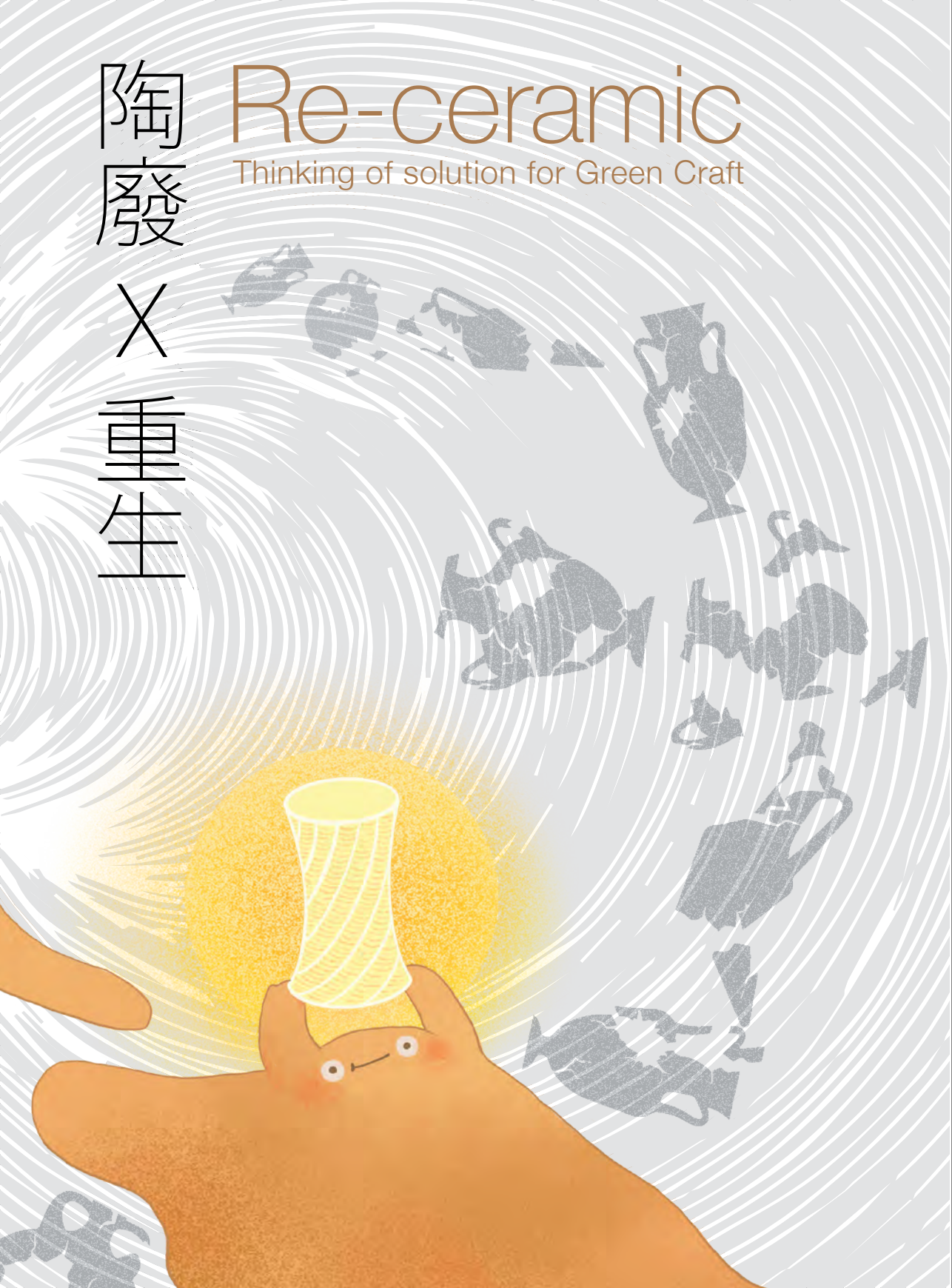
陶廢X重生

Re-ceramic

Thinking of solution for Green Craft



Contents
目次

編輯的話 *Editor's Note*

以包容與想像，串起工藝與永續

Connecting Craft Art to Sustainability through Connecting Craft Art to Sustainability through Understanding and Imagination

計畫策劃執行
工藝中心技術組技士 翁子馨

Project manager and executive

Weng Tzu-hsin

Technician of Technique Section, National Taiwan Craft Research and Development Institute

我是在大學時第一次接觸陶藝，在那個什麼都想嘗試的年紀，陶藝的多變與神秘讓我的手作慾望有了很棒的宣洩管道；然而當時陶藝教室裡隨處可見被遺忘的作品孤兒，角落也總堆置著破裂的廢器陶瓷與碎片，那樣的環境與景象，在我心裡留下問號。後來進入工藝中心服務，接手管理中心內的陶瓷工坊，這才知道那些無人認領的作品及陶瓷廢棄物從何而來。它們就像見證工坊經營的年歲般，彷彿吹開上面的灰塵就能閱讀到每年工坊技術訓練與產品研發的故事。不過在浪漫的工坊記憶之外，也揭開實際面上的問題。

I was first introduced to ceramic art in college. At that time, where everything seemed worth a try, ceramic art satisfied my strong desire to make things on my own thanks to its variety and mystique. However, I noticed countless ceramic “orphans” that could be found anywhere in ceramic classrooms, along with broken pottery and ceramic fragments being placed in corners. The scene left me in confusion, which had not been cleared up until I began working for the National Taiwan Craft Research and Development Institute (NTCRI) and took charge of the ceramic workshop affiliated to the institute’s management center, where I finally knew where those unclaimed ceramics and ceramic scrap come from. Each of these objects represents the history of the workshop where it was made. It seems that once you blow the dust off them, they could tell you stories about annual ceramic training events and product development projects happening across different ceramic workshops. Despite the romantic memory, these orphans reveal existing problems in the ceramic industry.

因為在地清潔隊沒有回收陶瓷廢棄物的服務，即使想丟也查無管道。許多陶瓷工藝的創作者，尤其是經營獨立工作室或微型工坊的創作者，在陶廢無處可去的情況下，只能無奈地讓陶廢在自家角落越積越多。這一堆，衍生出空間成本又形成環境問題，但卻不知如何消化處理。

One can hardly recycle ceramic scrap in Taiwan as there is no such service provided by local trash pickup authorities. Many ceramic artists, particularly those running their own studios or small workshops, have no choice but to let ceramic scrap pile up in corners, which have added to spatial costs and environmental problems without a solution.

工藝中心倡議綠工藝精神，包含著自然、循環、平衡、寬容與生命力等內涵，是工藝作為物件以外附載的文化與人情。我們意識到工藝串起人對環境的關懷，讓追求經濟效益的資本文化中，多了對環境友善循環的訴求。於是在陶瓷廢料處理問題中，發起陶瓷廢料循環議題一系列探討行動。一如書名立下的「重生」一詞，除了正面講述陶瓷廢料在製程中被回收再利用，也期待讀者能撇開「廢棄」與「無用」的想法，以更具包容與想像的角度，重新定義陶瓷廢料、賦予更多可能。

The NTCRI has long been dedicated to developing green craft ideas that emphasize the nature, ecological circulation and balance, tolerance and vitality, which are related to the cultures and people behind any craft as a physical object. We have realized that crafting can encourage people to care about the environment and prompt them to call for environmental circulation rather than simply focusing on maximizing economic benefits in the culture of capitalism. To solve problems of ceramic scrap treatment, we have launched a series of action plans to explore ceramic scrap-related issues. As the word “rebirth” indicates—in addition to its positive meaning for ceramic scrap recycling during manufacturing—we expect our readers to put aside thoughts like “wasted” and “useless”, and use their imagination to redefine ceramic scrap and develop its potential with a greater tolerance instead.

編輯的話 *Editor's Note*

為產業面儲備資源與能量

Saving Resources and Energy for the Craft Industry

2022年度專案執行
鋐蘊科技有限公司　簡淑君

Executive of the 2022 annual project
Chien Shu-chun
Fortune Tech, Ltd.

承接國立臺灣工藝研究發展中心「陶廢循環設計應用與推廣委託採購案」執行，除了須熟捻陶瓷作為傳統媒材在作品實務的處理外，也應理解當前的科技與永續趨勢。這不僅拓展了個人觀念與眼界，更是一項極富成效的挑戰。

Managing the Procurement Project for Application and Promotion of Ceramic Scrap Circular Design assigned by the NTCRI requires not only expertise of processing ceramic—as a traditional material—in practice, but also understanding of cutting-edge technologies and trends in sustainability. Taking on this job has helped me broaden my mind and horizon, which is also a challenge accompanied by fruitful results.

在2022年的專案中所辦理3場陶廢循環議題推廣活動，透過講座與體驗創作，拉近參與者與陶廢議題的距離，使參與者更切身體會陶瓷廢料問題，以及將其再利用的可能。總體來說，陶廢議題在工藝中心跨多邊領域合作與技術深化後，成功地獲得參與者熱烈迴響。

For the 2022 project, we launched three campaigns to raise awareness of ceramic scrap issues. By holding various lectures and workshops, participants were allowed to have first-hand experience in relevant issues, thereby understanding scrap-related problems and identifying the possibility of ceramic scrap recycling. In brief, the NTCRI has received positive feedback from participants after achieving cross-domain collaboration and technological optimization.

另外，在這次專案中邀請16位工藝創作者與設計師，提供新材料(陶瓷廢料)、與議題，並藉由彼此技術領域的交流機會，完成了16件陶廢應用創作的成品。過程中除了不斷試驗、嘗試不同媒材組合，也在設計思維的引領下將發散的各種想法收攏成為作品。不僅是對於將陶廢作為新材料回歸創作的思考馬拉松，更藉由工藝實踐了作品、在成果上展現材料之美。

A total of 16 craft artists and designers were invited to develop new materials (using ceramic scrap) and explore new issues for the 2022 project. They exchanged opinions on technical aspects and created 16 works made of ceramic scrap, for which they integrated various design-oriented ideas in addition to countless trial and error with different material combinations. The artists brainstormed ideas of transforming ceramic scrap into a new material for their creations. Moreover, they created
works using their craft expertise, demonstrating the beauty of this novel material.

在專案中邀請到工業設計師鍾毓珊擔任設計總監，在整個陶廢應用創作的歷程負責設計引導，藉由8次課程討論陪伴創作者逐步完成各自作品。第一次課程時鍾老師引導創作者們一起為設計主題思考，最終定調為「視角重組」，希冀透過不同視角看待我們面對的陶廢，在視角起點、實驗、失敗與成功乃至重生間，為陶廢應用創作賦予具個人語彙的詮釋。

It is our pleasure to invite industrial designer Chung Yu-shan to be the design director for the project, for which she provided design guidance during the entire process of innovating ceramic scrap use and helped artists finish their works in eight lectures. At first lecture, Ms. Chung guided artists to brainstorm the design theme and chose “Perspective Reorganization” as the final theme, hoping that the public can look at ceramic scrap from different perspectives. Ultimately, creations inspired by ceramic scrap use will have more room for individuals to interpret a work and even its failed or successful experiment as well as regeneration process.

創作者需在美學跟材料的認識基礎上，從想法發展到作品造型，除此之外還得留意材料在作品呈現的效果變化，時時記錄。過程中來回不斷產出新的問題，比如添加陶廢不同比例而產生的結構問題、3D列印在參數設定上的問題、產品製作過程的風險與選擇等等，挑戰著創作者們各自的專業和經驗。

Based on their knowledge of aesthetics and materials, the artists underwent the process from idea development to work creation. They had to monitor and take records of the chosen material as regards its physical changes when being made into an artwork. During this process, they encountered problems from time to time, such as structural defects in relation to slurry formula with different ceramic scrap proportions, parameter setting problems of 3D printing, and risk and decision-making during product manufacturing, all of which tested their skills and experience.

2022年陶廢專案從循環議題出發，透過陶廢推廣活動拓寬觸及群眾、引發議題思考，另一方面更在應用創作中，促成一連串工藝研創與跨域合作，產出陶廢應用的成果作品、為陶廢再利用起到示範作用，實現綠工藝價值。工藝中心在陶瓷廢料循環議題上，持續深化與推展，相信將為未來陶廢循環機制落地儲備有效資源與能量，也呼應綠色環保、回收再利用，使永續產品發展有了材料研究基礎。在此感謝專案所有參與人員，在綠工藝價值實踐上付出一份心力！

Emphasizing circulation-related issues, the 2022 project has attracted more people to engage in ceramic scrap recycling through various campaigns and contemplate relevant issues. The project has facilitated craft research, innovations, and cross-domain collaboration, as well as giving birth to artworks featuring smart use of ceramic scrap, thereby exemplifying ceramic scrap recycling and demonstrating the value of green crafts. The NTCRI proceeds to explore and promote issues related to ceramic scrap circulation, which will help identify effective resources and save sufficient capacity for the establishment of a ceramic scrap circulation mechanism in the future. The project also corresponds to concepts of environmental protection, recycling, and reusing, laying down the foundation for sustainable product development, materials, and research. I would like to thank all those who participated in this project for their efforts to realize the value of green crafts.

前言
Preface

從計畫不斷延伸，探究綠工藝的未來之路

Continuously Expanding the Project to Explore the Future of Green Crafts

工藝材質自造實驗室 *Craft Application with Material Experience Lab*

以呼應世界對於環境與自然的尊重，從思考在地材料、循環材料到未來性材料，工藝中心於2018年基於三大核心價值：材料(Material)、製作(Making)、意義(Meaning)成立工藝材質自造實驗室(Craft Application with Material Experience Lab, CAMEL.)，目的在從傳統學習過程中思考各種框架以外的維度，包含材質意義、技術製程到文化意涵，期待透過更多實驗性的挑戰，在設計之上展現工藝在實踐與實作上的力度，以及對於人與生活的承諾，達到臺灣工藝保存、復原、轉化、再創造的永續目標。

Echoing the world's growing respect towards the environment and nature, the NTCRI considered local materials, recycled materials, and future materials when it established the Craft Application with Material Experience Lab (CAMEL) in 2018 based on the three core values: material, making, and meaning. The goal is to consider different dimensions outside the box, including the meaning of materials, manufacturing techniques, and cultural connotations through the traditional learning process. Experiments are expected to demonstrate the feasibility of the design and craft, as well as realizing the commitments made towards people and life. This is expected to achieve sustainable objectives, including the conservation, restoration, transformation, and re-creation of Taiwanese crafts.

陶廢計畫發起 *Initiation of the Ceramic Scrap Project*

陶瓷原料是人類歷史上被廣泛應用的工藝材料。製陶的歷史可追朔至萬年前，對考古而言，從遺址挖掘出的的陶片特徵，也是判斷文明發展程度的指標之一，人們可以從陶片的燒製狀況、材料緻密程度、裝飾與否等等解讀出古人類的發展歷程，同時也在根本反映了陶瓷材質可佩的耐久特性。當陶瓷服務於生活、工業與科技等領域，並享譽於方便加工、價格親民、容易維護而耐用的特性；但當碎裂後則廢棄成垃圾，進而衍生為棘手的問題，燒不掉、埋不爛，就像陶瓷古文物在地下存在千年萬年。

Ceramics are craft materials that have been extensively used in the history of humankind. The history of ceramics can be traced back to ten thousand years ago. For archeologists, characteristics of ceramic fragments unearthed at archeological sites can be used as one of the indicators to identify levels of civilization development. People can interpret the evolution of ancient civilization through how ceramic fragments were fired, density levels of materials, and whether the ceramic fragments were decorated. These characteristics of ceramic fragments concurrently reflect the durability of ceramic materials. When ceramics are used in daily life, industry, and technology, they enjoy a reputation for being easy to be processed, their prices are affordable, and they are easy to be maintained and durable. However, when they are broken, they are disposed of as scrap, causing difficult problems such as they cannot be burnt and they do not rot after they are buried. They will be like ceramic artifacts that have been buried for thousand or ten thousand years.

秉持著綠工藝精神，工藝中心由工藝材質自造實驗室引導，在面對同時觸及生活與產業的陶廢問題，工藝中心以「新材料」角色定義陶廢。於是 2020年工藝中心首先啟動陶瓷廢料回收再利用的方法初探，又在隔年納入3D列印製程，嘗試藉由3D列印技術的普及易散布，開創一個在陶工藝現場就能執行的陶廢循環製程，讓工坊產出的陶廢經過處理後，能就地投入新穎的創作製程。為此，工藝中心投入一連串軟硬體研發調整及陶廢漿料的配方試驗，並於同年舉辦工作坊發起製程方法演示。而今年度（2022）則接續前階段的累積知識，除了持續致力列印技術與材料處理流程的優化，更由陶藝創作者與設計師實踐將陶瓷廢料用於創作或產品開發，打開陶廢應用的想像。

Upholding the spirit of green crafts, the NTCRI, under the guidance of the CAMEL, re-defines ceramic scrap as “a new material” when encountering everyday life and industrial ceramic scrap. In 2020, the NTCRI initiated its first exploration of recycling and reusing ceramic scrap. In the following year, the NTCRI added 3D printing and attempted to use 3D printing’s popularity and ease of expansion to create a ceramic scrap circulation process that can be implemented at the ceramic craft site. This allowed the workshop to process its ceramic scrap and then reuse it in new creations. Thus, the NTCRI invested in a series of software and hardware to develop, adjust, and experiment on ceramic scrap slurry. A process demonstration was organized by the workshop in the same year. In 2022, the institute follows up on the previously accumulated knowledge, and continues to optimize the printing technology and material processing procedures. Moreover, ceramic ware creators and designers have opened the door to ceramic scrap application by using ceramic scrap in their creations or product developments.

第一章
Chapter 1

責任生產、永續設計的思考開端

The Beginning of Thoughts on Responsible Production and Sustainable Design

永續設計如何翻轉陶廢

How Sustainable Design Provides a New Perspective for Ceramic Scrap

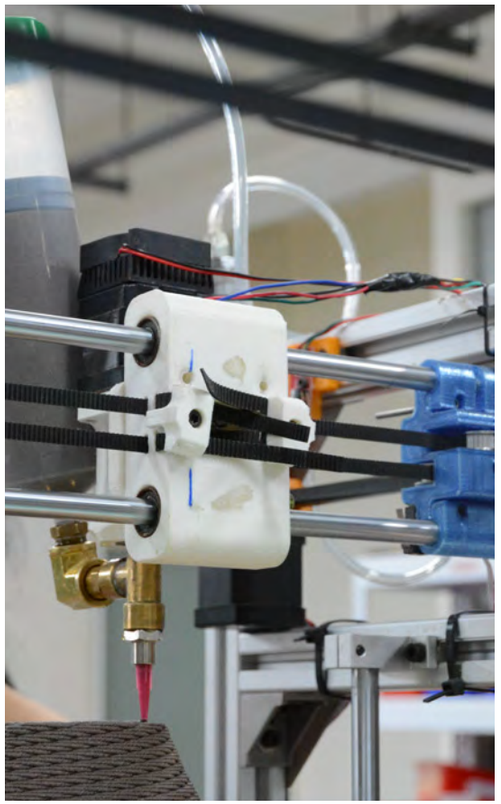
重生之路

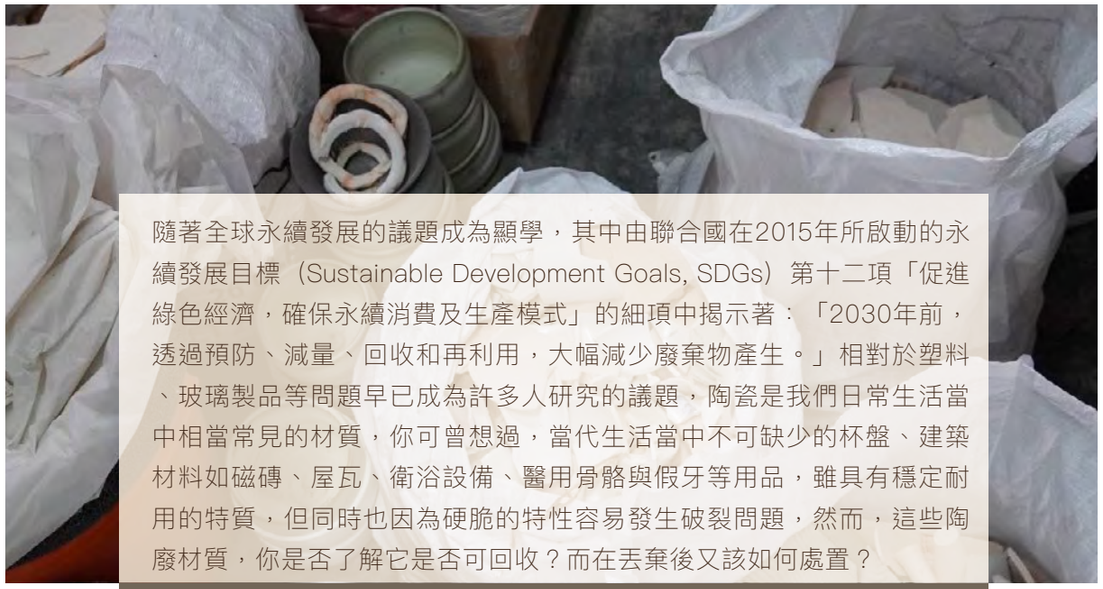
陶瓷3D列印技術開創陶廢的重生之路

Pathway to the Revival of Ceramic Scrap through Ceramic 3D Printing

3D陶瓷列印製造有何特殊之處？而這項數位科技將帶給陶瓷產業何種貢獻？因應循環經濟的議題上，工藝中心檢視著已然逐漸成熟的陶瓷3D列印，除了探究陶廢創新的可能，也展現出臺灣綠工藝的可能性。

What's special about ceramic 3D printing? How does this digital technology contribute to the ceramics industry? In response to the call for creating a circular economy, this project analyzes the increasingly mature technology of ceramic 3D printing, identifies innovative approaches to ceramic scrap transformation, and explores the possibility of green crafts in Taiwan.





隨著全球永續發展的議題成為顯學，其中由聯合國在2015年所啟動的永續發展目標（Sustainable Development Goals, SDGs）第十二項「促進綠色經濟，確保永續消費及生產模式」的細項中揭示著：「2030年前，透過預防、減量、回收和再利用，大幅減少廢棄物產生。」相對於塑料、玻璃製品等問題早已成為許多人研究的議題，陶瓷是我們日常生活當中相當常見的材質，你可曾想過，當代生活當中不可缺少的杯盤、建築材料如磁磚、屋瓦、衛浴設備、醫用骨骼與假牙等用品，雖具有穩定耐用的特質，但同時也因為硬脆的特性容易發生破裂問題，然而，這些陶廢材質，你是否了解它是否可回收？而在丟棄後又該如何處置？

Issues related to sustainable development have been widely discussed worldwide. For example, the United Nations specifies, "by 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse" in the Sustainable Development Goals proposed in 2015 as Goal 12.5. Unlike plastic and glass products that have been widely studied, ceramic—a material commonly seen in everyday life—has been relatively unfamiliar to the public. This material is indispensable for goods like tableware, building materials (e.g., tiles, roof tiles, bathroom fittings), artificial human skeletons for medical use, and dentures. Despite its high stability and durability, ceramic can break easily due to its brittleness. Have you ever wondered whether a broken ceramic is recyclable? And how should it be treated after being disposed of?

在工藝中心所啟動的Re'ramic陶藝跨域加值製造計畫中，讓人們了解了工藝技術的轉化與應用之外，更發現了陶瓷製品因製程以及臺灣尚無有效的回收產業鏈的機制，因此再度開啟陶廢循環設計應用計畫，期待能將此議題引發討論，作為一個更好的責任消費與生產者，達成更好的生活目標。

To help the public learn about the transformation and application of crafting technologies, the NTCRI launched the Re'ramic Cross-domain Value-added Craft Production Project (hereinafter "the Re'ramic Project") in 2020. During project implementation, the NTCRI also identified that the ceramic industry in Taiwan is still lack of an effective recycling mechanism. Therefore, the institute proposed a plan concerning the design and application of ceramic scrap recycling, aiming to raise public awareness about the issue so that every individual can become a better, responsible consumer and producer, ultimately living a more sustainable lifestyle.

從問題開始檢視，無法分解的陶廢品

Start with Problem Analysis: Ceramics Can Hardly Decompose

循環經濟（circular economy）作為一種再生系統，具有多重的定義，主要希望藉由減緩、封閉與縮小物質及能量循環，讓資源的投入或廢棄後得以達成零浪費的想法。尤其，當社會隨著科技、生活的促進之下，地球有限的資源與消耗遠超過自然資源的再生速度，此外，大量消耗的材料也造成地球的負載，因此循環經濟所構築的是希望從製造、生產到回收都能經過良好的循環與精心安排，讓一個製程的輸出可能為另一個製h程的輸入，達成零排放與零廢棄的可能性，實踐「搖籃到搖籃（Cradle to Cradle, C2C）」的目標。

As a regenerative system, the circular economy has multiple definitions, but it basically involves concepts aiming to achieve zero waste of resources or waste minimization through mitigating, enclosing, and shortening material and energy cycles. With technological and lifestyle advancement, limited resources on Earth have been consumed far faster than their natural regeneration. Moreover, a large number of wasted materials have imposed a heavy burden on the planet. Under such circumstances, the circular economy aims to achieve good circulation and arrangement from manufacturing to recycling. In this way, outputs from a manufacturing process could be input of another process, thereby increasing the possibility of net-zero emissions and zero waste and ultimately reaching the goal of Cradle to Cradle (C2C).

陶瓷作為古老的工藝與文化，隨著現代科學與工藝製造技術的進步，逐漸走入人們的生活之中，然而一般人並不可知的是，陶瓷製品在燒製後無法自然分解，也無法焚化，常有民眾將破碎的陶製品交由垃圾車回收才得知陶製品需以垃圾處理，因此如何處置一直成為陶瓷產業的難題之一；此外，臺灣在陶製廢棄物的回收制度也未能有良好的全面性規劃與機制，根據行政院環保署統計資料顯示，台灣於2010年垃圾處理量為10,081,614　公噸，而陶瓷所屬之其他不燃類項目佔比0.67%，推估當年度全台灣受官方環保局轄下處理之廢棄陶瓷約為67,546公噸，因囿於資源回收技術的不足以及再利用的管道有限，處置的方式大多為掩埋與堆置，也對環境與土壤帶來許多影響。

As a symbol of ancient crafting techniques and cultures, ceramic has gradually entered our daily life thanks to advancement in modern technology and crafting know-how. What is little known is that ceramic products cannot easily decompose, nor can they be incinerated. Normally, people would not know that ceramic products should be treated as general waste until they hand in some broken ceramics to waste management staff, making product recycling a great challenge in the ceramic industry. Moreover, the ceramic scrap recycling system in Taiwan has long been lack of a comprehensive plan. According to data compiled by the Environmental Protection Administration of Executive Yuan, of the 10,081,614 tons of waste treated in Taiwan in 2010, only 0.67% was categorized as “other non-combustible waste”, which included ceramic products. Accordingly, roughly 67,546 tons of such waste was ceramic scrap treated by agencies governed by the environmental protection authority on the island throughout the year. Today, ceramic scrap is still largely disposed of in landfills or dumped due to lack of resource recycling technology and limited channels to reuse it, causing widespread impacts on the environment and soil.

在面對全球因應氣候變遷所提出的淨零排放議題之中，作爲以出口導向的臺灣，其供應鏈至關重要，為了實踐永續消費與生產，身為減碳後段班的臺灣必須開始加快腳步，由政府至企業同心以循環經濟的角度，改變傳統線性經濟有效節約主要資源，並搭配回收與廢棄物再利用等措施，來達成結構性的改變，而陶製品作為生活產業中相當大的比例，如何透過數位科技的應用，重新為陶瓷廢料找尋新解方則刻不容緩。

Countries worldwide are racing to achieve net-zero emissions for climate change mitigation, where Taiwan, an export-oriented economy, plays a critical role throughout the supply chain. Taiwan must also accelerate the pathway to sustainable consumption and production as its carbon reduction agenda has fallen behind other countries. To create a circular economy for saving major resources, entities on the island from government agencies to enterprises should work together by transforming the existing linear economic patterns, adopting recycling and waste reuse measures, and achieving a structural change. As ceramic is a raw material that has been widely used to produce daily necessities, solutions for its scrap treatment using digital technologies must be devised without delay.

延續再演進，將陶廢議題落實應用設計

Evolution Continues: Putting Ideas of Ceramic Scrap Treatment into Real-world Designs and Applications

1970年代作為世界性環境保護的元年，隨著時代的發展，綠色設計逐漸成為一種設計策略上的變革，並形塑今日的循環設計概念。2012年艾倫.麥克阿瑟基金會(Ellen MacArthur Foundation)與麥肯錫顧問公司發表的循環經濟系統圖中顯示，循環歷程人們必須在產物走向生命盡頭前(通常被掩埋或焚化處理)，依產物損壞程度竭盡所能地採取不同手段進行修理維護或資源延續。而陶廢處理的產業現況多以堆置或掩埋方式處理，顯然還有資源延續的探討空間，而循環經濟將是問題解方的核心。工藝中心自2020年所啟動的Re'ramic陶藝跨域加值製造計畫中開始提出陶廢循環機制，提出回收再利用方法的初探，2021年則正式提出陶廢用於3D列印製程概念，開始一連串軟硬體研發調整及材料配方試驗累積，並透過工作坊發起方法演示，藉由3D列印硬體研發與軟體程式的調整中，邀請14位學員於工作坊中進行操作，最終產出14組製程應用試樣、75隻試驗配方。而在2022年中，為了因應循環經濟的議題，持續推廣陶廢議題，持續致力於技術優化之餘，希冀能探究創新應用作為未來落實發展的可能性。

Public awareness of environmental protection began in 1970. Several decades later, green design has revolutionized traditional design strategies and formulated the concept of circular design nowadays. In 2012, the Ellen MacArthur Foundation and McKinsey & Company announced the circular economy system diagram, emphasizing that humans must adopt different strategies to repair, maintain, or prolong the lifetime of a product—depending on the degree of damage—before its life comes to an end (where it is usually disposed of in a landfill or burnt). Currently, landfilling and dumping are mainstream methods of ceramic scrap treatment, leaving more room for improvement in resource extension, with the concept of circular economy being a key to problem solving. The NTCRI proposed a ceramic scrap circulation mechanism for the Re'ramic Project launched in 2020, signifying a preliminary exploration of recycling. In 2021, the NTCRI introduced the concept of applying ceramic scrap to 3D printing. Since then, the institute has extensively transformed software/hardware research and development strategies, conducted experiments using various materials and formula, and presented the research results by holding workshops. For example, a total of 14 workshop attendees were invited to use modified 3D printers and applications, after which they produced 14 samples and 75 trial formulas. Entering 2022, the NTCRI has endeavored to find innovative ways of recycling ceramic scrap for future development in addition to its continued efforts to raise awareness of ceramic scrap-related problems and dedication to technical optimization.

數位製造顛覆產業的可能性

Digital Manufacturing: Its Potential to Revolutionize the Industry

3D列印又名添加式製造（Additive Manufacturing,AM），在1980年代之後崛起的創新技術，其利用立體模型的數位資料，運用特定材料混合的溶膠與混合物，一層一層列印出成品，隨著越臻進步的科技，3D列印的範疇逐漸進入各項產業如航太、醫療、汽車甚至是建築領域，讓世人一再讚嘆此項技術如何顛覆了各種可能性。尤其，3D列印最大的優點是可以突破造型限制，製作出許多複雜而精細的作品；再者，可以降低製作門檻，打破傳統製造業中冗長的製程與邏輯，可隨時生產，更重要的是，可滿足當代全球所關注的永續議題，少量生產的方式不僅可省下大量生產所造成的耗損與廢氣等問題。

Three-dimensional (3D) printing, also known as additive manufacturing, is an innovative technology that rose to fame in the 1980s. With 3D model data, the technology can physically construct a 3D object layer by layer using glues and mixtures made of specific materials. Thanks to increasingly mature technologies, 3D printing has been used in the aerospace, healthcare, automotive, and even architecture industries, leaving people amazed by its potential for any applications. Particularly, the technology is best known for its ability to overcome various shape limitations, enabling the creation of complex and delicate works. Additionally, 3D printing helps reduce manufacturing costs as it can be adopted any time and is free from the time-consuming process required in traditional manufacturing. Importantly, 3D printing is able to meet sustainability goals set by countries worldwide. The small-scale production pattern helps avoid problems of heavy resource consumption and gas emissions caused by conventional large-scale production.

2012年開始，全球吹起自造者（Maker）風潮，其中3D列印技術則是在這項運動當中最容易連結在一起的關鍵項目，在這個以「去中心化」與「開源」為精神，並熱愛以科技及雙手改變世界的自造者運動中，徹底的顛覆了傳統製造業的產業結構，十年的變化裡，也可看見自造者運動從「想製作屬於自己的東西」的期望中，逐漸演變為促成產業振興與轉型，以市場利益為主的「創客」，各式各樣的創客空間、展會、加速器、電商、募資平台如雨後春筍般的出現。然而，隨著時局的快速發展，自造者運動如何在數位科技的並進下，可真正落地與實踐，並實現產業化，以及如何與在地人文、自然環境等脈絡相結合，這項技術也對傳統「工藝」的變革帶來許多可能性。

Since 2012, the idea of being a “maker”—anyone who is dedicated to changing the world using high tech and their own hands—has gone viral over the world, to which 3D printing is instantly related. Centering on concepts of “decentralization” and “open source”, the maker movement has deeply reformed the industrial structure of traditional manufacturing. A decade later, the movement has shifted from the initial expectation of “making a thing that I want on my own” to strategic development for industrial revitalization and transformation. These makers aim to boost market profitability, thereby giving rise to a variety of makerspaces, exhibitions, accelerators, e-commerce businesses, and fundraising platforms. As digital technologies have taken off over the past decade, the maker movement now focuses on putting ideas into reality, achieving industrialization and integrating its philosophy with local cultures and the natural environment. This technology-based movement also creates numerous opportunities for the transformation of traditional craftsmanship.

陶瓷3D列印

Ceramic 3D Printing

3D列印的主要原料，除了塑料、石膏、金屬之外，陶瓷也成為近年來備受關注的材料之一，尤其，在工藝領域佔據相當比例的陶瓷器，藉由數位設計對於造型、結構的表現上的多樣性，讓陶瓷3D列印成為新興而有效率的陶瓷物件歷程，更可藉由可行可試錯的方式，探索回收陶瓷廢料如何進行再加工的實驗，進而達到永續性效益。

In addition to plastic, gypsum, and metal, ceramic has recently become a popular raw material for 3D printing. By combining ceramics—capturing a great share in the craft industry—with digital technologies enabling flexible shape and structural designs, ceramic 3D printing becomes a new, efficient ceramics manufacturing technique. With its doable trial-and-error nature, this technique also enables experiments on reprocessing ceramic scrap materials to achieve sustainability.

由國立臺灣工藝研究發展中心技士翁子馨、皇冠工藝設計有限公司負責人陳瓊茹與國立陽明交通大學應用藝術研究所助理教授李建佑所進行的《回收陶瓷廢料應用於3D陶瓷列印漿料之可行性初探》報告中提及：「傳統陶藝技法中，本就存在一項技術，在製作大型陶藝創作或雕塑時，創作者會在土料中混入熟料(即燒結土料的碎粒，但熟料的碎粒不含有釉藥)，以降低收縮率且可增加質感。而在數位製造技術方面，將陶瓷材料應用於3D列印製程的研究案例多樣，技術多元而成熟，且透過數位設計為陶瓷材料開展了結構與紋理表現空間，以及自動化過程帶來的勞力解放(Zhao, 2021)。

“Application of Recycled Ceramic Scrap Materials to Ceramic Slurry for 3D Printing: A preliminary study ”, compiled by Weng Tzu-hsin (technician of the NTCRI), Chen Chiung-ju (CEO at Crown Craft Design), and Li Jian-you (assistant professor at the Institute of Applied Arts, National Yang Ming Chiao Tung University), describes that “There is an existing technique often adopted by artisans when producing large ceramics or sculptures; specifically, they mix grog with soil (i.e., aggregates of sintered soil, except that grog does not contain any glaze) so as to reduce the shrinkage rate and enhance their works’ texture. Regarding digital manufacturing techniques, numerous studies have applied ceramic materials to 3D printing using diverse and mature digital technologies. Digital design can help expand the structural and textural characteristics of ceramic materials and create a labor-saving process through automation (Zhao, 2021).”

陶瓷3D列印的過程，是依照一定的比例混合陶瓷粉末、粘結劑、添加劑，製成粉末、醬料、線材、薄片等型態後，以適合的3D機具與技術列印成型，最後列印出來的部件仍須經過施釉與窯燒等二次加工。然而3D列印技術有七種，包含粉體融化成型技術、指向性能量沈積技術、黏著劑噴塗沈積技術、光聚合固化技術、材料噴塗成形技術、材料擠壓與熱熔沉積成型法與疊層製造成型技術，而應用製陶瓷方面，指向性能量沈積技術與材料擠壓與熱熔沈積成型法並不適用外，就以噴嘴擠壓成型技術最為成熟，但在歐洲專利局於2020年所針對3D列印專利趨勢分析報告中指出，陶瓷原料因為良率與成本問題仍低於塑料等主流材料。雖是如此，陶瓷3D列印應用於陶瓷工藝上，也為傳統陶瓷工藝的立體造型賦予更為豐富的多樣性，充滿潛力。

Ceramic 3D printing works by mixing ceramic powder, binders, and additives in a specific ratio, transforming the mixture into powder, sauce, wires, or films, and constructing the final object using a suitable 3D printer and printing technique; the object requires secondary processing including glazing and kiln firing. There are mainly seven types of 3D printing technologies: powder bed fusion, directed energy deposition, binder jetting, photopolymerization, material jetting, material extrusion-based fused deposition modeling, and laminated object manufacturing. Except for directed energy deposition and material extrusion-based fused deposition modeling that are unsuitable, nozzle extrusion modeling is currently the most mature approach to ceramic manufacturing. However, as the European Patent Office reported in its 2020 analysis of the trend in 3D printing patents, the market size of 3D printed ceramics is still lower than that of mainstream materials such as plastics. Nevertheless, 3D printing is a promising approach that will help diversify the shapes of traditional ceramics with great potential.

陶瓷廢棄因材料的不可逆性，以及無法回收再利用，透過越臻成熟的數位科技與應用，如何翻轉不可能？在國際上如印度、英國等地的設計師皆可看見其運用陶瓷廢棄物再進行創作，留下眾多精彩的設計品。而在台灣應用於陶瓷3D列印的技術上，如華梵大學與品牌法藍瓷等可見其應用的身影，不過應用於陶廢的議題上仍需有賴更多精彩的創意與實驗加以探索。這次透過本計畫的開展，借助於傳統陶藝相關的燒製經驗，結合瓷土粉、陶廢粉，以及自來水，將回收陶瓷廢料透過粉碎處理後，以重量比10:3的比例（土料：陶瓷廢料）作為基礎配方，混入列印漿料中進行3D列印，假設廢料在列印漿料中可發揮熟料的效果，提高列印支撐性，同時驗證此製程是否對於消化廢料具有永續效益。

在最後研究結果中，回收陶瓷廢料再利用於3D列印製程是具有可行性且得發揮材料循環效益，並且，在回收陶瓷廢料混入配置的漿料，是可提高列印製程中的支撐性，平均可達2.2倍，然而這項研究當中是以回收的陶瓷廢料為主，並未加入陶廢上固有釉料對配方的影響，然而隨著數位科技的發展，陶瓷3D列印與陶瓷廢料的結合相信會具有更多突破性的進步。

Now the question is: How to reuse ceramic scrap—often considered an impossible mission due to its irreversible and unrecyclable nature—with the help of the increasingly mature digital technology and related applications? Successful cases can be seen overseas; for example, designers in India and the UK have adopted ceramic scrap to create astonishing artworks. In Taiwan, Huafan University partnered with porcelain art brand Franz Collection to create works using ceramic 3D printing. However, more creativity and experiments are needed for this technology to advance in the Taiwanese ceramic industry. The Re'ramic Project aims to make ceramic scrap sustainable by utilizing expertise gained from traditional ceramic manufacturing. First, an experiment was implemented. Specifically, powdered porcelain, powdered ceramic scrap, and tap water were mixed and made into basic formula with a weight ratio of 10:3 (soil: ceramic scrap); the mixture was then added to printing slurry for 3D printing. The researchers proceeded to verify whether the slurry can serve as grog and strengthen support structures as well as whether the process could make the recycled scrap sustainable. The research results showed that using recycled ceramic scrap in 3D printing is possible and can help achieve material sustainability. Moreover, adding ceramic scrap to printing slurry could boost structural support by 2.2 times. However, the research only focused on the use of recycled ceramic scrap without exploring the effects of ceramic scrap glaze on the formula. That being said, more crucial breakthroughs for the combination of ceramic 3D printing with ceramic scrap materials will surely be seen in the coming years as digital technologies advance.

第二章
Chapter 2

執行脈絡初探

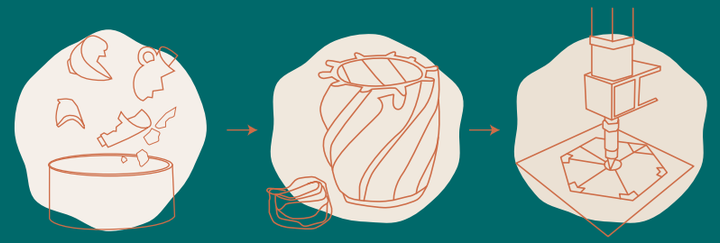
Exploring the Use of Recycled Ceramic Scrap

陶廢原料與陶瓷原料的結合與設計再現

he Union and Redesign of Ceramic Scrap and Ceramic Raw Materials

扣合著全球循環經濟的議題層面上，隨著陶瓷 3D 列印的硬體技術越見成熟，也帶來陶廢品新出路，在本計畫中所進行的陶瓷廢料再生研究案當中，本章節從材料試驗、列印式樣再到設計應用三階段，讓人一探陶廢品如何一步一步從比例、材質分配、製程與設計發想與應用等階段，逐步走向嶄新而充滿創意的綠工藝。

The issue of circular economy has become widely discussed worldwide and ceramic 3D printing hardware technology has become increasingly mature, creating new development possibilities for ceramic scrap. Accordingly, for this project, we conducted ceramic scrap regeneration research. The project is divided into several chapters. In this chapter, we will introduce the stages of material testing, printing styles, and design and application, allowing people to witness how ceramic scrap can be transformed into novel, creative green crafts via correct material distribution and product manufacturing, design, and application.



從科學分析與工藝經驗驗證

Performing Scientific Analyses and Referencing Craft-related

陶瓷是相對易碎的材料，不僅在消費者使用過程中容易由意外破碎，在正常創作運作流程中，不免因產品研發、試釉、打樣等產生淘汰掉的次品或試片，而這些都是陶瓷廢料的來源。國立臺灣工藝研究發展中心自2019年開始以跨域為題，推動「整合傳統產業中技藝與材料創新應用」，持續在金屬、鍛敲工藝、數位製造、陶瓷3D列印等計畫中探索各種進程。2020年啟動陶瓷廢料循環議題的探究，並與傑作陶藝有限公司共同合作，投入陶瓷廢料再生研究，也讓循環經濟在設計應用的議題上，寫下更多可能性。

Ceramics are fragile materials that are easily broken when carelessly handled by consumers. Additionally, they are discarded during product development, glaze testing, and sampling; these incidents create ceramic scrap. Accordingly, since 2019, the NTCRI has engaged in interdisciplinary endeavors and promoted the idea of integrating the skills and materials of traditional industries to introduce innovative material application. The institute has examined various processes in metal, forging technology, digital manufacturing, and ceramic 3D printing projects. In 2020, the institute explored the topic of recycling ceramic scrap, working with Excellence Collection to research ceramic scrap recycling. Such an effort has enabled the concept of circular economy to be applied to the design and application of ceramic scrap.

· 五大類別廢料的分析比較

Analyses of and Comparisons between the Five Categories of Scrap

據財團法人台灣建築中心解釋：「再生綠建材」係指「利用回收材料，經過再製程序，所製造之建材產品，並符合廢棄物減量(Reduce)、再利用(Reuse)及再循環(Recycle)等3R原則製成之建材。」而目前區分為三大類，包含木質再生綠建材、石質再生綠建材與混合材質再生綠建材，而陶瓷廢料即屬於石質再生綠建材的類別，可經適當篩分後製成建築用的骨材粒料。應用至工藝層面上，藉由3D陶瓷列印技術，除了可逐步測試並建立起未來陶瓷廢料的再生機制，並期待著對於消化廢料與兼具工藝品質的未來性。

According to the Taiwan Architecture & Building Center, “recycled green building materials” refers to “building materials manufactured using recycled materials and remanufacturing procedures that comply with the 3 R’s (i.e., waste reduction, reuse, and recycling).” At present, recycled green building materials are divided into wood-recycled green building materials, stone-recycled green building materials, and mixed material-recycled green building materials, with ceramic scrap being categorized as stone-recycled green building materials. Ceramic scrap that is properly sieved can be made into architectural aggregate granules. By applying ceramic 3D printing technology that transforms architectural aggregate granules into crafts, we gradually test and establish a ceramic scrap regeneration mechanism, reducing the amount of ceramic scrap created while producing crafts featuring favorable quality.

成立於1909年的傑作陶藝，見證與參與了陶瓷業的興衰與轉型，在這項計畫中，其運用了長期累積的專業與技術，並收集了來自宏洲窯業股份有限公司、春熙陶、大宇陶藝、美美陶土社、自然燒工陶藝坊、東享瓷器有限公司與其他回收商等涵蓋五大類的廢料，如耐火棚板、石英磚、壁磚、陶器、瓷器，再依據個別材質特性，加上不同比例進行試驗，此外，所有製程則必須涵蓋的原材料則包含了黏性強、可塑性高的蛙目土原料以及在陶瓷工業中作為主要原料的鉀長石，製成可供灌漿生產及手工製作之再生再製陶瓷原料，作為陶瓷禮品、食器等，並結合遠紅外線、抗菌材料以增加產品機能性，最終能真正實現陶瓷廢料再生陶瓷品量產及市場行銷，促進與推動陶瓷產業的循環經濟。

Founded in 1909, Excellence Collection has witnessed and participated in the rise, fall, and transformation of the ceramic industry. In this project, Excellence Collection utilized the expertise and techniques that it has accumulated over the years and collected five categories of ceramic scrap (e.g., fire-resistant shelf boards, quartz tiles, wall tiles, pottery, and porcelain) provided by Horng Jou Ceramics Co., Ltd., Chun Syu Ceramics, Dayu Ceramics, Meimei Potter's Clay, Natural Pottery Art, Dongxiang Porcelain Co., Ltd., and other recyclers. Experiments were performed according to the characteristics of each individual material and by changing the ratios of the materials. Additionally, ball clay and potassium feldspar, a raw material that was highly viscous and plastic and a raw material used in the ceramic industry, respectively, were used in all production processes to manufacture recycled ceramic raw materials that could be used for grout production and as handmade ceramic gifts and tableware. Finally, far-infrared and antibacterial materials were added to increase product functionality, realizing the goal of mass producing and marketing recycled ceramic products made from ceramic scrap, and facilitating and promoting a circular economy for the ceramic industry.

· 成分分析、配方 *Component Analyses and Formulas*

歷經半年時間，傑作陶藝從試驗試片製作、測試分析、產品設計再到產品試做與測量。首先，在粉體分析的步驟中，將蒐集來的陶瓷廢料碾碎並磨細後，使用科學儀器XRF分析儀進行成分分析，並將破碎磨細的粉體過篩200目後，加以進行粒徑分布檢測。

For half a year, Excellence Collection has endeavored in activities including test piece making, test analyses, and product design, trial production, and measurements. During powder analyses, Excellence Collection crushes and finely grinds the collected ceramic scrap before placing it into XRF analyzers for component analyses. The crushed and finely ground powder is then filtered via a 200-mesh sieve before particle size distribution tests are performed.

在成分分析後，則是要獲得可完成漿料、捏塑及拉胚方式適合的再生料配方。因此再生材料配方使用三成分的三角配料法調製，包含不同陶瓷廢料、蛙目土原料與鉀長石原料，而依據傑作陶藝在製程上的經驗，提出灌漿、手拉胚以及貼加棚板廢料在配方上各有不同比例如下：

Component analyses were performed to obtain the formulas for recycled materials used to make slurry via suitable kneading and throwing methods. The recycled materials were prepared using a three-component triangular batching method and contained different ceramic scrap, ball clay, and potassium feldspar raw materials. Based on the experiences of Excellence Collection in production processes, the ratios of grout, hand-drawn clay, and shelf board scrap used are described as follows:

1.灌漿Grout：

蛙目土比例約在30%–35%之間，使泥料有塑性有利於成型脫模；鉀長石比例約在22%–30%之間，視燒成溫度而定，陶瓷廢料的使用比例約在 35%–42% 之間。

Approximately 30%-35% of ball clay was used, allowing the clay materials to be highly plastic and conducive to molding and demolding; approximately 22%-30% of potassium feldspar was used according to the sintering temperature; and approximately 35%-42% of ceramic scrap was used.

2.手拉胚Hand-pulled clay：

蛙目土比例約在 43%–50%之間，鉀長石比例約在 22%–30% 之間，視燒成溫度而定，添加 2%皂土，廢料使用比例約在 30%–38%之間。

Approximately 43%-50% of ball clay was used; approximately 22%-30% of potassium feldspar was used according to the sintering temperature; 2% of bentonite was added; and approximately 30%-38% of scrap was used.

3.棚板廢料Shelf board scrap：

棚板廢料為耐火材料，為調配成低膨脹係數材料以製造耐熱鍋等產品，因此另外使用以蛙目土、木節土、葉長石、鋰輝石加上棚板廢料。

The shelf board scrap was a fire-resistant material. To transform the material into one with a low expansion coefficient in order to manufacture products such as heat-resistant pans and others, ball clay, kibushi, petalite, spodumene, and shelf board scrap were added.

· 粉體分析之流程 *Powder Analysis Procedure*

接著，在原料配方的比例大致上定義出數據後，則依據不同再生材料的熱機械性質、熱重/熱差分析、滲水測試，以及再生材料在灌漿製程時使用再生材料的泥漿解膠能力，強度測試與吸水率測試等多方實驗，最終獲得在五大陶瓷廢料再生原料與兩大原料的粉體分析。

After determining the ratios of raw materials to be used, we performed different tests (e.g., thermogravimetric/differential thermal analyses, water seepage tests, tests for determining the slurry peptization abilities of recycled materials during grouting processes, strength tests, and water absorption tests) based on the thermomechanical properties of the different recycled materials. These efforts enabled us to identify the recycled raw materials to be used for each of the five major ceramic scrap as well as the powder analysis results of two major raw materials.

粉體分析流程 Powder Analysis Procedure

陶瓷廢料/測試分析 Ceramic scrap/test analyses

陶瓷廢料/測試分析 Ceramic scrap/test analyses	棚板 Shelf boards	石英磚 Quartz tiles	壁磚 Wall tiles	陶器 Pottery	瓷器 Porcelain
粉體粒徑分析優先順序 Powder particle size analysis, listed by performance (in descending order)	4	2	3	5	1
熱膨脹係數（100–400度c） Thermal expansion coefficient (100°C–400°C)	較低 Lowest	分布於107–144E–7之間 Between 107–144E–7			
燒成溫度訂定（1240度） Sintering temperature (set at 1240°C)	無燒成軟化 Did not soften	超過1250度燒成軟化 Softened at >1250°C	超過1250度燒成軟化 Softened at >1250°C	無燒成軟化 Did not soften	無燒成軟化 Did not soften
熱重/熱差分析 Thermogravimetric/ differential thermal analysis	皆無明顯熱效應No obvious thermal effects				
滲水分析 Water seepage test	需降低25%廢料 Needed to lower scrap by 25%	合格 Passed the test	合格 Passed the test	合格 Passed the test	合格 Passed the test
抗強度分析高到低 Strength test, from highest to lowest	3	4	5	2	1
吸水率分析 Water absorption test	低 Third lowest	較高 High	最高 Highest	次低 Second lowest	最低 Lowest

綜觀最終實驗結果當中，從陶器與瓷器廢料之各項材料、製程，以及熱分析數據顯示此兩類材料相對於其他廢料材料，更加適合於高溫燒製瓷器之製程使用，低吸水率與高抗折強度，可令其被用於生產較精良之陶瓷再生再製產品。然而，最優的部分則是由「瓷器」可做為陶瓷廢料再生材料中具有最高經濟的效用。壁磚與石英磚廢料則須於攝氏 1,250 度下熱處理以取得再製商品，棚板廢料則須以約 25% 廢料量製作。

According to (a) the final experimental results; (b) the materials and manufacturing processes of pottery and porcelain scrap; and (c) thermal analysis data, pottery and porcelain scrap are better suited for making ceramic products at high sintering temperature than the other scrap materials are. The low water absorption rates and high flexural strength of pottery and porcelain scrap allow them to be made into superior recycled ceramic products. Among the different types of scrap used to make recycled ceramic products, porcelain scrap is the most profitable. Wall tile and quartz tile scrap must be heat-treated at under 1,250°C to manufacture recycled ceramic products. When making recycled ceramic products using shelf board scrap, approximately only 25% shelf board scrap can be used.

從永續議題走出創新的未來性

Finding Innovative Possibilities to Support the Idea of Sustainability

隨著科技與疫情帶動了許多日常生活應用的革命，循環經濟的議題亦是全球不可忽視的議題，而材料的試驗與製程往往需要長時間的研發，在面對數位轉型中能夠帶給陶瓷廢料甚麼樣的新契機？2020年藉由加入3D列印技術的小型測試，我們看到了陶廢材料的潛力。

Technology and the COVID-19 pandemic have revolutionized our daily operations, and circular economy has become an issue that cannot be overlooked worldwide. Material testing and manufacturing processes are research and development activities that often take years to complete. Following digital transformation, what opportunities are there for ceramic scrap? By conducting small-scale tests using 3D printing technology in 2020, we discovered the potential of using ceramic scrap.

· 以工作坊實作開展陶廢價值

Teaching the Value of Ceramic Scrap via Workshops

工藝中心在2019年立下材料試驗的基礎後，得出再生材料應用的可行性與未來實現於再生產品的價值，2020年更進一步加入3D列印技術，如前章所述目前陶瓷原料在3D列印市場上的發展不如主流材料，但卻充滿潛力，為了建構陶廢材料新的回收消化出口，則在當年度先後開啟了兩項子計畫，包含列印設備的軟硬體輕型調整，同時進行陶廢列印漿料的配置與試驗，建構起陶廢循環應用於3D列印製程的模板(Model)雛形，

接著再發起「Re'ramic」陶瓷廢料循環技術人才培訓工作坊，由參數式專家李建佑老師及陶藝師陳瓊茹老師引導14位參與者使用陶廢料進行3D列印製程演示；期待以循環永續的概念將陶瓷廢料視作新材料，使廢棄堆置掩埋不再是陶瓷製品生命週期的終點，反而能在適當處理後，以原料的身分重回製程、發揮價值。

In 2019, the NTCRI established the foundation for material testing, confirming the feasibility of using recycled materials and the value of recycled products in the future. In 2020, the institute incorporated 3D printing technology. As mentioned in the previous chapter, today, the development of ceramic raw materials in the 3D printing market pales in comparison to that of other mainstream materials. Nevertheless, it has great potential. To build a new ceramic scrap recycling platform, the institute launched two sub-projects in 2020. The sub-projects involved making slight adjustments to printing equipment software and hardware, and performing ceramic scrap printing slurry configuration and tests, creating a 3D printing model template prototype for ceramic scrap recycling. Next, the institute hosted the "'Re'ramic' Ceramic Scrap Recycling Technical Personnel Training Workshop," inviting parameter design expert Li Jian-you and ceramic artist Chen Chiung-ju to demonstrate ceramic scrap 3D printing to 14 workshop participants. The goal was to teach the participants the concept of recycling and sustainability by using ceramic scrap as a new material, showing that dumping ceramic scrap in landfill was no longer the only option for used ceramic product cycles and using proper treatment to remanufacture ceramic scrap into valuable products.

· Re'ramic行動的開端，文化根基與數位科技的融合

Re’ramic Workshop Begins, Bringing Culture and Digital Technology Together

本計畫中，陶瓷廢料用於3D陶瓷列印的新循環製程，期待成為消化陶瓷廢料的機制，同時也利用陶瓷3D列印數位製造的優點發展陶藝新創作表現。陶瓷廢料循環技術人才培訓工作坊的舉辦，是一場為期160小時的工作坊，由14位學員參與，背景涵蓋傳統陶瓷、工業設計、參數設計、機械等領域，須歷經兩個月技術訓練，運用陶廢議題操作，並結合創作者的概念進行嘗試，不僅需挑戰陶瓷廢料在材料上的限制與未知性，更需學習參數式設計如何運用至陶瓷3D列印中，而這也是工藝中心在對接與扶植產業的同時，實踐了設計驅動創新(Design Driven Innovation,DDI)及材料驅動設計(Material Driven Design,MDD)的概念。

In this project, ceramic scrap was used in a new ceramic 3D printing process; the goal was to develop a mechanism that reduced ceramic scrap. Concurrently, digital ceramic 3D printing technology was employed to create ceramic art. A workshop that taught people ceramic scrap recycling technology was held. The workshop was 160 hours long and received 14 participants. The participants had background in various fields including traditional ceramics, industrial design, parameter design, and machinery. The participants received two months of technical training, using the concept of recycled ceramic scrap and their creativity to explore the potential and limitations of ceramic scrap, as well as learning how to apply parametric design to ceramic 3D printing. This is how the NTCRI realizes the concepts of design-driven innovation (DDI) and material-driven design (MDD) while connecting and supporting different industries.

設計驅動創新是讓設計思考在跨域創新上扮演著重要的橋接角色，而材料驅動設計則是支持以材料為出發點來為材料的性質與作用，讓每位參與工作坊的設計師可以依據2020年由傑作陶藝所實驗出來的「配土知識及實驗方法」，再讓個人創意發想以及材料本身的性質來重新在材料體驗設計中完成自己的配方，例如學員張益誠以生物的紋理與網狀物為發想，在陶廢與純瓷土兩種材料相互比較，持續修改參數設計，最終獲得了兼具透光性能且以捕獲意象詮釋的作品；抑或是如學員郭琦的作品，則在瓷土與陶廢之外加入咖啡渣，藉由陶瓷3D列印測試不同比例下的強度與滲水度等，創造出不同紋理的咖啡濾杯形式。另外，其他學員也於工作坊中實際測得材料實驗結果，在各方嘗試、歷經不斷的翻案與再出發後，最終獲得了可貴的產出，對於陶瓷3D列印技術的實際應用展現出多樣化的可能。而所有過程藉由完整紀錄，奠定下一階段設計應用的深度與廣度。

DDI allows design thinking to drive interdisciplinary innovation, while MDD allows the nature and functions of materials to drive design. The aforementioned workshop participants used the soil preparation and experiment methods introduced by Excellence Collection in 2020, their creativity, and material properties to complete their own material formulas. For example, Chang Yi-cheng utilized meshes and organism patterns to compare the pottery and porcelain scrap. He continuously revised his parameter design, ultimately creating an artwork that was translucent and conveyed the notion of a capture. Kuo Chi added coffee grounds to porcelain and pottery scrap, performing ceramic 3D printing and changing the strength and water seepage ratios to create coffee filter cups with different designs. Other workshop participants also obtained different material experiment results. By playing around with the scrap and making constant revisions, the participants obtained valuable results, demonstrating the potential of practical, diversified ceramic 3D printing application. All of the processes were fully recorded, building a foundation for the next stage of design and application.

跨域模擬，展現多樣化的設計成果

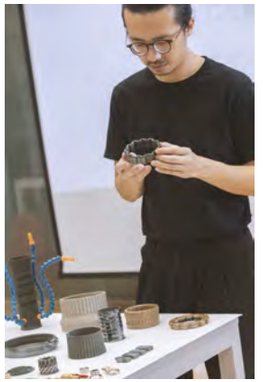
Interdisciplinary Simulations, Showcasing Diversified Design Results

2022年工藝中心持續辦理「Re'ramic陶藝跨域加值製造計畫」推進陶廢議題，除了辦理推廣性質的活動向外發酵議題，更召集了一群工藝師與設計師，一起探索陶瓷廢料進行應用創作。在這場設計行動中，主要由設計師鍾毓珊引導創作9位工藝中心扶植的參與者，在8堂課程裡詮釋議題並實踐為作品。另外還邀請到陳瓊茹、陳威恩及吳嘉倍3位資深陶藝家，以及創次方團隊的三位設計師加入本次創作行動，以個人獨特語彙詮釋出陶廢應用成果。

In 2022, the NTCRI held the Re'ramic Project once again, promoting the reuse of ceramic scrap. For this project, the institute organized activities that promoted the reuse of the said scrap and invited a group of craftsmen and designers to explore ceramic scrap application and creation. During the project, nine participants trained by the institute and led by designer Chung Yu-shan created ceramic art over the course of eight classes. Additionally, senior ceramic artists Chen Chiung-ju, Chen Wei-en, and Wu Chia-pei as well as three designers from Chuangcifang were invited to participate in the project. Through it, the participants presented new ceramic scrap application based on their unique interpretations.

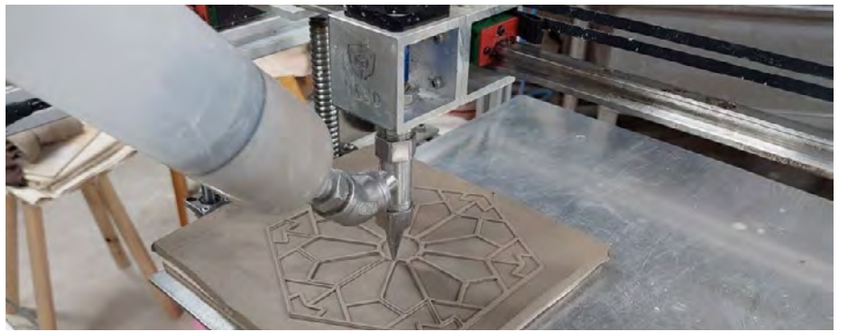
· 設計應用，從日常生活物件延伸至家居產品

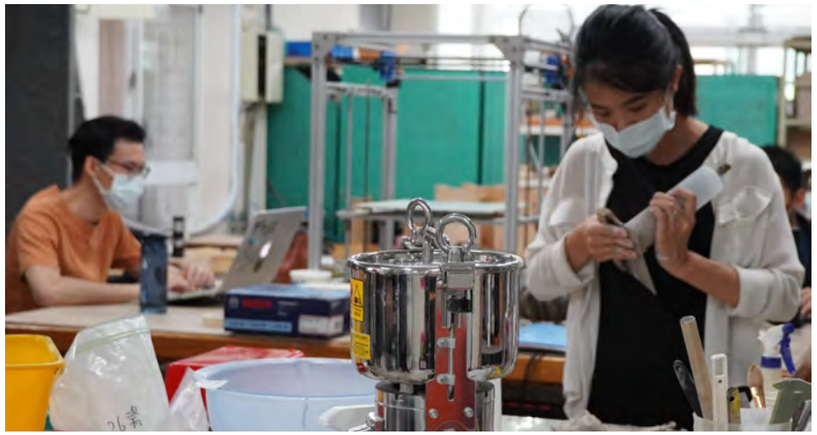
Design and Application, from Daily Living Objects to Household Products



在這次設計行動中，無論專業領域和經驗背景，大家相互學習與激盪，也在過程中逐漸收攏陶廢品在製作與運用上的知識。而縱覽創作者們的設計概念，皆從陶廢循環議題，以及在臺灣這塊土地必須審視的環保永續問題作為發想，其設計標的涵蓋日常生活物件，包含杯墊、餐盤、咖啡濾杯、啤酒杯、花瓶等器皿，抑或是對大型家用品的挑戰，如燈罩、座椅、茶几等，也顯見陶廢品的再製與利用有了可觀的成果。

For this design activity, participants from different professions and backgrounds interacted, learned from, and inspired each other, gradually creating new ceramic scrap production and application-related knowledge. All of the participants' designs stemmed from the notions of ceramic scrap recycling and environmental sustainability in Taiwan. The ceramic art designed included daily objects such as coasters, dinner plates, coffee filter cups, beer mugs, and vases as well as large household items such as lampshades, seats, and coffee tables, illustrating the remarkable potential of reusing and reproducing art using ceramic scrap.





近三年來，世界的變化快速，材料產業同樣面臨著加速設計變革的壓力，尤其，一個材料的開發其實是耗費時間、人力與成本，要如何縮短新材料開發的時程則是整個產業必須努力的課題，也才能更符合當前世界邁向循環經濟的趨勢。而對於材料處裡技術與製造方法的工藝產業而言，因其領域本身就具備跨域創新的能量，並且往往因應各種創意人才對於概念上的新激盪，讓藝術不再只是運用材料特性或是視覺表象來展現，更多的是因應新科技、新技術，扣合著永續的議題來回應世界的趨勢與社會相應的價值。

Over the past three years, the world has undergone rapid changes, and the material industry has faced the pressure of accelerated design changes. Because material development is a time-consuming, labor-intensive, and costly process, identifying ways to shorten the new material development time is a matter that must be addressed to meet current global circular economy trends. As for the craft industry, which is characterized by its material processing technology and manufacturing methods because it possesses interdisciplinary and innovative capacity and its creative, talented personnel often inspire novel ideas, art is no longer displayed using existing material characteristics and via visual representations; it is also displayed using new technologies and techniques, echoing global trends and the social value of sustainability.

誌謝
Acknowledgement

共創想像與永續 *Co-Creating Imagination and Sustainability*

工藝中心自2020年著手陶廢循環議題以來，至今（2022）已有三年時間，從陶廢材料的客觀科學性質瞭解，到嘗試以陶瓷3D列印開創陶廢消化的循環機制，最後藉由設計應用的實踐，讓陶廢材料化為一個個生活物件。這是由多邊跨域夥伴的協力，才能成就的果實。

It has been three years since the NTCRI began to work on the ceramic scrap circulation issue in 2020. The institute explored the scientific properties of ceramic scrap from an objective perspective and attempted to use ceramic 3D printing to develop a circulation mechanism for using ceramic scrap. Finally, actual application was used to turn ceramic scrap into daily living items. This success was only accomplished through the collaboration of many cross-field partners.

然而陶廢循環議題的推動與落實，還有很長的道路要走，尤其在制度面上仍缺乏產業線與市場端的結構整合。期待我們仍能保持在已知面前的謙卑以及面對未解的好奇、積極。走穩腳步，共創良善美好。

However, there is still a long road ahead for promoting ceramic scrap circulation and solving ceramic scrap issues. The system especially lacks integration between production lines and the market structure. We hope that we can maintain our humility regarding what is known and curiosity towards the unknown. We will take steady steps in co-creating goodness and beauty.

感謝名單

Special Acknowledgement

依姓氏筆劃排序

技術指導 李建佑　吳嘉倍　陳昱允　劉兆偉
李松萬　陳瓊茹　陳威恩　鍾毓珊

計畫參與　2021 Reramic陶瓷廢料循環技術人才培訓工作坊
林珮汝　莊沛穎　陳柏瑋　劉鋐霖　謝永和
林堃凱　郭琦　陳羿如　蔡慧玲　魏美華
張益誠　陳長韋　劉俊輝　賴建源

2022 Reramic陶藝跨域加值製造計畫
江采倫　林凱元　郭　琦　賴建源
林家琪　逄家妤　陳柏瑋　鍾佳宏
林堃凱　張益誠　廖仁光　嚴立心

計畫協力執行
傑作陶藝有限公司
鋐蘊科技有限公司

參考文獻

期刊或研討會論文

1. 翁子馨、陳瓊茹、李建佑(2022)。回收陶瓷廢料應用於3D陶瓷列印漿料之可行性初探。2022跨域創新國際設計研討會。
2. 黃吉正（2017）。空間・對話-黃吉正陶藝創作研究。國立台中教育大學，台中市。
3. Boyer, S. A. E., Jandet, L., & Burr, A. (2021). 3D-Extrusion Manufacturing of a Kaolinite Dough Taken in Its Pristine State. Frontiers in Materials, 8.
4. Chen, Z., Li, Z., Li, J., Liu, C., Lao, C., Fu, Y., Liu, C., Li, Y., Wang, P., & He, Y. (2019). 3D printing of ceramics: A review. Journal of the European Ceramic Society, 39(4), 661–687.
5. Godoi, F. C., Prakash, S., & Bhandari, B. R. (2016). 3d printing technologies applied for food design: Status and prospects. Journal of Food Engineering, 179, 44–54.
6. Hossain, S. S., & Roy, P. (2020). Sustainable ceramics derived from solid wastes: a review. Journal of Asian Ceramic Societies, 8(4), 984–1009.
7. McDonough, W., Braungart, M., Anastas, P. T., & Zimmerman, J. B. (2003). Peer Reviewed: Applying the Principles of Green Engineering to Cradle-to-Cradle Design. Environmental Science & Technology, 37(23), 434A-441A.
8. Praveena B. A., Lokesh N., Abdulrajak Buradi., Santhosh N, Praveena B. L., & Vignesh R.（2021）. A comprehensive review of emerging additive manufacturing (3D printing technology): Methods, materials, applications, challenges, trends and future potential. Materials Today: Proceedings, In Press, Corrected Proof, 21-42.
9. Zhao, B. (2021c). Research on The Application of Ceramic 3D Printing Technology. Journal of Physics: Conference Series, 1827(1), 012057.

書籍

1. 國立臺灣工藝研究所（2007）。台灣地方陶瓷發展史（一）台灣陶瓷的領航員－北投陶瓷發展史。國立臺灣工藝研究所。
2. 廖瑞章（2007）。形變與衍生: 廖瑞章有機抽象陶塑論述。紅豆。
3. Chris Anderson(2013)。自造者時代：啟動人人製造的第三次工業革命。天下文化。
4. Hod Lipson ，Melba Kurman (2014)。印出新世界：3D列印將如何改變我們的未來。馥林文化。

報告

1. 傑作陶藝有限公司(2020)。陶瓷廢料再生研究委託服務採購案研究成果報告書。國立臺灣工藝研究發展中心，未出版。
2. 國立臺灣工藝研究發展中心(2021)。110設計驅動跨域整合創新計劃—工藝驅動傳統產業探測研發計畫期末成果報告書。文化部，未出版。

網頁

1. 臺灣搖籃到搖籃平台，搖籃到搖籃(C2C)設計概念。檢自https://www.c2cplatform.tw/c2c.php?Key=1
2. 臺灣設計研究院產業創新組(2022)。【循環設計觀察系列1】產業循環減碳的第一步：為什麼我們需要設計。檢自https://www.tdri.org.tw/37211/
3. 臺灣設計研究院產業創新組(2022)。【循環設計觀察系列2】開始循環設計的第一步：運用循環設計策略與指引工具。檢自https://www.tdri.org.tw/37312/

找到最好的相容性，給予循環一個創新契機。
一次又一次的失敗，是為了層層堆疊起廢料重生。

Find the perfect match to provide an opportunity
for innovative circulation.
Countless failures are the key to scrap regeneration.

創 作 者｜鍾毓珊 Yushan
公司品牌｜一日之計 A design a day
作品名稱｜以為是奶油 Spice up with Cream
使用廢料｜瓷廢料

循環經濟對傳統產業的影響效應

The effect of a circulation economy on traditional industries.

創 作 者｜陳瓊茹 Chen,Chiung-Ju
公司品牌｜皇冠工藝設計有限公司 Crown Craft Design
作品名稱｜效應 effect
使用廢料｜陶廢料、瓷廢料

新舊生命的交疊，不管是作品的造型，還是陶土本身的材質都是。

An overlap of old and new life between the artwork's shape and pottery material.

創 作 者｜吳嘉倍 wu chia pei
作品名稱｜開屏 blossom
使用廢料｜陶廢料

珍惜 神所創造得之不易的地球
Cherish the Earth created by God.

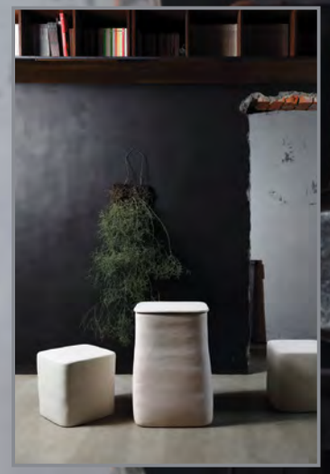
創 作 者｜陳威恩
公司品牌｜圭窯新彩燒 KUIYAONEO CHROMA
作品名稱｜企鵝的海與冰系列之初生 ocean and ice：newborn
使用廢料｜陶廢料

陶料取之自然，Purffer用之自然。
Made of "Purffer", a pottery material from the nature.

創 作 者｜嚴立心、江采倫、林凱元
Yen-Li Hsin、Tsai-Lun Chiang、Kai-Yuan Lin
公司品牌｜創次方股份有限公司 Power Creation D Co., Ltd.
作品名稱｜淳次 「Purffer」
使用廢料｜陶廢料

沉次的堆疊，是廢料重生的展現。
Piles of "Paltain" exemplify scrap material regeneration.

創 作 者｜嚴立心、江采倫、林凱元
Yen-Li Hsin、Tsai-Lun Chiang、Kai-Yuan Lin
公司品牌｜創次方股份有限公司 Power Creation D Co., Ltd.
作品名稱｜沉次 Paltain
使用廢料｜瓷廢料



找到最好的相容性，賦予其完整的新意義。
Find the best match to provide the work a new, complete definition.

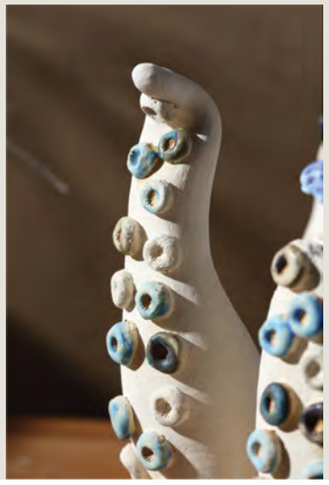
無形的背後，出自於有形的累積。
What lies behind an intangible is the accumulation of tangibles.

創 作 者｜嚴立心、江采倫、林凱元
Yen-Li Hsin、Tsai-Lun Chiang、Kai-Yuan Lin
公司品牌｜創次方股份有限公司 Power Creation D Co., Ltd.
作品名稱｜方角 Posible / 方隅 Placope（桌椅）
使用廢料｜瓷廢料

讓重視環保的心綻放成處處花田吧！
Let our advocacy for environmental protection grow and sparkle!

創 作 者｜逄家妤 PANG,CHIA-YU
作品名稱｜花綻 sparkle
使用廢料｜陶廢料、廢玻璃

創 作 者｜廖仁光 Liao Jen-Kuang
公司品牌｜木辛陶 mu-xin
作品名稱｜華爾茲怪獸 #2 Waltz Monster #2
使用廢料｜陶廢料、咖啡渣

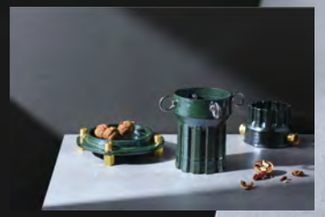


讓自己心愛卻破碎的陶瓷—新生
Revive the beloved but broken ceramic.

創 作 者｜林堃凱 Lin kun kai
作品名稱｜夏日啤酒杯 summer
使用廢料｜陶廢料

透過設計，讓不起眼的配角循環成為主角。
Transform an unnoticeable supporting role into the main character through smart design.

創 作 者｜陳柏瑋 Po-Wei Chen
公司品牌｜二拾家居 Twenty Lifestyle
作品名稱｜配角系列 Supporting Role Collection
使用廢料｜瓷廢料



被遺忘的，給予永恆；被捨棄的，賦予新生。
Make those neglected eternal; give new life to those abandoned.

創 作 者｜張益誠 Ｃｈａｎｇ，Ｙｉ－Ｃｈｅｎｇ
公司品牌｜益采工坊 ＹＣ３Ｄ
作品名稱｜雪白印記snow white history
使用廢料｜瓷廢料

一層一層堆疊出海浪的顏色。
Sea wave colors stacked layer by layer.

創 作 者｜賴建源 Lai Jian-Yuan
公司品牌｜格瑋 GEWAY
作品名稱｜浪潮 wave
使用廢料｜陶廢料

現在，你不再只是個廢棄物，而是喚起環保意識的鑰匙。
Now, you are no longer a loser but a key to raising environmental protection awareness.

創 作 者｜郭琦 Kuo,Chi
作品名稱｜棋中的寓意 The hidden meaning of a chess game
使用廢料｜陶廢料

如此特例獨行卻又想引人注目。
What an attention-seeking maverick.

創 作 者｜林家琪 LIN JIA QI
公司品牌｜左心坊藝術工作室 Lartium studio
作品名稱｜Kiang²
使用廢料｜陶廢料

從粒子堆砌，重新組構新構造與圖像，就如同當下無法成為作品的陶瓷廢料，
又重新回收再加入材料，又產生新的風景。

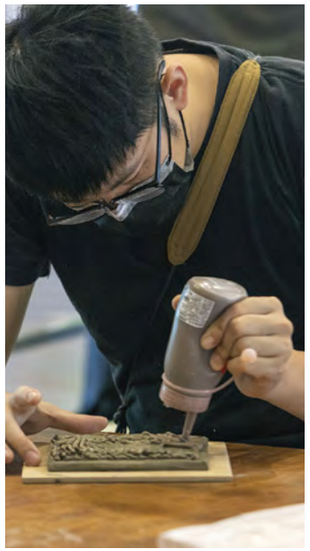
Reorganize structures and images as particles pile up, just like recycling and adding new things to ceramic scrap—normally considered unqualified to become an artwork—before it gains a new look.

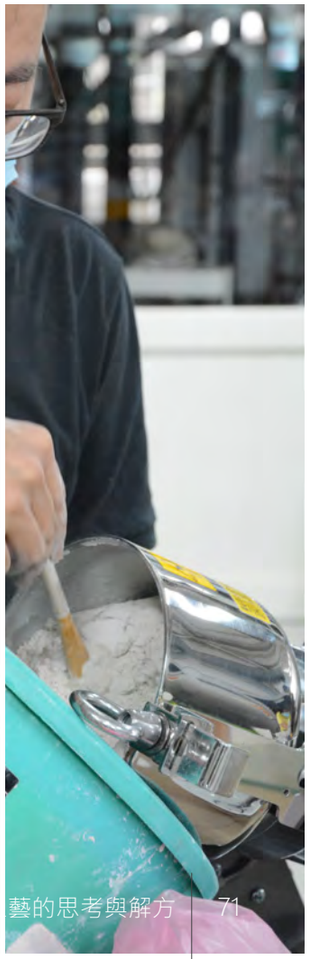
創 作 者｜鍾佳宏 Chung,chia-hung

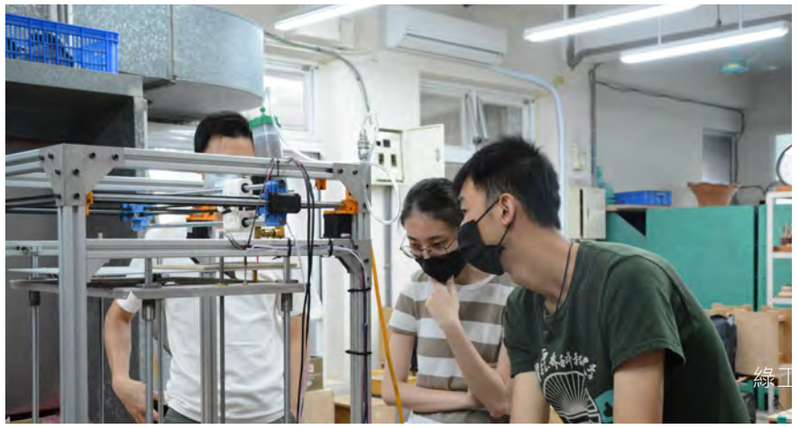
作品名稱｜風景凝視(花草集)condensed landscape(works of plants)

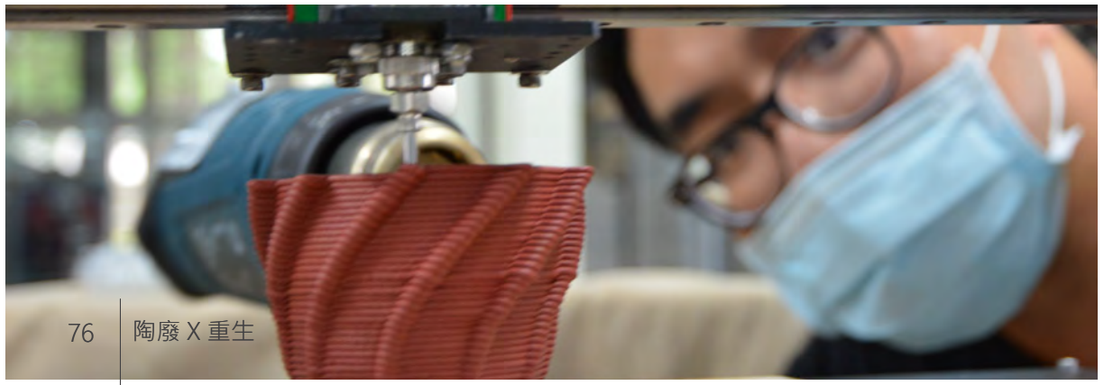
使用廢料｜瓷廢料

SITUATION









陶廢X重生 Re-ceramic

Thinking of solution for Green Craft

指導單位｜文化部
主辦單位｜國立臺灣工藝研究發展中心
發行單位｜國立臺灣工藝研究發展中心

發 行 人｜張仁吉
監　　督｜江瑞燐
策　　畫｜姚仁寬
行政總編｜翁子馨

撰　　文｜廖淑鳳、翁子馨、簡淑君
內容編審｜翁子馨、簡淑君
攝　　影｜張介宇攝影藝術工作室、林煒倫
美術設計｜如邑行動實業有限公司 / 宋守彥
插　　畫｜逄家妤
翻　　譯｜睿譯專業翻譯社
執行製作｜鋐蘊科技有限公司

地　　址｜國立臺灣工藝研究發展中心
電　　話｜049-2334141
網　　站｜www.ntcri.gov.tw

出版日期｜2022/12(初版)
定　　價｜280元
ISBN 9789865327606 (PDF)
GPN 4711100093

陶廢X重生

Re-ceramic

Thinking of solution for Green Craft