelerate their solidification. As can be seen in figure 27 on the smaller samples, even though the green mineral colour was coloured, the colour distribution was not uniform; the sand's original colour was exposed on the surface of the samples.

Accordingly, I concluded that although the mineral pigment could achieve the purpose of changing the colour, it is not considered an ideal method. Also, whether mineral pigments affect greenery and soil needs to be examined additionally. Therefore, to keep the practice in line with the original intent of this project, I abandoned the method of applying extra additives and instead focused on finding an alternative solution in the sand itself.

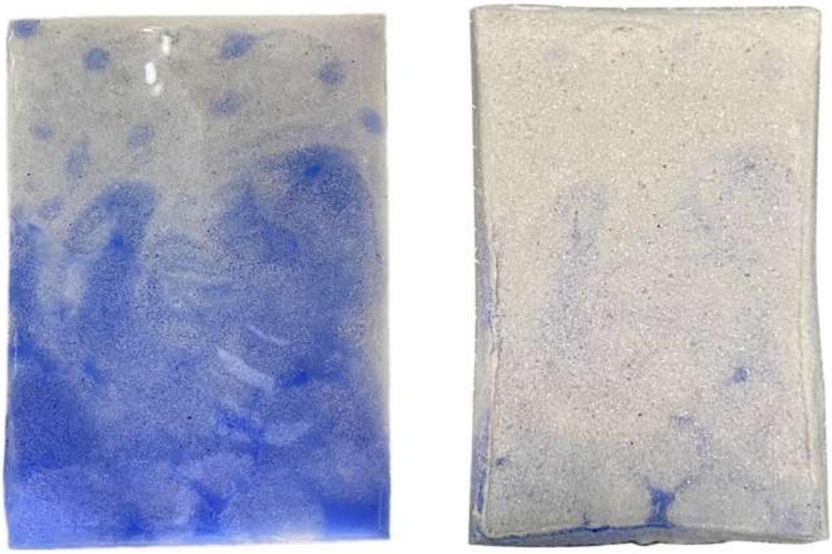


Figure 26. A sample of colouring with mineral pigments in 2022.

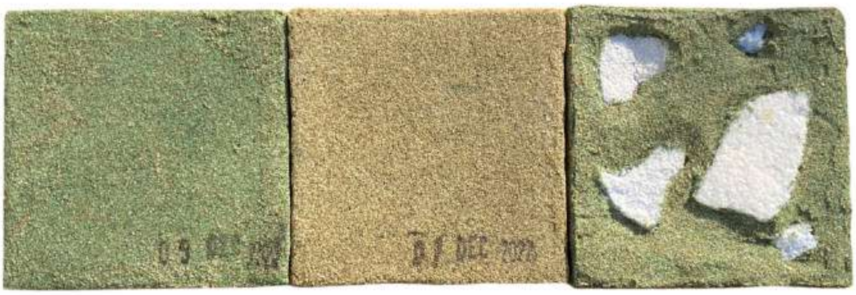


Figure 27. A smaller set of samples coloured with mineral pigments after changing the method.

The colour of sand depends on their regional origin and mineral composition of the sand. During my studies in New Zealand, natural sands from different regions were collected. Their colours and particle sizes varied from black, golden yellow, grey, and wood brown. These natural colours have given these sands a unique aesthetic quality and that it would be redundant to alter them artificially. Therefore, I pieced together different colours of sand into a pattern. Colour in a design or a pattern can serve to differentiate between the various elements and create a composition. Hence, I first drew a contrast pattern and then practised manual exercises with sands.

Required Materials:

1.Material	Black sand from Bethell Beach
	Golden sand from kaiteriteri beach
	3% SA solution (with 2.5% glycerol), proportions from SA-DS recipe
2.Other Materials	Wet clay, plaster and rubber-tipped clay tools

The outcome consists of black and gold colours and contains 64 small square blocks known as jigsaw puzzles. Each square was cast in a pre-made mould made of clay. It took 17 days from sketching to finishing.

Figure 28. A puzzle sample made using black sand and gold sand.

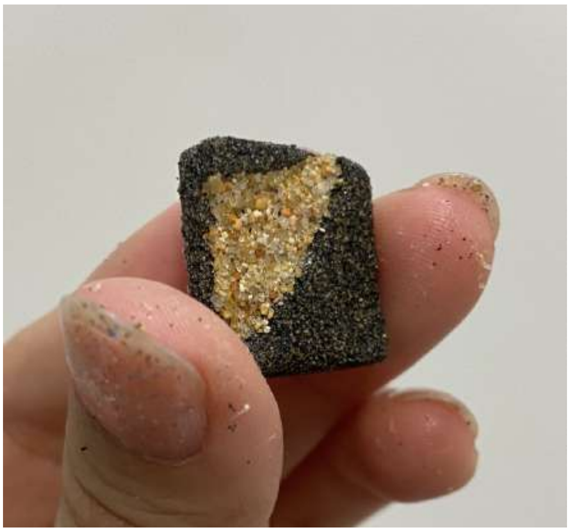


Figure 29. A detail view of a single block.

Discussion

The focus of this exercise was to create a pattern utilising different colours of the sand and to harmonise their proportions, creating a visually pleasing effect. As can be seen in figure 28, the puzzle's integral colours are distinct, and the pattern is well-defined. Looking at its details, the adhesion between these two types of sand is quite good without signs of bio-binder. The sand colour is perhaps mundane if it is just sand, however if it is used in a graphic way, it becomes remarkable and attractive. As a result, I have gained confidence in this exercise by working with original sand, that is not artificially coloured.

- Texture

This exercise involved building three-dimensional (3D) patterns using plasticity to create different textures to add visual interest and depth. The outcomes were divided into two types: one is cast using a 3D shape mould, and the other is hand carved on a piece of SA-DS.

Required Materials:

1.Material-Mountain	Desert sand from Mongolia's Kubuqi Desert
	3% SA solution (with 2.5% glycerol), proportions from SA-DS recipe
2.Material-Water Ripples; Circular Disc	Black sand from Bethell Beach
	3% SA solution (with 5% glycerol)
3.Other Materials	Wet clay, plaster, rubber-tipped clay tools, carving tools

The mountain-shaped outcome was produced in 2022 while in China, and the process took 6 days. It is known from figure 30 if SA-DS was utilised to mould the 3D shape pattern, its surface was not as fine as the simple shaped samples, it had a clear grainy texture, while the whole mountain texture was intact and consistent with the original clay mould.

Figure 30. A three-dimensional mountain shape sample.

The texture of the water ripples was cast directly from a ready-made mould, which took only 2 days. The surface of the texture is more rounded, and smoother compared to the mountain's, which looked like leather (Fig. 31). A contributing factor may be the relatively high glycerol content (5%) in SA-DS which improves the fracture toughness.

Figure 31. A water ripple textured sample.

The texture of the circular disc consisted of 3D lines formed by hand sculpting. I used a carving tool to shape the texture and make the lines as compact as possible to confirm whether the brittleness and hardness of SA-DS affect the texture. As can be seen from figure 32, the lines on the disc are smooth and clear, and there was no debris on the surface that was caused by the carving.

Figure 32. A circular disc sample with simple hand-carved patterns.

Discussion

Sculpting and moulding exercises are a means of adding aesthetic appeal and beauty. Through this exercise, even though I found that SA-DS can meet the demands of moulds and handcrafts, it cannot produce intricate and ornate patterns like plastic or plaster material. This is related to both the sand's own properties and the binder's composition. This shows that the SA-DS has some of the functionality of clay. For example, placing some sculptures made of SA-DS on a coastal beach and carving some marine elements, including shells, fish, and waves, emphasising the specific location and atmosphere.

- Smell

The sand itself does not have a smell, however SA, as a bio-binder, releases a slight odour, like plant rot, during the drying process. SA is hydrophilic, and of samples made of SA-DS are placed in a humid environment, its hydrophilic properties absorb moisture from the air, causing the dry SA-DS sample to re-soften and re-wet, and its decaying odour is aggravated, especially in high-humidity environments. This exercise attempted to solve the smell problem by understanding the conditions of odour dissipation, applying two methods: baking with external equipment and natural drying.

Required Materials:

1.Material	Black sand from Bethell Beach
	Golden sand from kaiteriteri beach
	3% SA solution (with 2.5% glycerol), proportions from SA-DS recipe
2.Other Materials	A high-temperature resistant rubber mould, candles

The brick-shaped samples in figure 33 were made from rubber moulds. The SA-DS were baked in an oven at 180°C for 30 minutes to dry. While these bricks had no noticeable odour once just cooled however moisture returned after a week.

Even though the cylindrical-shaped sample in figure 34 was originally developed as a prototype, it gave off an unpleasant odour as it dried naturally. However, only a little of the odour remained after lighting the candle and leaving it in the centre of the cylinder.

Besides, one point worth pondering is that the jigsaw puzzle in figure 28 has not been odourless or re-softened in the three months since it was made, and it was stored indoors without any other external wrapping.

Figure 33. Brick-shaped samples baked dry using an oven.

Figure 34. A cylindrical-shaped sample.

Discussion

Based on these experiments, I realised that the underlying factor affecting the odour intensity is the external environmental conditions as the sample turned from wet to dry, i.e., if the material is left in a humid environment during the natural drying, the odour will become intense and will not disappear as the sample dries out. Sand has a high melting point of up to 5000°C, which can act as a heat barrier (Wikipedia Contributors, 2019), so the candle heated the sample and did not show any signs of breaking or burning. This finding reduced the risk of odour affecting the usability and quality of the material. Also, it can be confirmed that no odour is produced if a piece of work is completely dry and stored appropriately.

- Hardness and Toughness

The biodegradability of SA is both an advantage and disadvantage, which prevents it from having high durability like cement. In the previous SA-DS study, I applied glycerol to increase the fracture toughness and thus reduce brittleness. This effect was prominent in thin-thickness samples, such as 0.1cm thick samples (Fig. 16), where glycerol played a crucial role in allowing it to roll up and not suffer from fracture. This allowed the design of SA-DS in the form of lightweight objects, as shown by the triple Venn diagram (Fig. 19). For this purpose, I developed the thin SA-DS to use as a lampshade. Even though the initial results were flawed, I identified the potential issues and improvements in the exercise of its production process.

Required Materials:

1.Material	Black sand from Bethell Beach
	3% SA solution (with 2.5% glycerol), proportions from SA-DS recipe
2.Other Materials	Plaster, 25cm diameter balloon,rubber-tipped clay tools, brushes miro

The lampshade I made in the figure 35 is the effect with the bulb installed; the total making time was 4 days, height: 5cm, bottom diameter: 14cm. Its outer shell was made of black sand, 0.1cm thick, and the inner shell was formed by plaster, 0.1-0.2cm thick. The whole shape of the lampshade was made by utilising the curvature of the inflated balloon. The material was applied directly to the surface of the balloon and can be fixed and formed after drying.

However, a problem arose during the demoulding process -the material and the balloon were tightly stuck together. After removing the balloon with the tools, the edge of the lampshade was broken as it was too thin. To solve this problem, I applied an additional material, light plaster, to the inner shell of the lampshade. After improving the hardness and durability, the lampshade can be easily punched to facilitate the insertion of the bulb. The rounded hole was smooth and intact, with no chipping.

Figure 35. A lampshade sample - outer shell made of SA-DS, inner shell coated with light plaster.

Discussion

The toughness of SA-DS suggested a new direction, the hardness was still a drawback that affected the form and aesthetics for practical purposes. The light plaster is a non-toxic, low-density aggregate, its naturally hygroscopic nature allows it to act as a desiccant to prevent the material from getting wet (Wirsching, 2000). It is also easy to recycle at the end of its lifetime, as the low hardness of SA-DS allows plaster and sand to be separated with polish or cutting tools. Although plaster cannot be recycled in a biodegradable form, its raw material is sustainable and can be 100% recycled into renewed plaster (Geraldo et al., 2017). A report also explained that plaster is a treasure for horticulture; recycled plaster can be added to the soil as a soil enhancer, and it can provide extra calcium for some fruit trees (Heeringa, 2023). Therefore, the utilisation of plaster is to make the structure of subsequent prototypes more stable and solid.

3.4.2 Prototyping

Creating an advanced version of the prototype before designing the final artefacts can test the techniques and knowledge gained from the aesthetic exercises. Prototyping involved the iteration of a lampshade and a set of planters.

Advanced Lampshade

The intention was to improve on the issues and flaws left in the initial version. I have reflected on the process and made changes accordingly:

1. The thickness of the SA-DS shell was increased to 0.2 - 0.3cm to reduce the probability of cracking while preventing the inner shell (plaster) from being exposed during sanding.
2. Use fabric mesh to isolate SA-DS from direct contact with the balloon mould, reducing resistance and thus avoiding breakage during demoulding.
3. Increase the glycerine content to 5% to make the lampshade tougher and prevent the surface from cracking.
4. Use cotton thread around the balloon to mark the lampshade's edges and keep the bottom flat (the initial version in figure 35 has a zigzagged edge).
5. Use plaster to cover the whole inner shell of the lampshade to improve the overall hardness.

Required Materials:

1.Material	Black sand from Bethell Beach
	3% SA solution (with 5% glycerol)
2.Other Materials	Plaster, fabric mesh (made of cotton thread and lime), vinegar, 30cm diameter balloon, rubber-tipped clay tools, brushes miro

Considering practical requirements of a lampshade, the expansion of both the diameter and the height was greater than the initial version, which took 10 days to complete – the dried outcome measured height: 19.5cm, bottom diameter: 18cm. The production of this lampshade was based on the above reflections with a significant increase in efficiency.

Figure 36. A lampshade prototype using SA-DS.

Discussion

The perfection of the handcrafted steps is also an essential factor in making SA-DS materials into any shape. The success of this advanced lampshade gave me confidence to continue developing further applications in this direction. During the iteration, I became clearer about my expectations and situational applications of SA-DS materials. The prototyping revealed the outstanding potential of SA-DS material for lightweight interior products, which is also an opportunity to enter the product market in the future.

A Set of Planters

The inspiration for the container prototype was obtained from hand-drawn sketches so that the SA-DS material could be used in a botanical planter as a decorative and functional application. The prototype design considered the interaction between materials and plants according to the design vision of the flexible utilisation mentioned in section 3.3. The planter visualised a situational application of interior or garden landscape plants, which incorporates an organic recycling method to return the material to the soil. In contrast to the traditional planter shape in figure 37, this prototype added my personal aesthetic.

Required Materials:

1.Material	Black sand from Bethell Beach
	3% SA solution (with 2.5% glycerol)， proportions from SA-DS recipe
2.Other Materials	Wet clay, plaster, rubber-tipped clay tools, carving tools

Figure 37 shows that a set of planter resembles stones inspired by minimalism and smooth stones with moss growing near the waterside, individually made over 12 days. The dimensions of the completely dried outcomes are 17.4x8cm; 9.4x7.6cm; 6.5x7.8cm (Length x Width). This prototyping followed the production process like the lampshade, including casting, hardening the structure, polishing and repairing. In addition，there was a plaster layer inside the planters to strengthen the structure and hardness, with a thickness of about 0.2cm, which can also avoid moisture return, shrinkage and deformation.

Figure 37. A set of planter prototypes using black sand, stone shapes.

Discussion

The planter prototype inspired the form design of the botanical ornament. Adding visual elements to the exterior can evoke an appreciation of the material, thus improving information communication and aesthetic appeal. Through this approach, I intended to emphasise the dual utilisation of SA-DS as a sculptural item and a plant container. Moreover, this design considered that as the plants grow, the planter gradually biodegrades and disappears. Then, the disintegrated SA-DS enters the garden together with the plants, and the separated plaster is used for recycling.

3.5 Phase 4: Forming Design

This phase summarises the outcomes of the above practice. I chose prototype 1- lampshade as one design basis to form a set of artefacts with practical applicability. Prototype 2-planter derived a promising design concept for me to investigate the prospects of SA-DS. This concept was concluded with a 3D effect drawing.

3.5.1 Lamp Design

The final artefacts consist of four lamps for exhibition developed from the previous prototype design of the lampshade. The design started from common shapes and elements to create 4 differently shaped lampshades. Their features are like gourd, thus distinguishing them according to the gourd's identification: kettle, bushel, bottle and zucca (Fig.38). Their production process is consistent to prototype 1. These lampshades were mounted with LED bulbs during the exhibition and suspended vertically from the ceiling, giving them a practical function illuminating the space.

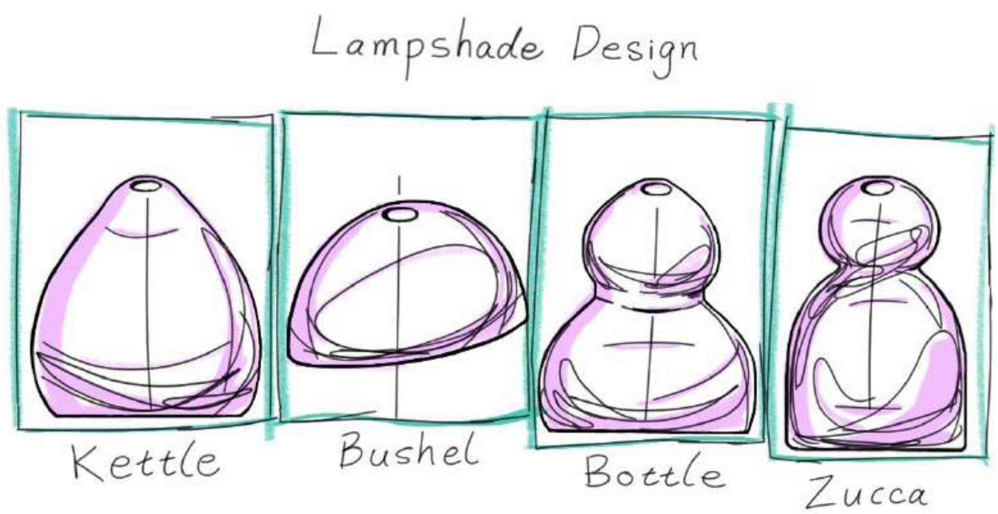


Figure 38. A lampshade sketches inspired by gourds.

The SA-DS material utilised in the production involves three types of native New Zealand sand collected from different locations. The design retained the original colour and has not changed it through artificial intervention. This not only is a call to reduce reliance on chemical pigments it is also to see these sands as a metaphor through which the audiences look to understand the ecological information behind them. This is an artistic means to express my concern about environmental issues and encourage more people to pay attention to the sustainability of materials.

Figure 39. A photograph of the physical effect of the lampshades.

3.5.2 A Symbiotic Blueprint

The design concept proposed for future research is a combination of a planter and a lampshade. Even though it extended the research outcomes of this project it was not included in the final exhibition. I drew a digital model with Sketchup (a 3D modelling software) (Fig. 40). The concept conceived a symbiosis between the plant and SA-DS. The plants grow on the lampshade made by SA-DS and mimic the colour and texture that adorn the lampshade, creating an interesting visual effect.

However, it is a challenge to maintain the plant's vitality on the lampshade without affecting the whole structure and shape. Based on the hardness of the currently developed SA-DS, it can be predicted that the lampshade will have a very short lifespan, indicating that the currently developed SA-DS cannot meet the construction of this symbiotic blueprint. It requires new properties: (1) a higher durability to stabilise the lampshade structure from being disintegrated by the plant; (2) a greater water retention to meet the requirements of the plant's growth, which is not possible by manipulating a single SA additive.

The current research stage focuses on the primary development of SA-DS for application in artwork. This symbiotic blueprint led me to reflect on the project shortcomings and identify directions for future development. Thus, this "symbiotic design" will serve as a new situational vision, and it will become the subject of future research.

Figure 40. A symbiotic blueprint of SA-DS lampshade and planter drawn by Sketchup.

3.5.3 Reflection on Practice

Based on the methodologies of PBR and MLDR, the research questions were answered through practice, enabling me to develop new techniques and knowledge. Experiments confirmed the convergence of secondary resources harvested from existing research databases (discussed in the Literature Review) and primary resources gained from hands-on practice.

The project was originally focused around desert sand as the primary research object. However, since I moved to New Zealand, access to desert sand became limited, so the project expanded to include other types of sand resources available locally. Although the research outcomes were constructed from SA-DS made from local New Zealand sand rather than desert sand, the results still illustrated the research purpose effectively. The form design improved the aesthetic appeal of the final artefacts and added visual elements to demonstrate the sand's potential as a sustainable material.

The final effect of the exhibition was as I expected. The lampshades with the bulbs installed have a practical value as interior ornaments. The outer shell of SA-DS showed its unique texture, that is different from other common materials. The inner shell was made of plaster, which acts as a supporting structure so that the lampshade can remain stable and suspended by the threads in the air. SA-DS material was developed with the initial intention to have a short life cycle to fulfil the daily needs of disposable materials with zero waste. As a result, the hardness and cohesion of the material is less strong than that of plastic, so even though the lampshade was slightly crumbled during manual installation and handling, this did not affect the presentation of the installed effect. The quality of the SA-DS material ensures that it can remain stable in indoor environments. Due to the time constraints of this project, I did not develop the symbiosis blueprint, nevertheless, this provided an opportunity for future research to mature SA-DS.

CONCLUSION

This study took desert sand as a starting point to explore its potential as a sustainable material. To ensure that the material is 100% biodegradable, the project chose sodium alginate (SA) derived from brown algae as a main bio-binder to increase the cohesion of the sand from a discrete state to a solid state; the material is called SA-DS. The exploration focused on how SA-DS replaces some non-biodegradable and degradable materials in the short-term and in small-scale artworks. It helped to understand SA-DS's individual properties and to define its value.

The project's main outputs consisted of two essential aspects: 1. the creation of a mouldable material based on desert sand (SA-DS) and 2. the extension of SA-DS's value in horticulture to maximise biodegradability, considering the recycling management. SA is an important component of this study, and its concentration and proportions directly impact optimising the material's plasticity. The recipe and process of SA-DS was defined in the process of exploring these inherent properties and based on the proportion of sand to SA of 3:1 as the standard, adding 2.5ml of glycerol to every 100ml of SA solution as it can improve the anti-fracture toughness. This standard applies to artistic handcrafting and casting. In addition, an organic recycling route has been developed that allows SA-DS's value as substrates for growing plants to continue beyond its lifecycle through the intersection of soil mechanics and horticultural knowledge. This approach highlights the multiple functions of SA-DS, as it can be flexibly utilised throughout the ecological cycle with the aim towards zero waste.

This project demonstrated the research and design process from understanding to developing an unfamiliar material. Based on the PBR approach, the research involved a series of hands-on practices in obtaining data from primary sources to supplement the material and to verify that knowledge gained from the existing research literature tended to align with the experimental results, reducing the potential for cognitive bias present in a single data resource. During the MLDR process, a series of samples and prototypes were created by manipulating sensory attributes (colour, texture, smell, hardness and toughness). These samples and prototypes contributed to the strengths, limitations, and aesthetic appeal of SA-DS, and from them, and to explore new processes and methods of material experience.

The final work showed the personalised properties of the SA-DS. The lightweight lampshade highlighted its good fracture toughness; the shaped planter displayed its dual-purpose nature of a decorative container and a growing substrate. The exhibition showed the advantages of SA-DS in replacing some petroleum-based plastics and disposable hazardous materials. However, it also revealed the weakness of its hardness, which prevented the practical implementation of the symbiosis blueprint between plants and SA-DS because it requires higher SA-DS durability than existing research results. It was expanding the research direction of new bio-binders to enhance the hardness of SA-DS. This is crucial for the future of SA-DS material to move from artistic practice to market application as a mature material.

Furthermore, the production process requires further optimisation. The current research adopted a handmade approach to model building as a “back-to-hand” way to experience the material closely, expanding the meaning, knowledge, and technology. However, the productivity of this method is relatively slow, and users often do not choose this method to avoid delaying the production schedule. Therefore, future research may consider using 3D printing to shorten the production process. It will involve new knowledge and techniques to ensure the material is successfully extruded through the syringe of the 3D printer and maintain its form without deformation. Even though these new research directions are challenging they could enhance the practical applicability of SA-DS.

Overall, the goal of this project is to bring more attention to the abundant desert sand resources and to resist the current material usages and manipulations that run counter to sustainability. The development of SA-DS highlights the way materials and ecosystems can interact with each other without sacrificing the well-being of nature. The products and samples from the practical research complement the creative applications of sand-based bio composite to inspire a new material medium for art and design practitioners.

The prototype of planters with the plants

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Appendix

Appendix One: Bio-binder Alternatives

The following is a brief description and experimental process documentation of five comparable bio-binders. This process demonstrates why SA stands out from the rest (In conjunction with figures 11 and 12).

	Carboxymethyl Cellulose (CMC)	Sodium Alginate (SA)	Agar	Gelatin	Pine Resin
Sources	Plant cellulose from cotton and wood pulp.	Natural polysaccharide hydrocarbons from brown algae.	Polysaccharide from red algae.	Collagen from animal epidermal tissues.	Secretions of coniferous trees.
Colours & Forms	White powder, transparent colourled gel after dissolution			Pale yellow granular	White, pale yellow, caramel coloured solid
Properties	Cold gelation biopolymer		Thermo-gelation biopolymer		
Solubility	Soluble in cold water and swell into a gel		Soluble in warm water and form gel at 32-43 °C.	Soluble in hot water, form gel at less than 70 °C.	Non-hydrophilic, re-soften to liquid at 70-130 °C.
Restriction	-Climate sensitive, stability depends on humidity and water content in the air		-Insoluble in cold water; -Difficult to decompose by microorganisms	Temperatures above 70 degrees cause excessive decomposition.	-Fragile in solid state due to poor cohesion; -Operating at high temperatures does not guarantee safety
Reasons for Alternative	-Non-nutritive; -non-toxic; -biocompatibility; -biodegradability; -better viscosity; -water retention; -higher toughness; -transparency; -the viscosity higher than SA for the solution >3.6 % concentration. (Yaradoddi et al., 2020; Zhu & Zhang, 2008)	-Non-nutritive; -non-toxic; -biocompatibility; -biodegradability; -better viscosity; -water retention; -higher toughness; -transparency; -Bind with calcium ions or low pH substances to form insoluble colloids -the viscosity higher than cmc for solutions <3.6% concentration. (Senturk Parreidt et al., 2018; Zhu & Zhang, 2008; Morozkina et al., 2022)	-Non-nutritive; -non-toxic; -higher gelling properties than gelatin; -better viscosity; -water vapor barrier properties; -better elasticity. (Mostafavi & Zaeim, 2020)	-Non-nutritive; -non-toxic; -biocompatibility; -biodegradability; -foam forming ability; -antioxidant activity; -higher toughness; -higher viscosity; -water vapor barrier properties. (Hanani, Roos, & Kerry, 2014)	-biocompatibility; -biodegradability; -higher viscosity; -water vapor barrier properties. (Pavon et al., 2021)

Figure 41. Table III: Individual qualities of the five binders

According to the table III above, these alternatives can be traced back to their organic composition; they all have sufficient viscosity for utilisation as binders and have environmentally friendly characteristics. Their dissolution conditions and production processes distinguish them into thermal gels and cold gels. They all have been utilised commercially in a wide range of fields. However, their application in creative artwork has yet to be explored. Online academic databases provide access to existing research data, such as ScienceDirect, ResearchGate and the National Center for Biotechnology Information, which facilitated me to review and reflect to minimise barriers to practice.

Process Documentation :

a: The first test was pine resin and gelatin which required an additional heating apparatus (induction cooker). The experiment was set up with constructed sand (CS) as a control group for desert sand.

- **Pine Resin**

  Firstly, the solid pine resin was placed directly in an iron pot and heated. When the temperature reached 110 °C, the solid-state transformed into a liquid. Mixing the sand required a quick operation and stirring evenly before the pine resin liquid is cooled down and poured into moulds (the moulds used were thermal deformation-proof material, rubber or wood). After 20 minutes of cooling, the resin and sand mixture had completely solidified and could easily be demoulded. The poor cohesion of the resin caused damage to the corners when the proportion of CS to resin was 2:1, but its surface can keep smooth when the sample cube was taken out from the mould. While when the proportion of the sand to resin was 5:1, or the resin proportion was less, the texture was hard and not easy fragile, yet its surface became rough and had obvious air holes. In addition, the yellow resin affected the original colour of the CS in the experiment, and the sample presented a dark olive-green colour. In contrast, white resin retained the original colour.

- **Gelatin**

  The gelatin tinkering was tried two times. This gelatin from Alibaba smelled pungent and rubbery during the dissolution. I suspected that the raw material of the gelation might contain additional ingredients. The first time, the granular gelatin was dissolved by continuous heating on an induction cooker, but did not solidify with the DS after cooling, and the sample collapsed into a sludge-after demoulding. A review of the sources revealed that the gelatin’s proteins would break down excessively and fail to re-gelatinise at temperatures above 70 °C (Rodsuwan et al., 2016). Recognising this mistake, in the second experiment, I directly mixed 60 °C hot water with gelatin and stirred it until it completely dissolved into a gel. To allow the gelatin-treated sand to take shape in the mould, I used a quick cooling down in the fridge. The experiment turned out to be successful, with the samples curing and forming complete cubes. The dried sample had better hardness and less slagging, and the surface was finer than that of the resin (2:1), despite accidental damage during demoulding.

b: Agar which is also a thermal gel but does not require higher temperature conditions, was similar as an alternative to gelatin.

- **Agar**

  Agar powder was placed in warm water at 40 °C and stirred until the powder was fully swollen into a gel. In order to prevent it from reversing into a solid after cooling down, the mixture with DS was poured into the mould while still hot, although the agar gel was more stable than gelatin. The mould was placed in a dry, ventilated place for drying. However, the experiment revealed a high degree of shrinkage on the mixture during the drying; the faces and corners of the sample showed varying degrees of deformation.

c: Research focus turned to vegetable gels, such as CMC and SA, which can be dissolved directly in cold water, overcoming the limitations of temperature.

- **Carboxymethyl Cellulose (CMC) & Sodium Alginate (SA)**

  The CMC used in the experiment was dissolved in the water by stirring and left to form a gel for approximately 20 minutes. SA powder can be poured into the water without stirring and left to form a gel gradually for one day. Neither of them released any odour during the dissolution process. To prevent shrinkage and deformation, the treated sand (both CMC and SA) was laid at 0.5 cm thick. After drying, no obvious shrinkage occurred, and the original colour of the DS and CS still remained. In comparison, the samples of CMC and SA appeared no different from their appearance; but their hardiness was the weakest of all the alternatives. When moved around, a few sand particles fell out of the samples. However, when comparing texture and plasticity, both the dried samples were closer to being an applicable material that was more delicate, smooth, and lightweight. The different shapes and sizes of the particles on the surface of the CS samples, as well as the small black impurities were reminiscent of natural materials.

  Insoluble gel-like substances were produced when SA contacts lower PH solutions, such as vinegar, (Morozkina et al., 2022), e.g., on the surface of SA-DS in contact with vinegar it immediately solidified to form a jelly-like texture. In this state, the SA's samples can be demoulded directly and keep the cast shape intact. In contrast, samples made from CMC must be demoulded after drying, and it did not react with the vinegar.

  Summary: CMC and SA displayed excellent properties in terms of plasticity, original colour preservation and smoothness. SA can interact with vinegar to speed up the drying process and is the ideal bio-binder for this study. The other three alternatives have limitations in dissolution conditions and production techniques, which are challenging for hands-on work or artwork and even increase time and cost. Hence, this project expanded and increased the interaction between the SA and the sand in the artwork.

Appendix Two: Scanning Electron Microscope (SEM) of SA-DS

The following microscopic imaging complements section 1.3.4 of *Mechanical Properties of SA-*

treated Sand regarding SA as a bio-cement (binder) to bind the sand, resulting in an increase of the contact surface between the particles, thus improving the mechanical properties of the sand.

The equipment used was an electron microscope from the Science Building on the AUT campus. The scanned samples are Bethell's black sands and Mongolia’s Kubuqi desert sand.

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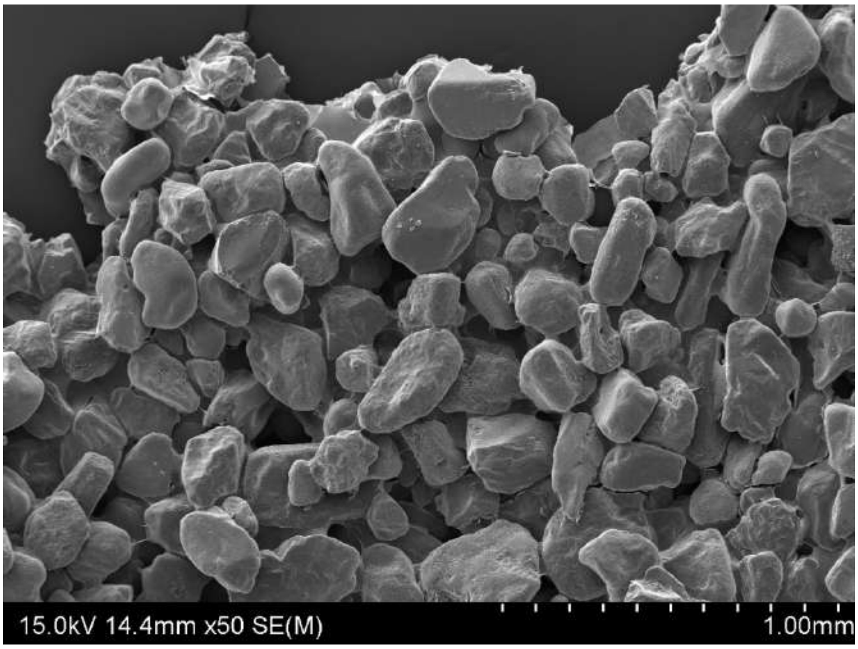

Figure 42. A scanning electron microscope of SA-DS (black sand) sample.

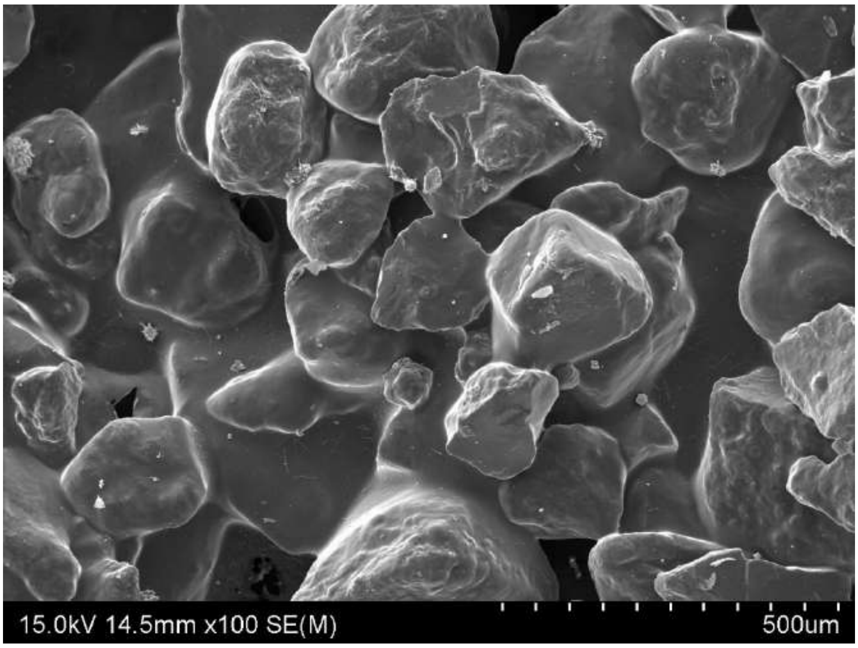

Figure 43. A scanning electron microscope of SA-DS (desert sand) sample.

SEM clearly shows the structure of the completely dry SA-DS material, how the SA wraps around the sand particles and fills the gaps. This helped me to understand the interaction between SA and sand, and also confirmed the perspective that SA has the potential to be used as a bio-binder.

Appendix Three: SA-based Plastic

SA has good toughness and can be made into bioplastics. A 3% SA solution was made according to the instructions in section 3.3.1. It is important to note that over-stirring the solution before pouring it into the mould is to be avoided, as the resulting large number of air bubbles can lead to undesirable aesthetic results on the dry sample. Pour the SA solution into a flat mould, and after the water has completely evaporated, a transparent layer of SA-based plastic is formed with a thickness of about 0.2-0.3 cm.

3.3.3 *Section Greenery in Practice* - Experiment B was conducted with SA bioplastics (split into small sheets.) to test biodegradability. Coloured samples were used in the experiment (Fig.44)to highlight the SA sheets' visibility in the soil. The natural pigment composition did not affect the experiment.

The coloured sample opens new ideas for developing SA independently in the future, e.g., SA plastic can replace disposable packaging. This idea came from an experiment in which I tried to use SA to store flowers. This experiment found that SA could be applied to storing dried flowers in good condition (Fig.45). The integrity of the flower in the figure 45 shows that it is still in good storage condition after 6 months of sealing (Fig.45). This finding provided more possibilities for disposable packaging, for example, whether disposable packaging can be replaced with bio-packaging made from SA for horticulture or gardening. This biodegradable packaging could seal vegetable and flower seeds, which are easy to sell and transport and could also be put directly into the soil to grow with the seeds without having to sort and recycle them again. This may seem like an easy way to manage recycling, but the idea still needs some practical testing before it becomes mature in the future. For instance, how will the pigments react with soil microbes during degradation? How durable is this kind of packaging? These questions are outside the scope of this project. However, my responsibility as an art practitioner is to understand better the ecological impact of a material and an object to practice environmentalism and new materialism.

Figure 44. A piece of coloured SA bioplastic.

Figure 45. Samples of dried flowers stored in SA.

Appendix Four: Exhibition Documentation

Some exhibition photographs of the final works.

Figure 46. All exhibits include prototypes and samples.

Figure 47. A detailed view of the “Bushel” lamp.

Figure 48. A detailed view of the “Bottle” lamp.

Figure 49. An overhead view of the lamps in a daylight environment.

Figure 50. An overhead view of the lamps in a dark environment.

Figure 51. The effect of the lamps in a dark environment.

Figure 52. A view of “Bushel” lamp in a dark environment.